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DRIVER BEHAVIOR WITH ADAPTIVE CRUISE CONTROL

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ABSTRACT−As an important and relatively easy to implement technology for realizing Intelligent Transportation Systems (ITS), Adaptive Cruise Control (ACC) automatically adjusts vehicle speed and distance to a preceding vehicle, thus enhancing driver comfort and safety. One of the key issues associated with ACC development is usability and user acceptance. Control parameters in ACC should be optimized in such a way that the system does not conflict with driving behavior of the driver and further that the driver feels comfortable with ACC. A driving simulator is a comprehensive research tool that can be applied to various human factor studies and vehicle system development in a safe and controlled environment. This study investigated driving behavior with ACC for drivers with different driving styles using the driving simulator. The ACC simulation system was implemented on the simulator and its performance was evaluated first. The Driving Style Questionnaire (DSQ) was used to classify the driving styles of the drivers in the simulator experiment. The experiment results show that, when driving with ACC, preferred headway-time was 1.5 seconds regardless of the driving styles, implying consistency in driving speed and safe distance. However, the lane keeping ability reduced, showing the larger deviation in vehicle lateral position and larger head and eye movement. It is suggested that integration of ACC and lateral control can enhance driver safety and comfort even further.

KEY WORDS : *Adaptive cruise control (ACC), Driving simulator, Driver behavior*

1. INTRODUCTION

Adaptive Cruise Control (ACC) automatically adjusts vehicle speed, if necessary, to maintain a desired distance to a preceding vehicle. As a safety enhancement and comfort system, one of the key issues associated with ACC development is driver acceptance. Control algorithms for ACC should be optimized in such a way that ACC does not conflict with driving behavior of a driver and further that the driver feels comfortable with ACC.

Human factor aspects of ACC have been studied by many researchers. Weinberger *et al.* (2001) studied period adapting in ACC and driver's driving behavior such as time to collision. Hoedemaeker and Brookhuis (1998) divided drivers into four groups using Driving Style Questionnaire (DSQ) and analyzed each group's driving behavior such as preservation ratio of left side lane, standard deviation of lateral distance and maximum vehicle speed. Higashimata *et al.* (2001) addressed driver's driving behavior in terms of relative speed with a preceding vehicle and headway-time, and designed a headway-time distance control system for ACC from their results. Stanton *et al.* (1997) studied performance of added work with ACC and driver's response at ACC breakdown using a driving simulator.

A driving simulator has many advantages in that it can reproduce actual driving situations in a safe and controlled virtual environment and enables to conduct various experiments including emergency situations that are not possible with actual test vehicles. The driving simulator, by allowing driver-in-the-loop simulation, is an ideal research tool for evaluating human factor and usability of driver support systems.

The objective of this research is to investigate driving behavior with ACC using a driving simulator. In this paper, ACC is implemented on a driving simulator and performance of ACC is evaluated. Human factor aspects of ACC are addressed by taking into account driving styles of drivers in two experiments. Driving behavior of drivers with different driving styles are addressed in terms of preferred headway-time, lateral position of a car, and head and eye movement.

2. ADAPTIVE CRUISE CONTROL IMPLEMENTATION

2.1. Driving Simulator

Figure 1 shows the driving simulator used in this study (Lee and Cho, 2001). It has a four channel visual system with 150×40 and 50×40 degrees of front and rear fields of

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Figure 1. Kookmin university driving simulator.

view, and a two degree-of-freedom electric motion platform. The simulator is controlled and operated in a network of nine PCs connected by Ethernet. It has been used for a variety of studies in the areas of vehicle electronic control, sudden acceleration, drunken driving, and road design (Lee *et al.*, 2001; Kim *et al.*, 2004).

2.2. Control Algorithm

An ACC algorithm adopted in this study is based on the work by Kim (2002). Figure 2 shows the algorithm structure. A driver activates ACC and sets a vehicle speed and headway-time. When a preceding vehicle is not detected, the ACC vehicle maintains the set speed. If a preceding vehicle is detected, the ACC vehicle activates either speed or distance control by using radar sensor information on relative distance and speed between the preceding and the ACC vehicles, and computes throttle angle or brake pressure. The throttle angle or brake pressure is converted into the corresponding gas or brake pedal angle in the

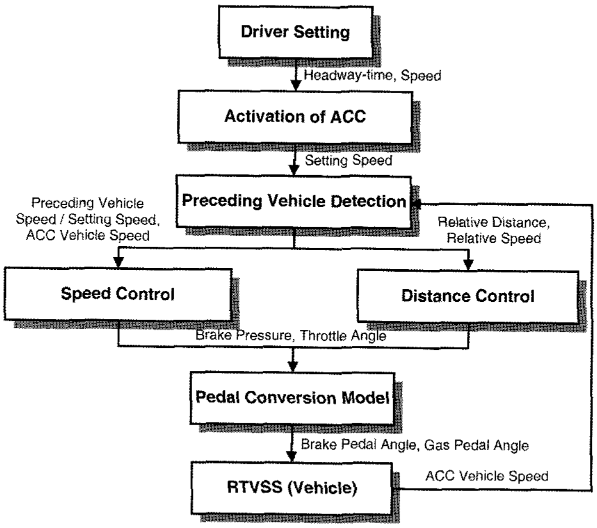


Figure 2. Adaptive cruise control algorithm.

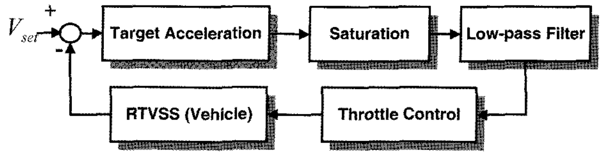


Figure 3. Speed control.

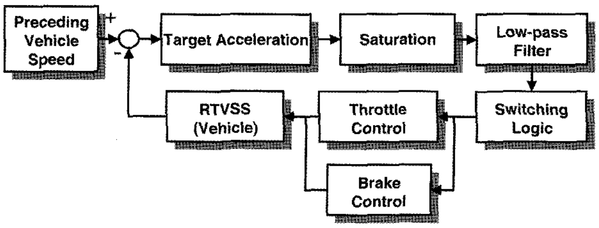


Figure 4. Distance control.

pedal conversion model. The pedal angle becomes input to the real-time vehicle simulation system in the driving simulator to determine the ACC vehicle motion.

Speed control is activated when the preceding vehicle is not detected or the preceding vehicle, if detected, is outside headway-time distance. The speed control algorithm is shown in Figure 3. A saturation function is used to limit the target acceleration/deceleration considering the driver's driving pattern and preference.

Distance control is activated when the preceding vehicle is within headway-time distance. Figure 4 shows the distance control algorithm. Throttle control enables to maintain the preset speed when desired acceleration is achievable with engine torque only. Brake control is activated if the target acceleration is not achievable by throttle control. A switching logic is used to decide whether to use the throttle or the brake control based on the target acceleration.

2.3. System Integration

Figure 5 illustrates a concept of integrating the ACC simulation system and the driving simulator. In ACC simulation, realistic behavior of ambient cars should be ensured to obtain meaningful results. Such a scenario control, requiring artificial intelligence of many ambient cars running in real-time, has been implemented by using SCANeR II (OKTAL, 2001). Information about a preceding vehicle displayed on a simulator screen is also extracted and passed to the ACC simulation system using SCANeR II. The system then calculates desired accelerator and brake pedal angles and pass them to the real-time vehicle simulation system (RTVSS) in the driving simulator. RTVSS simulates ACC vehicle motion and passes all the necessary information about the vehicle status to the ACC simulation system and other subsystems of the driving simulator for necessary cue generation.

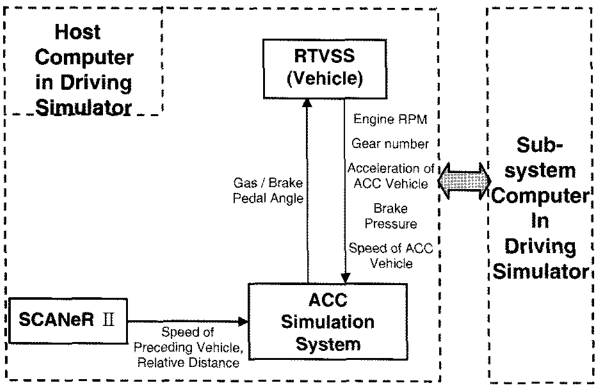


Figure 5. Integration of ACC and driving simulator.

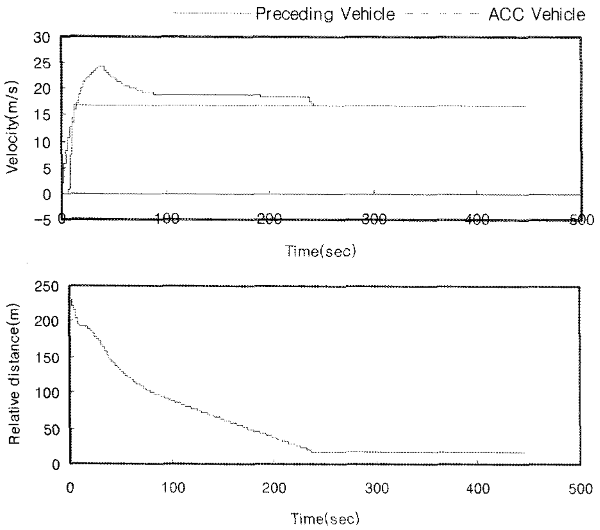


Figure 6. Approaching a preceding vehicle results.

2.4. Performance Evaluation

After the ACC simulation system has been implemented in the driving simulator, two types of maneuvers, including approaching a preceding vehicle and cut-out of a preceding vehicle, have been simulate to evaluate ACC performance.

For the case of approaching a preceding vehicle, the preceding vehicle is located about 230 m ahead of an ACC vehicle when ACC is activated. The ACC vehicle speed has been set to 100 km/hr. The driving simulation results, as shown in Figure 6, show that the ACC vehicle initially accelerates to catch up with the preceding vehicle and then successfully maintains headway-time distance.

For the case of cut-out of a preceding vehicle, the ACC vehicle follows a preceding vehicle that changes a lane later, and then a new preceding vehicle. As shown in the driving simulation results of Figure 7, the ACC vehicle follows the preceding vehicles faithfully and keeps headway-time distance well.

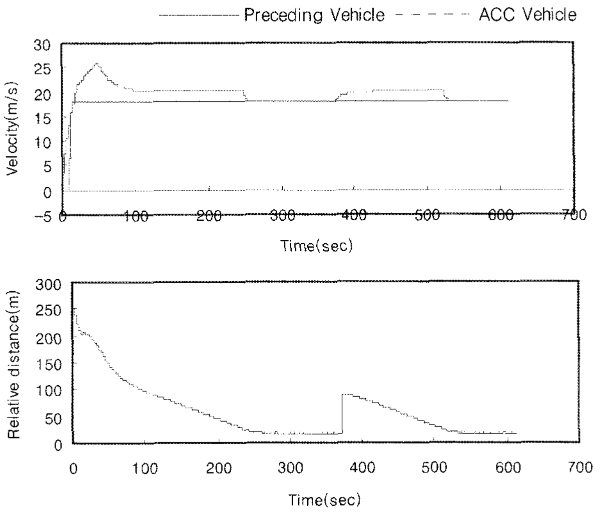


Figure 7. Cut-out of a preceding vehicle results.

3. DRIVING BEHAVIOR STUDY

3.1. Participants

Forty participants were recruited among the staff and students of Kookmin University. All the participants, consisting of 21 male and 19 female, were of ages between 19 and 52 and had current driver's licenses with an average driving experience of 3.7 years.

The Driving Style Questionnaire (DSQ) (West *et al.*, 1992) has been used to classify driving styles of the participants. The DSQ contains 6 dimensions: Speed (driving fast and exceeding the speed limit), Calmness (staying calm in dangerous situations and when there is little time to think), Social Resistance (disliking being given advice about driving), Focus (driving cautiously and ignoring distractions), Planning (consulting a map and planning places to stop and rest before setting out) and Deviance (jumping the lights and overtaking on the inside). Speed and Focus are related most with driving characteristics.

Table 1 shows the DSQ scores of the participants. The highest and lowest DSQ scores were 23.0 and 9.1, respectively, but of the possible scores between 35 and 5. Participants are divided into the following groups: high and low DSQ score drivers, high and low focus drivers, and high and low speed drivers.

3.2. Procedure

Before the start of the experiment, each driver was given detailed explanation of the driving simulator, ACC, and the purpose of the experiment. The driver then practiced driving the simulator for about 10 minutes to feel comfortable. After the practice, the driver filled out the DSQ and took some rest.

Table 1. DSQ scores.

	Sp	Fo	To		Sp	Fo	To		Sp	Fo	To		Sp	Fo	To		Sp	Fo	To
M 1	3.21	9.31	20.42	M 9	0.83	7.31	13.53	M 17	-1.57	6.8	16.24	F 4	2.41	7.48	17.51	F 12	1.6	9.4	19.14
M 2	3.2	7.48	18.78	M 10	1.62	8	16.14	M 18	1.64	7.39	10.63	F 5	1.61	9.92	19.09	F 13	4.02	7.31	16.33
M 3	1.64	6.01	9.67	M 11	-0.77	10	12.1	M 19	2.4	8	17.21	F 6	0.85	8.08	18.78	F 14	1.61	5.41	12.57
M 4	2.42	7.39	18.1	M 12	0.83	7.92	12.36	M 20	2.42	8	17.9	F 7	2.45	8	22.96	F 15	-0.02	5.3	16.25
M 5	1.62	8	15.85	M 13	1.64	8.09	14.94	M 21	2.42	8.01	18.16	F 8	2.41	8.17	18.05	F 16	2.41	8.09	17.15
M 6	2.43	7.39	13.61	M 14	0.82	6.7	10.37	F 1	0.03	7.4	13.98	F 9	1.65	8.08	14.96	F 17	1.62	7.39	15.76
M 7	3.2	4.7	17.23	M 15	4.01	5.99	17.43	F 2	0.07	7.39	17.18	F 10	1.6	8.17	17.36	F 18	0.05	7.47	9.16
M 8	-1.57	7.39	9.08	M 16	1.62	7.39	15.1	F 3	1.64	6.7	14.73	F 11	0.81	8.62	13.72	F 19	1.6	6.6	17.32

(M : Male, F : Female, Sp : Speed, Fo : Focus, To : Total DSQ)

Figure 8. Simulator driving environment.

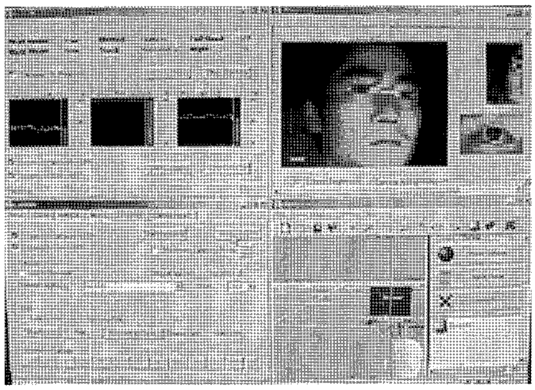


Figure 9. Screen shot of faceLAB.

During the experiment, the driver drove through a rural highway route without ACC first. The route consisted of straight lanes, curves and turns. Figure 8 shows a snapshot of typical driving environment. The lateral position of the car and headway-time were measured while the driver maintained a small but safe distance from a preceding car moving with a speed of 90 Km/hr. The faceLAB (SeeingMachines, 2002), a stereo-vision based tracking device for head and eye movement, was also used to analyze head posture and eye behavior.

The driver then drove with ACC with the set speed of 90 Km/hr. A speed setting button for conventional cruise control had been modified to allow the driver to change and select the most comfortable headway-time between 0.5 and 2.5 seconds with an interval of 0.5 seconds. Once headway-time was set, the driver drove with the setting. Meanwhile the lateral position was measured, and also head and eye movement was measured using the faceLAB. Figure 9 shows a screen shot of faceLAB. Red lines on the eyes of a person indicate eye gaze directions and a green line on the nose indicates head direction. After the experiment, the driver answered a questionnaire regarding acceptance to ACC.

3.3. Results

Figure 10 shows average headway-time for different driver groups. When driving without ACC, each group keeps different headway-time. No significant interaction with the driver groups was found. When driving with ACC, however, these group differences are minimized so that average headway-time is 1.5 seconds. This shows a behavioral adaptation effect by ACC.

As shown in Figure 11, the standard deviation of the

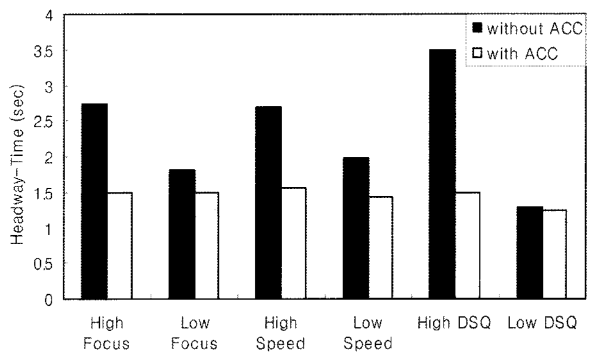


Figure 10. Average headway-time for different groups with and without ACC.

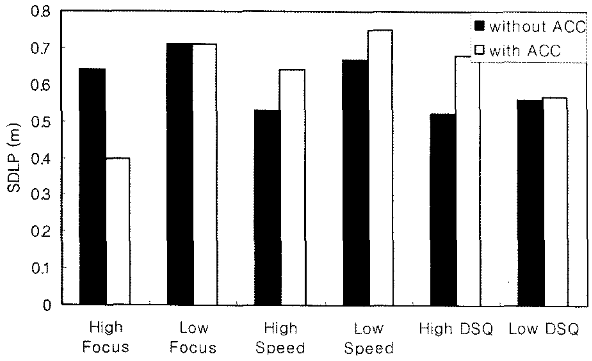


Figure 11. Standard deviation of lateral position for different groups with and without ACC.

lateral position of the car is bigger when driving with ACC, except for the high focus drivers, as compared to driving without ACC. No significant interaction with the driver groups was found. This shows another behavioral adaptation effect, although undesirable, by ACC.

Driving with and without ACC also showed a difference in head movement. Figure 12 shows the head movement of particular high and low DSQ score drivers. The movement area was obtained by projecting head direction vectors on the planes perpendicular to their faces. It is shown that the head movement area for driving with ACC is larger than driving without ACC. Larger area implies that a driver looks around more while driving. The same trend was observed for the drivers with top and bottom 10% DSQ scores.

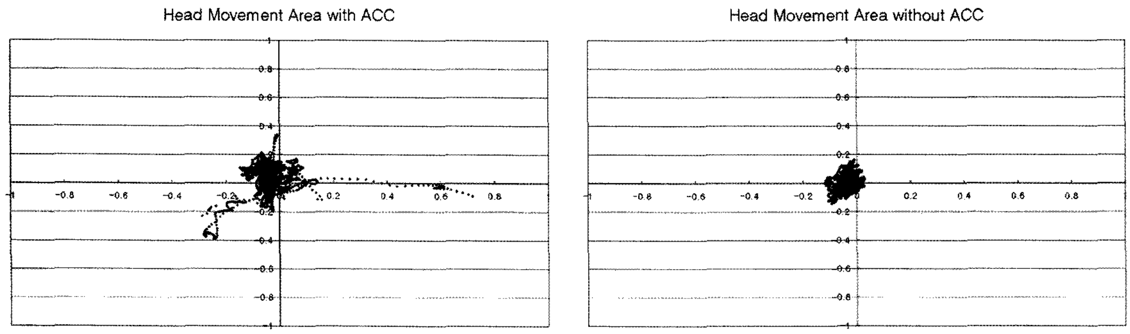
Figure 13 shows the eye movement of the same drivers. The movement area was obtained in the same fashion by projecting gaze direction vectors on the planes perpendicular to their faces. It is also shown that, when driving with ACC, the gaze movement area becomes larger, similar to the head movement area. The gaze movement area for a low DSQ driver is narrow. Larger area implies that a driver looks around more while driving.

4. CONCLUSION

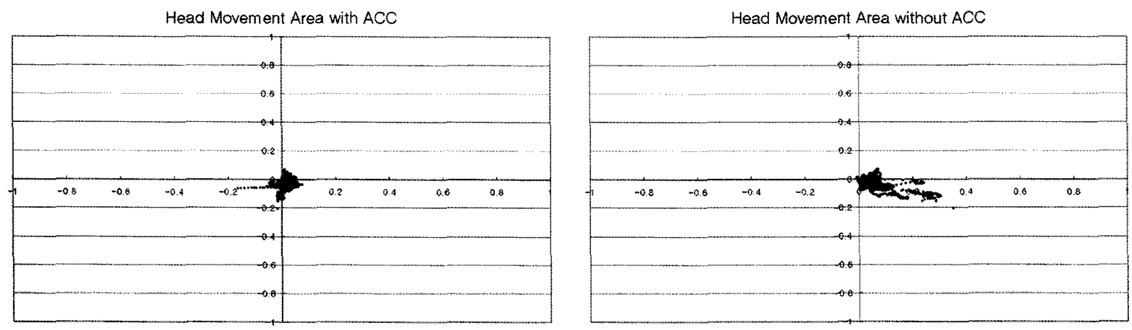
In this study, driver behavior with Adaptive Cruise Control was investigated in terms of preferred headway-time, lateral position of a car, and head and eye movement.

When driving with ACC, the drivers selected 1.5 seconds to be the most preferred headway-time, regardless of their driving styles. Without ACC, on the other hand, the preferred headway-time varied depending on the driving styles. This implies that ACC, with its robust longitudinal control capability, draws consistency in driving speed and safe distance.

However, when driving with ACC, the lane keeping ability of the drivers reduced, showing the larger standard



High DSQ driver



Low DSQ driver

Figure 12. Head movement area for high and low DSQ drivers with and without ACC.

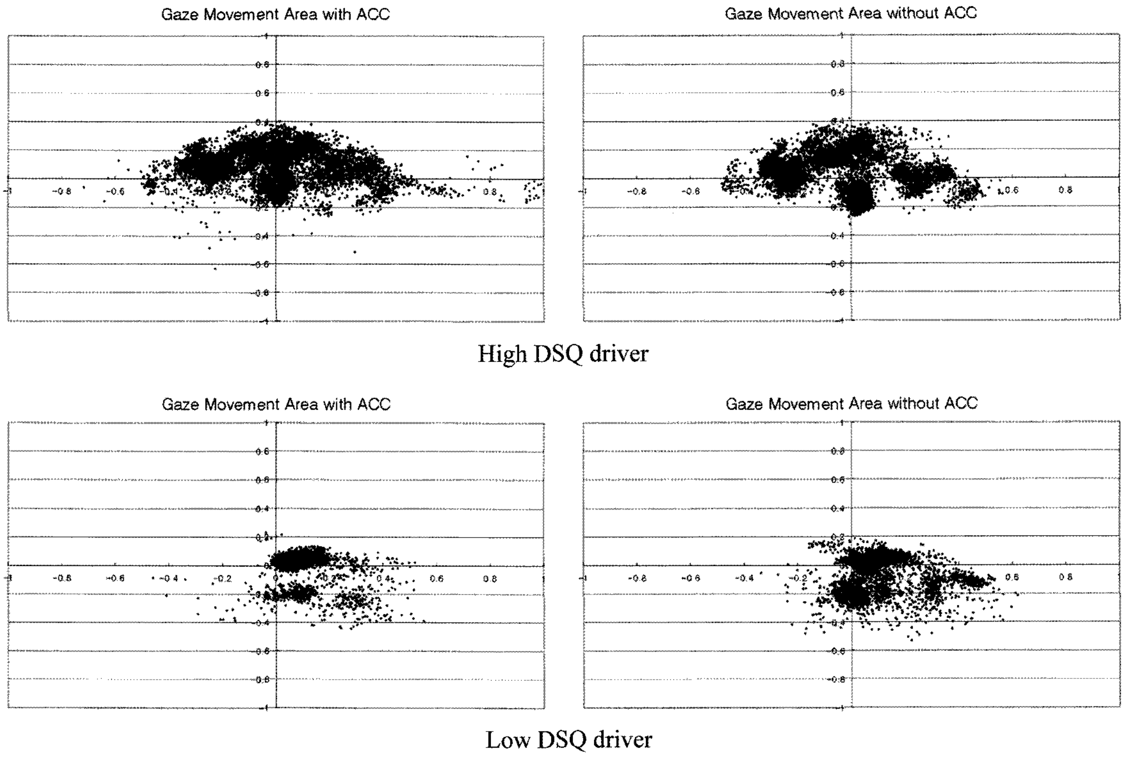


Figure 13. Eye movement area for high and low DSQ drivers with and without ACC.

deviation of lateral position of their cars. This is consistent with the finding by other researchers. The larger head and eye movement area of the drivers, implying reduced attention during driving, supports the result.

In order for ACC to become a more promising technology for enhancing traffic safety and driver comfort, lateral control such as lane keeping and lane departure warning can be added, leading to unified chassis control.

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