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INFLUENCE OF PROVIDING BODY SENSORY INFORMATION AND VISUAL INFORMATION TO DRIVER ON STEER CHARACTERISTICS AND AMOUNT OF PERSPIRATION IN DRIFT CORNERING

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ABSTRACT−Driving simulations were performed to evaluate the effect of providing both visual information and body sensory information on changes in steering characteristics and the amount of perspiration in drift cornering. When the driver is provided with body sensory information and visual information, the amount of perspiration increases and the driver can perform drift control with a moderate level of tension. With visual information only, the driver tends to easily go into a spin because drift control is difficult. In this case, the amount of perspiration increases greatly as compared with the case where body sensory information is also provided, reflecting a very high perception of risk. When body sensory information is provided, the driver can control drift adequately, feeding back the roll angle information in steering. The importance of the driver's perception of the state of the vehicle was thus confirmed, and a desirable future direction for driver assistance systems was determined.

KEY WORDS : Automobile, Maneuverability, Human engineering, Human interface, Vehicle dynamics, Stability

1. INTRODUCTION

In "smart" driver assistance systems, the information that can be obtained while the driver is driving includes not only visual information but also body sensory information. In particular, when a driver is controlling a difficult vehicle in drift cornering, it is thought that visual information only is insufficient and that body sensory information could be fed back to assist in steering control. In the present research, drift cornering was performed using a driving simulator with vehicle motion function turned either on or off, and changes in steer characteristics and the amount of perspiration were evaluated. Moreover, at the same time. The degree of tension that the driver experiences when the drift is controlled and the degree danger felt when arriving at spin were evaluated based on the amount of perspiration in simulations with vehicle motion turned either on and off. The tries by various measurements concerning the degree of tension etc. in the previous report are the references (Kamiya *et al.*, 1993; Sawada, 1983).

2. OUTLINE OF EXPERIMENTAL DEVICE (DRIVING SIMULATOR)

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Figure 1 and Figure 2 shows the driving simulator used for this research. Regarding the simulator, a visual display and sound generation system simulating the engine sound of a vehicle when running were built in to reproduce an actual driving situation. Also, a motion device including two freedom degrees of roll and pitch is built in. The roll of the motion device operates by inputting the roll angle signal of the model of the vehicle movement. The motion device does not reproduce the roll experienced with lateral acceleration however. This aspect is not reproduced because with high lateral acceleration the motion experienced by the driver can lead to giddiness and

Figure 1. Driving simulator.

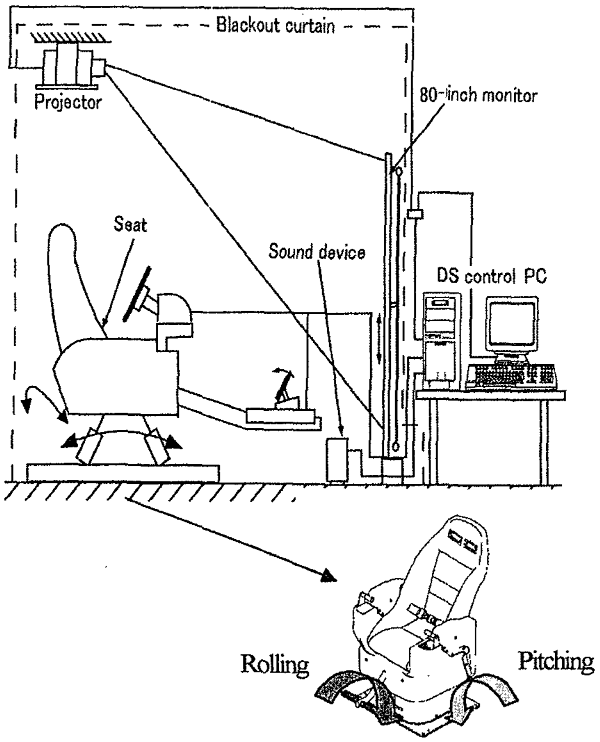


Figure 2. Outline of driving simulator.

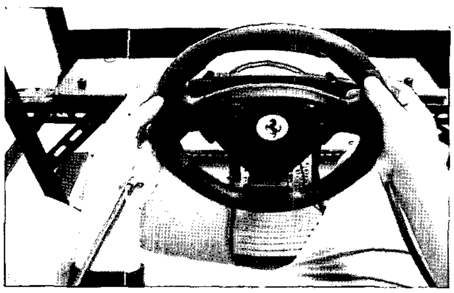


Figure 3. Capsule sensors of perspiration meter attached to palms of hands.

nausea. Then, the roll of the motion device simulates the roll of running by the volume control. In the experiments, the following items were measured.

(1) Vehicle drive state data: steer angle, steer torque, vehicle velocity, positional data, body slip angle, yaw rate, yaw angle, roll angle, pitch angle, lateral acceleration, and the steer angle of each wheel, etc.

(2) Human body response data: Amount of perspiration.

Figure 3 shows the capsules which perform as sensors for the perspiration meter; these are attached to the palms of the hands. The two channel type perspiration meter used in the experiment is measured with reference to a capsule in an environment of ventilated room air. As in previous models, neither dry air nor N_2 gas are needed, but a new method was used to supply room air to the capsule. The details are described in previous report (Kikuchi *et al.*, 2002).

3. EXPERIMENTAL METHOD, VEHICLE MODEL, AND VEHICLE CHARACTERISTICS

The subjects of the experiment were two subjects accustomed to the driving simulator and drift cornering, and two subjects who were relatively unaccustomed to the driving simulator as shown in Table 1. Each subject performed the simulation alternately five times with the motion turned on and the motion turned off. The subjects were then asked to rate of the ease of drift cornering after the simulations. The details are described in previous report (Kikuchi *et al.*, 2002).

3.1. J Turn Course Experiment

In this experiment, the driver was required to turn a curve 75 m in radius after a straight approach, and then to return to a straight line afterwards (Figure 4). The speed when the vehicle starts to turn is set to two levels (90 km/h or 100 km/h). (The vehicle velocity is set to the level such that drift cornering is performed.) The driver was obligated to maintain the specified speed by controlled acceleration while turning. The subjects were obligated to follow to the target course while drift cornering rather than grip cornering. The simulation ended when the vehicle completed the J turn course or inadvertently went into a spin.

3.2. Drift Turn Experiment

This experiment used a steady state turn course with a 75-m-radius turn (75R turn) (Figure 5). In a correct run, the driver performs a rear wheel power slide by depressing the accelerator during limit cornering, and then

Table 1. Subject.

Subject	A	B	C	D
Experience of DS†	More than 2 years	More than 2 years	Less than 1 year	Less than 1 year
Driving experience	More than 4 years	More than 3 years	Less than 1 year	More than 2 years
Frequency of using a car	Everyday	Everyday	Sometimes	Sometimes

All subjects are males.
†DS = Driving Simulator

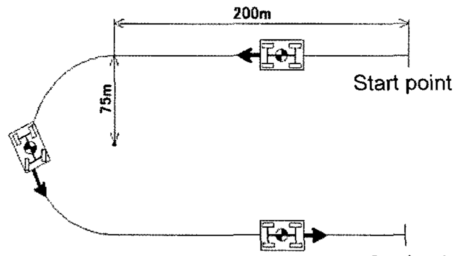


Figure 4. J turn course.

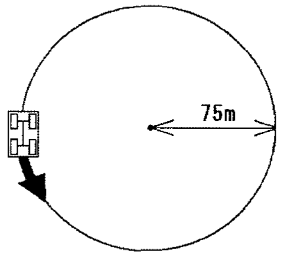


Figure 5. Turning course.

applies counter steering, controlling the amount of counter steering afterwards, and ultimately maintain control during the 75R drift turn while maintaining the drift angle. The driving simulator is based on the concept of a friction circle, assuming a braking driving force based on the tire characteristics of the driving simulator as described later, the vehicle tends to go into a spin when the rear wheel's lateral force is decreased by accelerating at the time of the critical cornering. To avoid spin, the driver applies counter steer control while maintaining the drift.

3.3. Vehicle Model and Vehicle Characteristics

As a vehicle model, the driving simulator uses the full vehicle movement simulation software named CarSim (Version 5.16) of the mechanical simulation corporation (MSC Co., USA). Figure 6 shows the outline of the vehicle model. Table 2 shows the number of main parts in the vehicle and the number of degrees of freedom. The rear axle is rigid and has two degrees of freedom (vertical movement of axle and roll, Figure 7). The details are described in a previous report (Watanabe and Sayers,

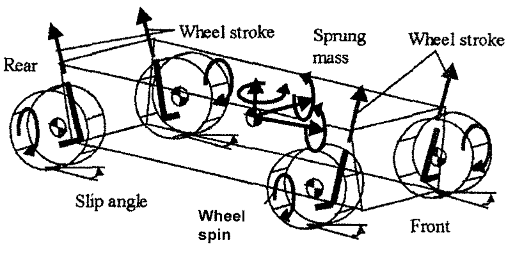


Figure 6. Rigid bodies in the vehicle math model.

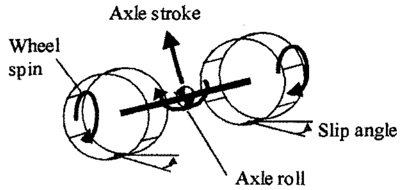


Figure 7. Solid–axle movement.

Table 2. Bodies and degrees of freedom in car model.

Bodies	
Sprung mass body	1
Unsprung mass bodies (wheel carriers)	4
Rotating wheels	4
Engine crankshaft	1
Total	10

Degrees of freedom	
Sprung body translation (X, Y, Z)	3
Sprung body rotation (yaw, pitch, roll)	3
Suspension stroke	4
Wheel spin	4
Powertrain (Engine crank shaft)	1
Tire delayed slip (lateral, longitudinal)	8
Brake fluid pressure	4
Total	27

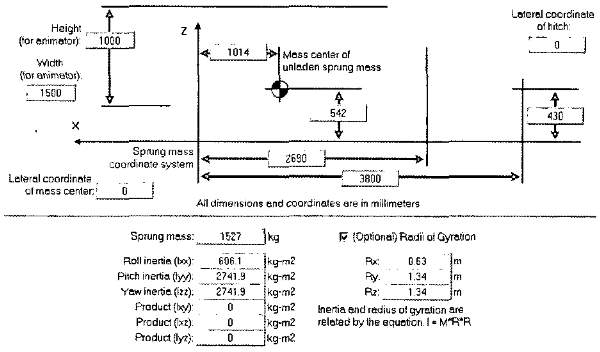


Figure 8. Experiment vehicle data.

2002).

Figure 8 shows the parameters for the vehicle model used in the experiment. For the engine layout and driving method, the vehicle model uses the FR layout (front engine mount and rear drive) which vehicle fell easily by the state of the drift. For the vehicle parameters, the width is 1500 mm, the wheelbase is 2690 mm, the distance from the front wheel center to the rear end of the vehicle is 3800 mm, the distance from the front wheel center to

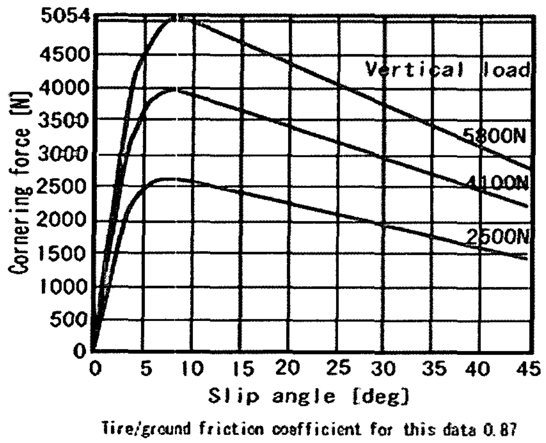


Figure 9. Tire cornering force characteristic.

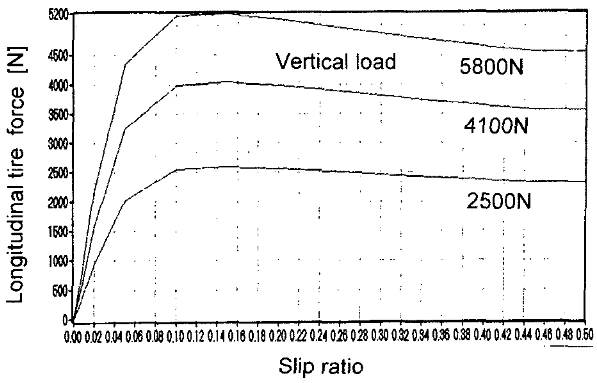


Figure 10. Longitudinal tire force characteristic.

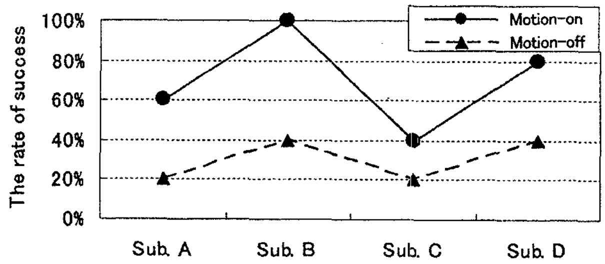


Figure 11. Rate of success (j-turn 100 km/h).

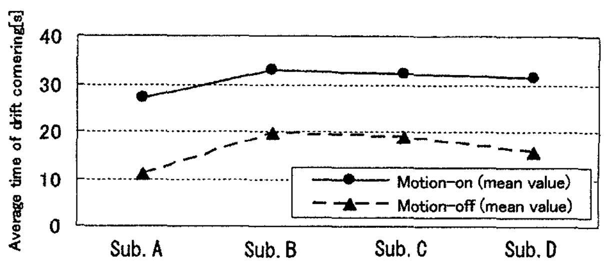


Figure 12. Average time of drift cornering (drift cornering).

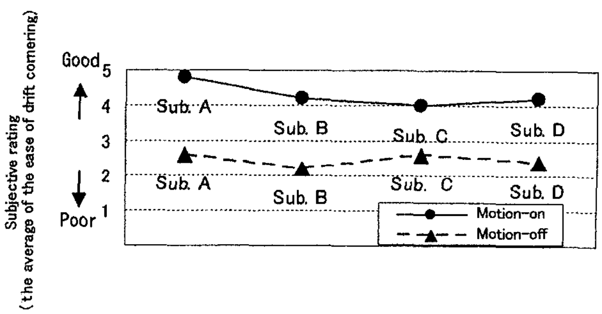


Figure 13. Subjective rating (j-turn 100 km/h).

the center of gravity is 1014 mm, the height from the ground to the center of gravity is 542 mm, the mass of the vehicle is 1527 kg, the roll inertia moment is 606.1 kg·m^2, the pitch inertia moment is 2741.9 kg·m^2, and the yaw inertia moment is 2741.9 kg·m^2.

The tire cornering force available follows the general tire characteristic shown in Figure 9.

Moreover, the tire characteristic during driving and braking was assumed to follow the data shown in Figure 10. By considering the slip angle and the slip ratio at the same time, the friction circle concept can be applied based on the combined characteristic of CarSim. The details of combined characteristic are described in previous report (Pacejka and Sharp, 1991). Therefore, based on the friction circle concept, the vehicle has a tendency to spin when the lateral force of the rear wheel decreases because of accelerating in critical cornering. In this case, drift cornering can be performed by counter steering, operating at similar to levels of a real car.

4. EXPERIMENT RESULT

4.1. Effect of Changes in the Steering Characteristic on the Amount of Perspiration

Figure 11 shows the success rate for completing the J turn course (at 100 km/h approaching the corner). Figure 12 indicates the drift maintenance time for the drift turn experiment. Figure 13 shows the subjective rating of the J turn course. The success rate for completing the J turn course was higher when the motion was turned on than when turned off (Figure 11), and similarly the time of maintaining drift cornering was longer when the motion was turned on (Figure 12).

It can be understood that when the motion is turned on, drift control can be performed relatively well by all subjects. Moreover, the subjective rating with the motion turned on was higher, and this was more similar in drift turn experiment (Figure 13).

Figure 14 shows the results for subject A in the drift turn experiment. The solid line indicating the amount of

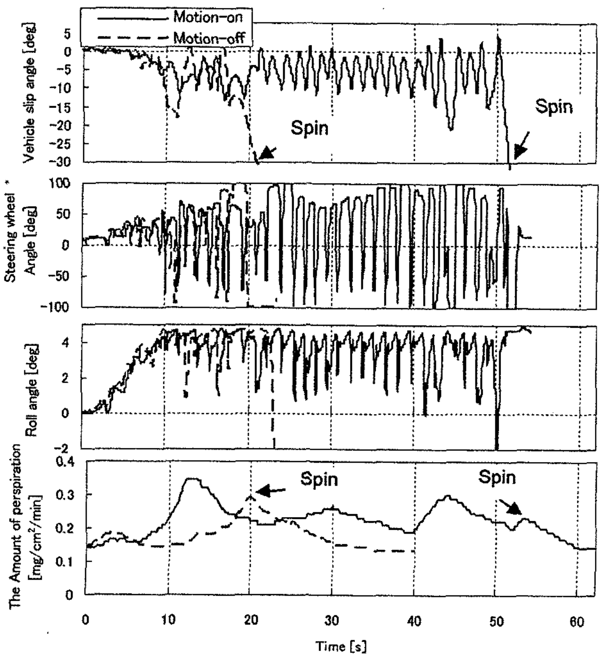
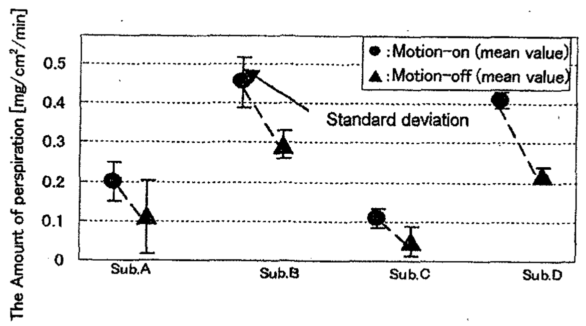


Figure 14. Experiment result of drift cornering (subject A) (drift cornering).

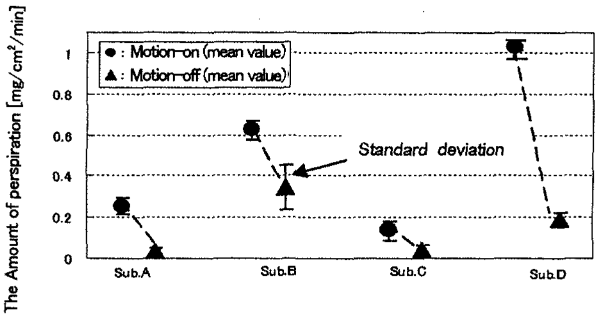
perspiration during drift cornering with the motion turned on (solid line) quickly diverges from the dotted line showing cornering with the motion turned off. With the motion turned off, the subject begins to apply counter steering with a change in body slip angle of about 15°. On the other hand, with the motion turned on, the subject begins to apply counter steering with about 10° body slip angle, and there was a tendency for counter steering to be initiated a little earlier. Moreover, with the motion turned off and with only visual information, the amount of perspiration after a spin, which reflects the perception of danger, was larger than that with the motion turned on. Such a tendency was similarly seen for other subjects. The result of the quantitative analysis are shown at next section.

4.2. Change in Amount of Perspiration with Motion Device Turned On or Off in Drift Cornering

Figure 15 shows the average value and standard deviation of the increase in the amount of the perspiration increment while performing drift turning with the motion turned on and off. For all subjects, perspiration with the motion turned on is greater than that with the motion turned off. In the drift turn experiment with counter steer operation performed while repeating the drift cornering, a remarkable difference was observed. When body sensory information and visual information were given, the subject experienced an increase in the amount of perspiration during drift cornering. Because the drift



(a) J-turn (v=100km/h)



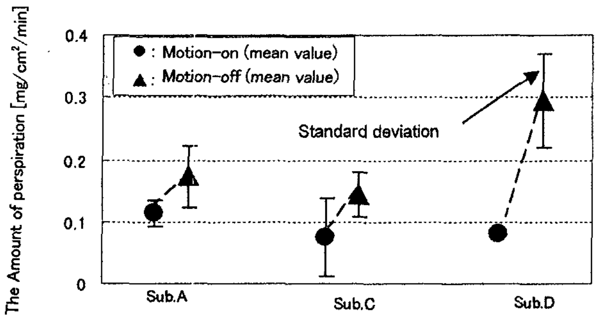
(b) Drift cornering

Figure 15. Comparison of perspiration (maintaining the drift cornering).

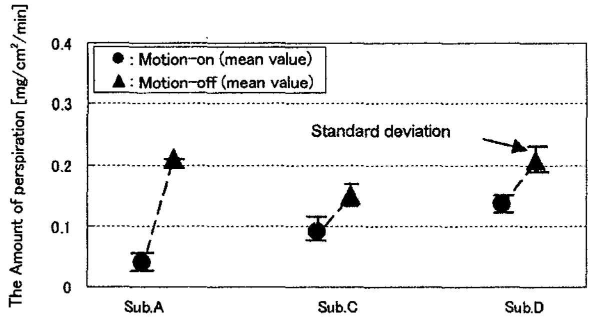
could be maintained relatively well with the motion turned on, it is thought that the increase in perspiration observed with the motion turned on is a result of the mental activity in response to the moderate stimulation for which drift is maintained while feeding back body sensory information.

4.3. Change in Amount of Perspiration Immediately After Spin with Motion Turned On or Off

When looking at the increase in perspiration immediately after a spin, a difference can be observed between motion turned on and turned off. The average value and standard deviation in the increase in the amount of perspiration immediately after the spin were compared for all experiments for the motion turned on and turned off. (Figure 16). Because subject B did not get into a spin in either experiment, a comparison could not be made between the case with the motion turned on and the motion turned off. For all subjects in the J turn course and drift turn experiments, the amount of perspiration increased after each spin by about 0.1 mg/cm^2/min on average with the motion turned on and increased by about 0.2 mg/cm^2/min on average with the motion turned off, a large increase. Because each subject commented that the awareness of spin occurred late with the motion turned off, it can be

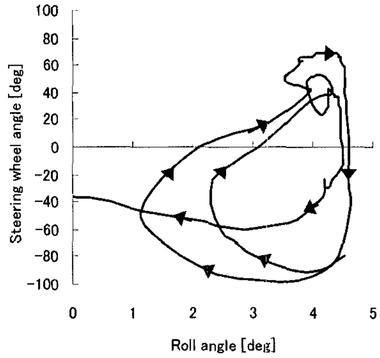


(a) J-turn (v=100 km/h)

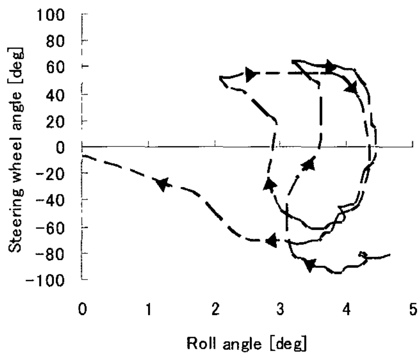


(b) Drift cornering

Figure 16. Comparison of perspiration (after spin).



(a) Motion-on



(b) Motion-off

Figure 17. Relation of roll angle and steering wheel angle (subject C, j-turn, v = 100 km/h).

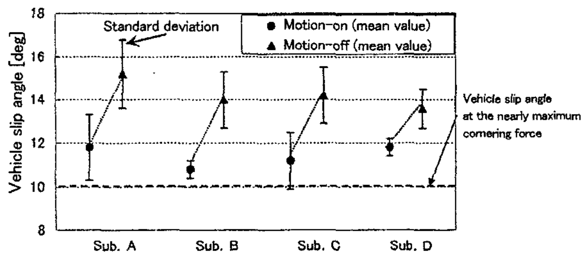
understood that the difference in the amount of perspiration sensation immediately after the spin with the motion turned is a reflection of the feeling of danger.

4.4. Influence of Roll Angle on Steer

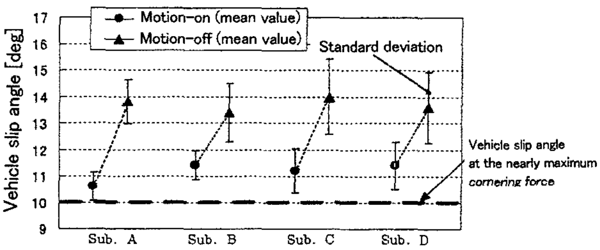
Figure 17 shows a phase plane trajectory of the steer angle and the roll angle. With the motion turned on, the roll angle decreased as counter steering was performed when the roll approaches the limit. With the motion turned off, the phase plane trajectory crosses itself several times and is irregular. This subject (Subject C) shows the tendency in which the roll angle is not fed back to the steering. With the motion turned on, it is observed that the subject is controlling the drift by repeating counter steering, feeding back the roll angle information.

4.5. Difference in Body Slip Angle at the First Counter Steer

Figure 18 shows the body slip angle when the driver performs the first counter steer. All subjects could perform counter steering with the motion turned ON with a body slip angle of about 10°. On the other hand, counter steering is delayed with the motion turned off and a difference in the timing of counter steer is observed.



(a) J-turn (v=100 km/h)



(b) Drift cornering

Figure 18. Comparison of vehicle slip angle at first counter steer.

Therefore, it can be concluded that the driver can control the drift cornering well with the motion turned on, as shown in Figure 18, by feeding back the body sensory information of the roll angle.

5. CONCLUSIONS

In experiments on driver assistance which investigated using not only visual information but also body sensory information, the following conclusions were obtained in terms of changes in the steering characteristics and the amount of perspiration during drift cornering.

(1) When body sensory information is combined with visual information for the driver, it is observed that the amount of perspiration increases overall and that the driver can perform drift control with moderate levels of tension.

(2) When only visual information is provided, the driver tend to easily go into a spin because drift control is difficult. Also, the amount of perspiration increases greatly compared with the case when body sensory information is provide; this situation indicates a high risk.

(3) The driver can control drift adequately with body sensory information provided as compared with driving with only visual information and in steering is able to feed back body sensory information on the roll angle. The importance of the driver's perception of the state of the vehicle was confirmed by giving the driver moderate body sensory information, and the preferable direction of the vehicle was clarified.

In future, it is important to further advance the field of driver assistance control systems and to feed back both visual information and body sensory information to the driver to assist in drift cornering. In addition, the future direction of driver-vehicle systems should be discussed.

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