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Research Article

PROPOSAL OF A SYSTEM USING A DRIVING SIMULATOR TO DEMONSTRATE HUMAN–MACHINE INTERACTION DURING AN EMERGENCY

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ABSTRACT:
In recent years, fatal accidents owing to errors in the control of the gas pedal (accelerator) and brake pedals by the elderly have become more frequent. It is therefore theorized that the arrangement of the brake and gas pedal may be inappropriate. Automatic driving is necessary to prevent stepping on the wrong pedal. Although research comparing the emergency response was conducted in a prior study, a completely automatic driving system has yet to be realized, and an appropriate foot pedal position has not been determined. In this paper, an experimental system using a driving simulator to demonstrate human–machine interaction during an emergency is proposed. The system was used in a basic experiment, and suggestions for improving the emergency braking system are presented. The experimental results showed that the redesign of brakes is an essential factor in improving automobile safety.

Keywords: *Human-centered design, Driving simulator, Fitts's law, Reaction Time, Emergency operation*

1. INTRODUCTION

The life expectancy in Japan is increasing each year. The total global population of 738,301 in 2015 is expected to reach 10,222,060 in 2060, with the proportion of people aged 65 and over increasing from 5.1% to 17.8%. Future estimates suggest that the population is expected to age rapidly in both developed and developing nations. As a result, the mobility restrictions and migration environment of the elderly are expected to become even more critical social issues in the future. Thus, there is a need to improve transportation systems to increase the opportunities for the elderly to go outside the house [1]. In terms of cognitive function, the risk of accidents among elderly drivers is expected to increase owing to their diminished vision, judgment, and operating ability [2]. An improper operation is the most frequent cause of fatalities in human-centered single-vehicle accidents, including those caused by the improper application of the gas and brake pedal. Safety measures include license revocation, emergency braking from the passenger seat, and an acceleration restraint system in the case of a pedal application error. Revoking car licenses from people who need a car or designing a machine based on mistakes will not lead to fundamental solutions. Some studies are using facial expression reading systems in driver-assistance applications, although they are still in the testing stage. In the present study, a system is proposed to improve the existing driving systems by analyzing the pedal application errors during emergency braking [3]. During an emergency situation, the driver is required to perform an agile and accurate braking action. Whereas other studies have examined the effects of aging on the emergency brake application behavior of older adults, the present study newly examines whether changing the

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position of the pedal affects the emergency brake application behavior. These papers provide primary data for a current automobile design by comparing the behavioral characteristics of both the elderly and the young [4-7].

Several studies have focused on the characteristics of foot movement [8-10]. In recent years, cars that can be operated with a single pedal have become available on the market, and we are investigating the effectiveness of such vehicles [11]. The foot behavior of inertial driving is also noteworthy. All of these are critical aspects of braking behavior [12, 13]. Active research on automated driving, brake placement, and driver behavior during emergencies is also being conducted. Some researchers have used a driving simulator to observe drivers operating a smartphone, drinking, or watching a movie while the car is driven automatically to determine how they react when the machine returns control to the driver during an emergency [14, 15]. These studies have focused on factors such as pedal application behaviors, and although they do provide correlations between age and other factors, they have not discussed pedal placement. Therefore, we attempted to develop a car that is easier to drive by changing the pedal placement. The human–machine model is validated by simulating an emergency using a car model. This will be useful in designing new vehicles and will enable us to propose vehicle operating systems that consider human characteristics from a human-centered design perspective, instead of factors such as emergency braking.

2. Mechanisms of Human Error in Vehicle Operation

Most industrial accidents, estimated at between 75% and 95%, are attributed to human error. A model called "Seven Stages of Action" proposed by Norman is based on modeling for times in which people take action. We will determine whether this model changes during a crisis. Human error is defined as a deviation from the "appropriate" behavior. However, an appropriate behavior is not known in all situations because such behavior can only be determined after the fact. Nonetheless, errors are still defined as deviations from the generally accepted correct or appropriate behavior. The model is shown in Fig. 1 [16].

When driving a car, professional drivers might not deliberately think about/follow this model, unlike beginners or inexperienced drivers. However, all drivers do so unconsciously. When encountering a critical situation, this process is likely to be disrupted. We will determine how such sudden changes affect the seven-stage model of driving behavior.

The UI/UX is not desirable from a design standpoint because the gas and brake pedal actions are the opposite of the foot pedal actions. The proximity of the foot pedals might also cause confusion when using one foot to operate the vehicle, and such factors can lead to an accident.

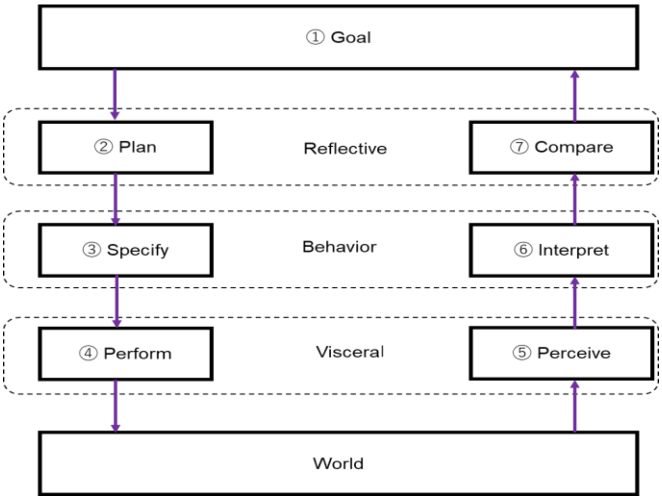

Fig. 1. Seven stages of action model [16].

3. DRIVING SIMULATOR APPLIED TO VIRTUALLY DEMONSTRATE HUMAN–MACHINE INTERACTION

3.1 Proposal to recreate an emergency situation using a VR driving simulator

The driving simulator used in this study applies virtual reality (VR). An emergency simulator is always used to test a new vehicle as part of the manufacturing process. A representative vehicle is crashed into a wall to check whether the mannequin inside the car is damaged, and various tests are conducted on the front and sides of the vehicle. The safety of the mannequins and the degree of deformation of the vehicle are inspected to ensure that the car is safe before being sold.

We recently began using computer simulations because using real vehicles for testing is expensive and may result in heavy losses. It also takes time to prepare, check, and verify the test results. Therefore, car manufacturers use a driving simulator based on a real car for testing and verification. Using a driving simulator in research is inexpensive (2,000 USD) and easy to create. The most critical factor in creating a simple simulator is that it be realistic. For drivers to perceive their environment, VR is used to simulate the feeling of driving in real life. VR-based experiments can be conducted at low cost because there are no restrictions on the size of the experiment space.

3.2 System setup

A VR driving simulator was developed using commercially available products because building a real driving simulator is expensive. The VR driving simulator used the same inputs and outputs as those of a real car.

The basic system it is composed of a head-mounted display (Oculus Rift) and a steering wheel controller (Thrustmaster T150 pro). The head-mounted display tracks the position of the subject's head, which is reflected through VR.

The vehicle used was from Unity Standard Assets, which is a free Unity-based software. The driving stage is Windridge City. Figures 2 and 3 show a block diagram of the driving simulator and a photograph of the driving simulator, respectively. Figure 4 shows the arrangement of the foot pedal.

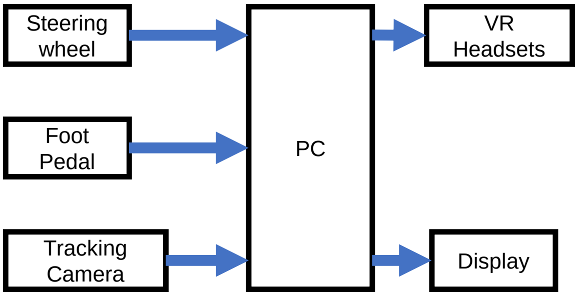

Fig. 2. Block diagram of the driving simulator used in the experiments.


Fig. 3. Driving simulator used for experiments.

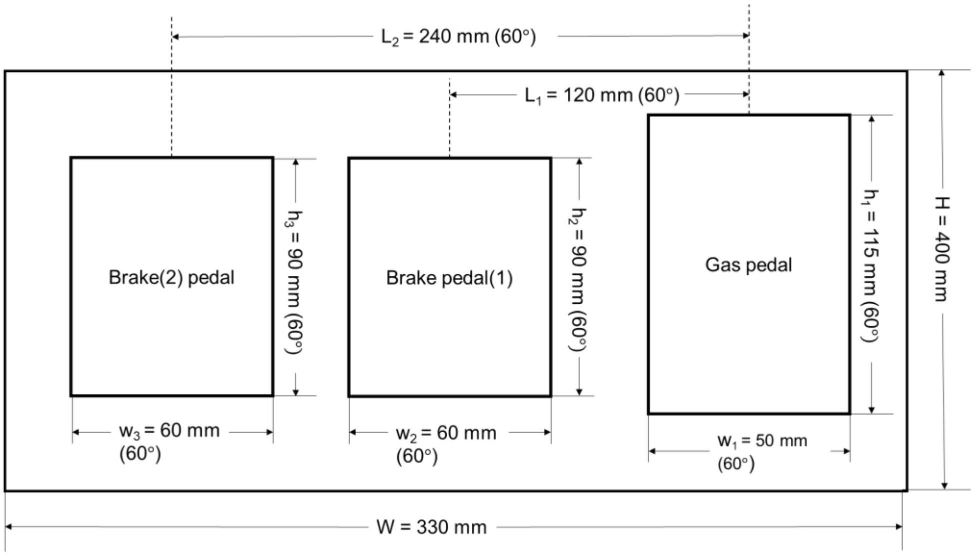

Fig. 4. Arrangement and dimensions of brake and gas pedals.

4. Experiments

To measure the reaction time of humans during a driving emergency, we derived a scenario in which a character suddenly jumps in front of a car while it is driving. Because it was difficult to secure a large space for the experiment, we developed a driving simulator using virtual reality. Using the VR driving simulator, we asked the subjects to drive along a particular course in Windridge City. The specifications of the PC and the Oculus Rift used in this study are shown in Tables 1 and 2.

Table 1: Specifications of the PC used in the drive simulator

	Oculus recommended specifications	**PC specifications used in this study**
OS	Windous10	Windous10
Processor	Intel Core i5-4590 AMD Ryzen 51500X	Intel®Core™ i5-85000 CPU 3.00 HZ
RAM	8.00 GB	16.00 GB
Graphics Board	NVIDIA GeForce GTX 1060/970, AMD Radeon RX 480/R9 290	Raden™ RX 570 Graphics

Table 2: Oculus Rift Specification Chart

Type	**Stationary type (PC axis type)**
Resolution/Frame Rate	2160 × 1200/90 fps
Video Panel	OLED
Viewing Angle	110 degrees
Tracking Area	1.5 m × 1.5 m (2 Oculus sensors) 2.5 m × 2.5 m (3 Oculus sensors)
Weight	470 g
Audio	3D sound headphone, microphone
Refresh Rate	90 HZ
Platform	Oculus Home, SteamVR
Detection Sensor	Infrared camera, Gyroscope, Accelerometer, Porcelain sensor

The subject of the experiment, a car driver, is stimulated by a CG character to apply a braking action. During the experiment, the subject depresses the gas pedal to drive the car at a constant speed (60 km/h), and when the character enters the roadway (10 km/h) while driving, the driver switches from accelerating to braking and the timing is recorded. The characters appearing on the road are of different colors in Experiments 1, 2, and 3 and in Experiments 3, 4, and 5, and are labeled Character A and Character B, in each case. Each character waits in the same place and starts running on the road at a specified time. According to the World Health Organization (WHO), the safe stopping distance for a car at 60 km/h is approximately 38 m [17]. During the experiment, the characters run out into the road just at the moment it is safe to do so based on WHO data. The characters wait in the shade of a tree, and start running when they are 40 m away from the car. The brightness of the characters is changed to verify the influence of the visibility. Character A is light and character B is dark. The colors of the clothing parts are #b4763e and #0f0f11 in hexadecimal colors. Therefore, the timing of character's emergence is set manually. During this experiment, the stimuli in the driving environment are presented using the Wizard of Oz prototype method to investigate the characteristics of the interaction. When the car reaches the point at 40 m, the character is run over or hit by the car. We also measured the time between the character's appearance on the screen and the subject's application of the brake. In this case, a screen capture and timer function of unity were used to measure the time required to change from the gas pedal to the brake pedal. During the experiment, the reaction time to an emergency situation was measured as the time when the gas pedal and brake pedal were depressed approximately halfway, and the gas pedal and brake input were defined as being in an ON state. The state in which the acceleration and brake pedals are not depressed or touched lightly is defined as an OFF state. The time between the last time the gas pedal was turned ON and the first time the brake pedal was turned ON is defined as the "change of step time," T1. The input time from when the character starts running to when the brake is pressed is T3, and the time from when the character starts running to when the gas pedal is pressed is T2. Figure 5 shows the relationship between each reaction time, and as indicated, shortening T3 is important in designing an automobile interface.

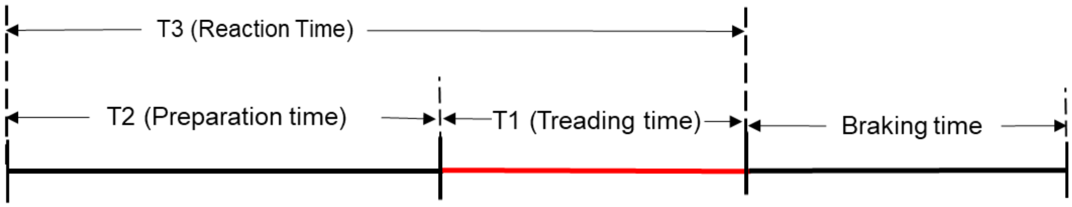

Fig. 5. Relationship diagram of T1, T2, and T3.

Five subjects who aged between 22 and 23 years participated in the experiments. Experiments 1, 2, and 3 were conducted using the brightly colored character A. The first experiment consisted of a gas and brake pedal (1). Figure 5 shows the manipulation using the feet during Experiment 1. The second experiment consisted of a gas and a brake pedal (2) using a single foot. Figure 6 shows the manipulation using the feet during Experiment 2. The third experiment is similar to the second one but both feet are used. Figure 7 shows the manipulation using the feet during Experiment 3. Figure 8 shows a view of the experiment from above. Experiments 4 through 6 were conducted using Character B. These are experiments 1, 2, and 3 with the dark character A. The actual subject drives from the driver's seat while watching the images on the head-mounted display. The following is the procedure explained to the subjects during the experiment as well as the measurements made during the investigation.

1. The subject was asked to view the course on the PC display instead of the head-mounted display.

2. The procedure for operating the car was described.

3. The subject wore an HMD and conducted the experiment.

4. The subject was asked to avoid running over the virtual character while driving the car. (Fig. 9)

5. The time between the appearance of the virtual character on the head-mounted display and when the driver stepped on brake (1) or brake (2) was measured.

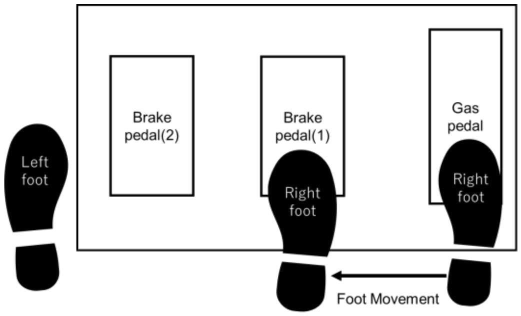

Fig. 6 Manipulation with the feet during Experiments 1 and 4

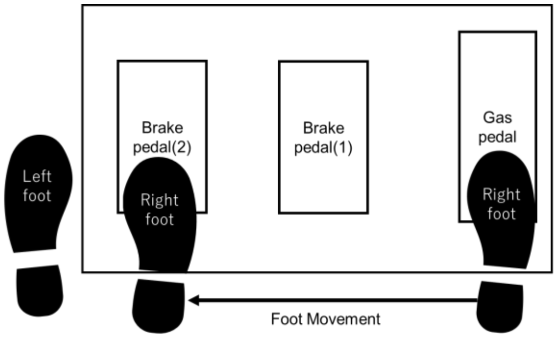

Fig. 7. Manipulation with the feet during Experiments 2 and 5

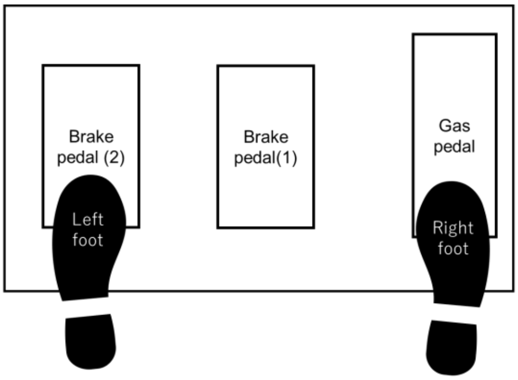

Fig. 8. Manipulation with the feet during Experiments 3 and 6.

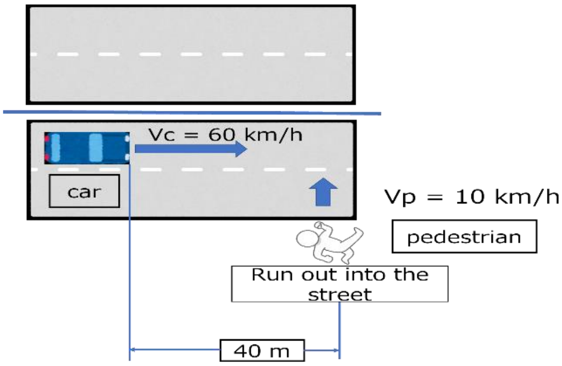

Fig. 9. When to press the brake.

5. Experimental Results

Figures 10 and 11 show the results of the experiments related to the time of a braking operation. In each experiment, where the color of the CG character of the pedestrian was changed by Character A or B, the changeover time of T1 varied depending on the manner in which the car was operated by foot. The two-footed operation (γ in the figure) was the fastest way to brake. Comparing Figs. 10 and 11, there was no significant difference in the pedal change time (T1) depending on the visibility of the character, and there was no significant difference in the pedal change time (T2) depending on the color of the character. The value of T2 varies depending on the color of the character. In addition, in the case of Character A, the median time for preparation is lower than that for Character B.

For the evaluation of reaction time T3 for legs operation time of a car, Fitts's law is used [18]. This law is often used for the reaction time and reaction speed in UI/UX based on Equation (1). Using Equation (1), we calculated α and β to determine the characteristics of the car's gas pedal and brake interfaces.

$$T = a + b \log_2\left(1+\frac{l}{w}\right) \tag{1}$$

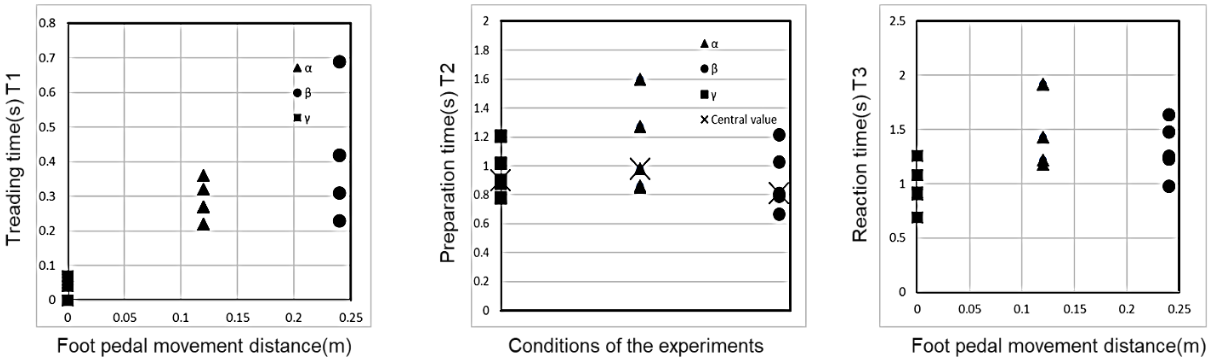

Figure 10. Graph of time related to reaction time for car stopping for experiments 1, 2, and 3

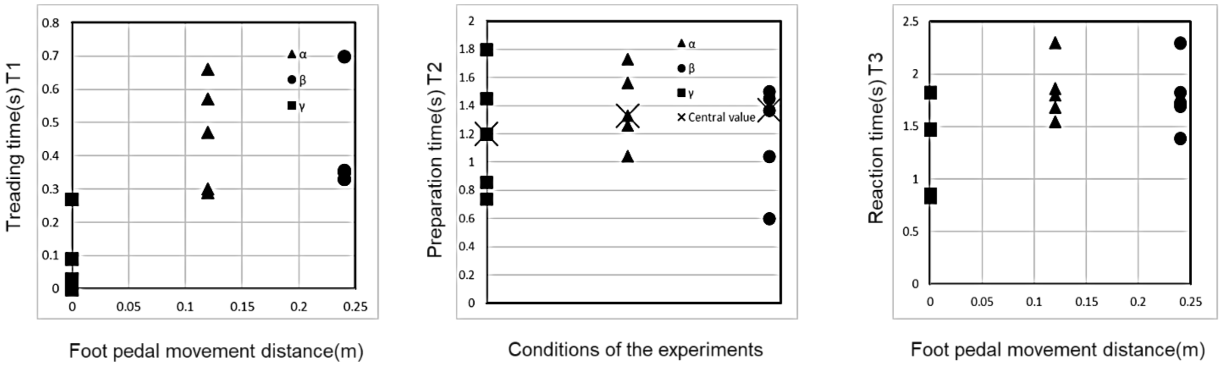

Figure 11. Graph of time related to reaction time for car stopping for experiments 4, 5, and 6

Calculate a and b in Equation (1) for the driver's reaction time when a light-colored pedestrian and a dark-colored pedestrian run into the road. In the experiment with light-colored pedestrians, a = 1.04 and b = 0.18. For dark-colored pedestrians, a = 1.34 and b = 0.234.

6. DISCUSSION

The experimental results show that, as a matter of course, the speed of operation with both legs is faster than that of an operation with one leg. This may be because there is no action required to change a step, and therefore, the two-legged operation can apply the brakes faster. Preparation time T2 was not influenced much by the placement of the gas pedal and brake, but rather by individual differences, and was affected by the color of the pedestrian's clothing. T1 to the treading time, as can be said in Fitts's law, the operation with the smaller distance of movement of the operation was able to brake more quickly. In the younger same age group, braking with both feet was the quickest way to stop the car immediately. However, if the experiment had been conducted with different age groups, the results may have been different.

There was no difference in visibility between the gas pedal and brake change times for T1, however, there was a large difference between "α", "β", and "γ" for T1.The observation of the participants during the experiment showed that they often pressed both the gas pedal and brake pedals at the same time when operating both feet. In an actual car, if the gas pedal and brake pedals are pressed at the same time, the brake takes priority. Therefore, it is considered practical to operate the gas pedal and brake pedals with both feet, and in an emergency situation, and both feet are suitable for operation. Based on the results of the experiment, it is important for pedestrians to improve their visibility by wearing brightly colored clothing. However, the experimental results show that redesigning the layout of the interface is a more important factor if we define the improvement of car safety as the ability to stop more quickly during an emergency.

In this experiment, conducted with five subjects in their 20s, it was confirmed that the braking time required by the car was almost the same for the reaction time using the driving simulator and the reaction time using Fitt's law. This allows us to calculate *a* and *b* using Fitts's law under a variety of conditions. Because *a* and *b* depend on the subject's level of proficiency and age, we believe that this simulator can be used to design appropriate brakes for older people, for example.

In the recorded video, the subject tended to brake hard both when running over the character and when not running over the character. The results of observing the behavior of the subject's feet suggest that "specify" is lost from the seven stages of action model in Fig. 1. It is difficult to establish a seven-step model of action under a crisis situation, and "cognition," "judgment," and "action" alone cannot avoid such circumstances. We believe such avoidance is difficult to achieve. The way to prevent this in a mental model can be considered to be a "prediction." However, a "prediction" is difficult and requires a constant focus on the surroundings. In the model shown in Fig. 1, "perform" is an operation at the interface, and the results of this experiment verified that by decreasing or eliminating the distance between the switching operations, we can shorten the time for the action and make it easier to stop the system during an emergency.

7. CONCLUSION

Using a proposed simple and effective driving simulator, we experimented with different layouts and operation methods of a gas pedal and brake for emergency stopping, and different conditions for a pedestrian jumping motion. The results showed that reducing the amount of foot movement during braking was more effective for emergency stopping than improving the visibility of the pedestrian.

In future experiments, we will deal with a critical situation occurring within a short period of time. However, it remains unclear whether a two-foot pedal operation is appropriate for prolonged driving. Therefore, it is necessary to examine how subjects respond to an emergency situation after driving for a long period time. In the future, it will be necessary to develop a new system to investigate the differences between the gas and brake pedal errors in a two-foot operation. It is difficult to use this driving simulator for a long period of time because it causes a significant disturbance to the user's semicircular canal. We believe that the experiment can be performed more comfortably by correcting this problem. Therefore, it is necessary to construct a driving simulator that can be used for longer periods. Moreover, it is necessary to create a system that induces mistakes in acceleration and braking.

NOMENCLATURE

a	start/stop time of the device, s
b	speed of moving object, mm/s
l	distance between start point and target center, mm
w	target width, mm
T	Time to target, s

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