

THE EFFECT OF PHYSICAL WORKLOADS ON DRIVING PERFORMANCE

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Paper Number 05-0435

ABSTRACT

Besides primary driving task, we used to have additional actions, for example, operating some buttons and looking for something. Such secondary actions have been the major cause of accidents. Using a driving simulator the effect of the physical workloads on driving performance was examined for two traffic situations. From the experimental results, the driving performance was influenced by the body movements caused by the physical workloads and the effects were verified by computational driving model in the case of the emergency avoidance.

INTRODUCTION

A wide range of driver support system has been proposed and a number of operations for these devices are increased[1][2][3]. Besides primary driving task, we used to have various actions, for example, we operate some buttons and look for something. These actions are necessary for drivers to drive comfortably in everyday life. However maneuverability will become narrow by these body movements. There are several researches that quantified the manipulability of the steering influenced by traffic situation and the sitting posture[4][5]. In this research, we refer to such secondary body movements as physical workloads. We investigate effect of the physical workloads on driving performance.

The physical workloads are classified by a distance from normal driving position to the target and the operational strategy for reaching. The targets are hazard switch, something on the passenger's seat and dash board as examples. The strategies can be classified into three categories as follows: i) stretching one's hand to the target after looking at the target, ii) glancing at the target without changing hand's position, iii) stretching one's hand to the target without looking at the target. There are nine physical workloads as combination of three targets and three strategies in this paper.

First of all, driver model with the physical workload is derived in order to investigate the effect of the physical workload on driving performance. Secondly, in experimental I, we measure a lane keeping ability while curved road running with the physical workloads using driving simulator. In order to quantify the physical workload causing the car deviation from the center line, body movements are measured by a motion capture system to evaluate the grade of the physical workloads. Moreover eye movements of drivers are also measured. In experimental II, we evaluate the avoidance ability using steering with the physical workloads in the emergency situation. Finally, we try to explain the results of experiment II by the proposed driver model.

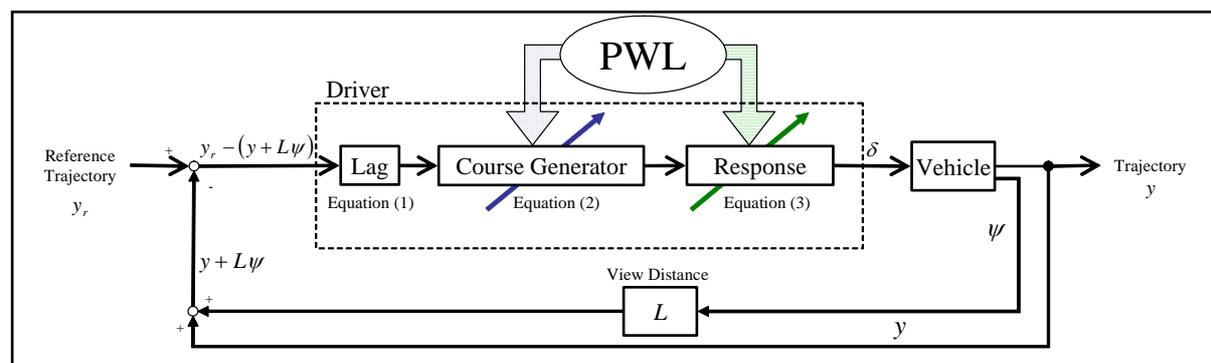


Figure 1. Driver Model with Physical Workloads.

DRIVER MODEL CONSIDERING PHYSICAL WORKLOADS

The driver model consists of a course generator, response, and a dead time (see Figure 1). The course generator is first order lead element to foresee and estimate the car position. The response is first order lag element to drive the car considering body position. They are defined as following equations.

$$G_{Lag} = e^{-s\tau}, \quad (1)$$

$$G_{eye} = 1 + T_{eye}s, \quad (2)$$

$$G_{body} = \frac{k_{body}}{1 + T_{body}s}, \quad (3)$$

$$\frac{\delta}{y_r - (y + L\psi)} = k_{body} \frac{1 + T_{eye}s}{1 + T_{body}s} e^{-s\tau}, \quad (4)$$

where τ is a dead time. The variables T_{eye} and T_{body} denote time constant for the course generator and the response, respectively. The variables k_{eye} and k_{body} means a gain for the response. As the whole, we adopt a driver-vehicle model that keeps a distance between the target lateral position and estimated lateral position to the minimum (see Figure 1 and 2). The equation (4) denotes the driver-vehicle model. The physical workloads that are looking aside and body movement cause lack of visual information and decrease in manipulability of the steering wheel, respectively. Thus we suppose that these workloads change the parameters of lead and lag elements, respectively.

In the physical workloads, there are various tasks that driver stretches one's arm to the targets. The manipulability becomes narrow by reaching ones arm. The targets of the physical workloads are classified by distance from the normal driving

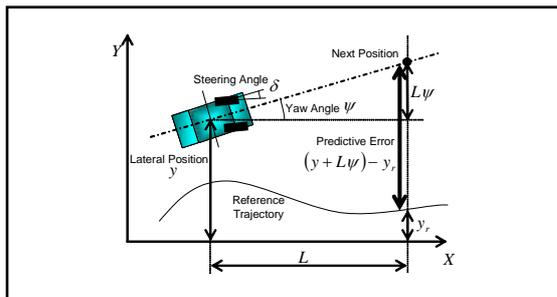


Figure 2. Predictive Control.

position to the target (see Figure 3) ;

- a) Hazard Switch
- b) A Something on the Passenger's Seat
- c) Dash Board

On the other hand, there are three strategies on the physical workloads while driving;

- i) Eyes and Body : Stretching one's hand to the target with looking at the target.
- ii) Eyes Only : Glancing at the target without stretching one's hand to the target.
- iii) Body Only : Stretching one's hand to the target without looking.

In the experimental I, there are nine physical workloads tasks as combination of three targets and three strategies.

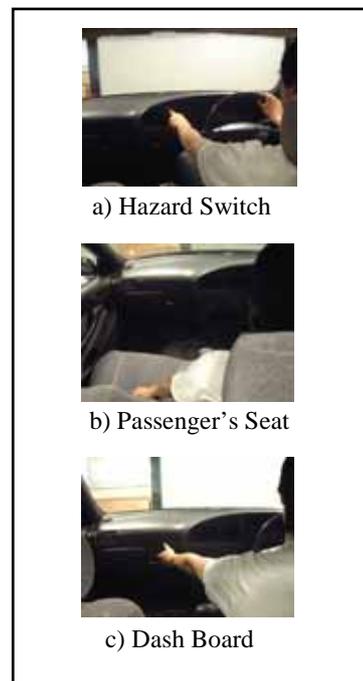


Figure 3. Targets of Physical Workloads.

EXPERIMENT OF LANE KEEPING

Experimental Procedure

We measure a lane keeping ability while curved road running with the physical workloads using a driving simulator (see Figure 4). The experimental course in the simulator is a curve with the radius of 300 [m], because the car deviation of lateral position is longer in the curve than in the straight. Subjects drive along the counterclockwise curve at 60 [km/h]. In order to quantify the physical workload causing the car deviation from the center line, body movements are measured by a motion capture

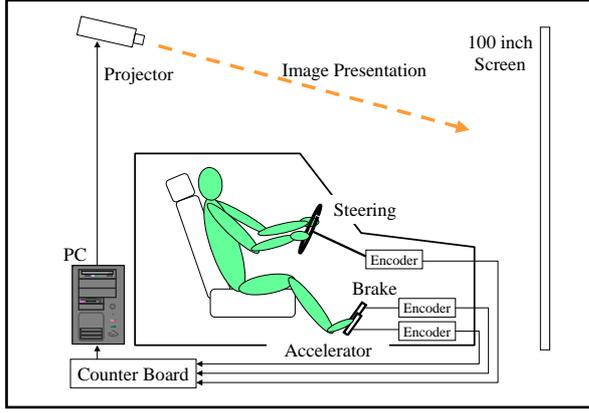


Figure 4. Experimental Setup.

system. Measured seven points are chin, both shoulders, elbows, and wrists. Eye movements of drivers are also measured.

The physical workloads in the experiments are nine kinds of tasks as shown above. In more detail, the strategy i) Eyes and Body is a repetition of stretching one's hand to the target after looking at the target at one's discretion. The strategy ii) Eyes Only is a repetition of looking at the target at one's discretion. The strategy iii) is a repetition of stretching one's hand to the target looking forward.

The seven points of the body, eye movements, and the deviation of car lateral position are measured for 30 minutes. Five subjects of 20 to 23 years old are employed. Every task is measured twice. The subjects have enough practice to measure the driving performance.

As the estimation, three indices are defined as below. The car deviation index D , the eye movement index E , and the body movement index B are defined as following equations;

$$D = \sqrt{\frac{\sum_{i=1}^n (d_i - d^*)^2}{n}}, \quad (5)$$

$$E = \sqrt{\left(\frac{\sum_{i=1}^n (\theta_{xi} - \theta_x^*)}{n}\right)^2 + \left(\frac{\sum_{i=1}^n (\theta_{yi} - \theta_y^*)}{n}\right)^2}, \quad (6)$$

$$B = \sqrt{\left(\frac{\sum_{i=1}^n (x_i^B - x^*)}{n}\right)^2 + \left(\frac{\sum_{i=1}^n (y_i^B - y^*)}{n}\right)^2 + \left(\frac{\sum_{i=1}^n (z_i^B - z^*)}{n}\right)^2}, \quad (7)$$

where n is sampling number measured at 30 [Hz]. The variables d_i , θ_{xi} , θ_{yi} , x_i^B , y_i^B , and z_i^B denote deviation of car lateral position, horizontal and vertical eye directional angles, and positions of measured points by the motion capture in Cartesian coordinates at the i -th sampling, respectively. Every asterisked variable means standard value at the normal driving posture.

Experimental Results

Figure 5 (a) shows the correlation between the car deviation index D and the eye movement index E . There are less correlation between B and D for strategy i) and ii). This means that the eye movements do not influence on the car deviation so much.

Figure 5 (b) and (c) show the correlation between the car deviation index D and the body movement index B for the right and left wrist, respectively. There are high correlation between D and E for the strategy iii) Body Only. The correlation ratio between B and D of the left wrist is higher than that of the right wrist for the strategy iii). This means

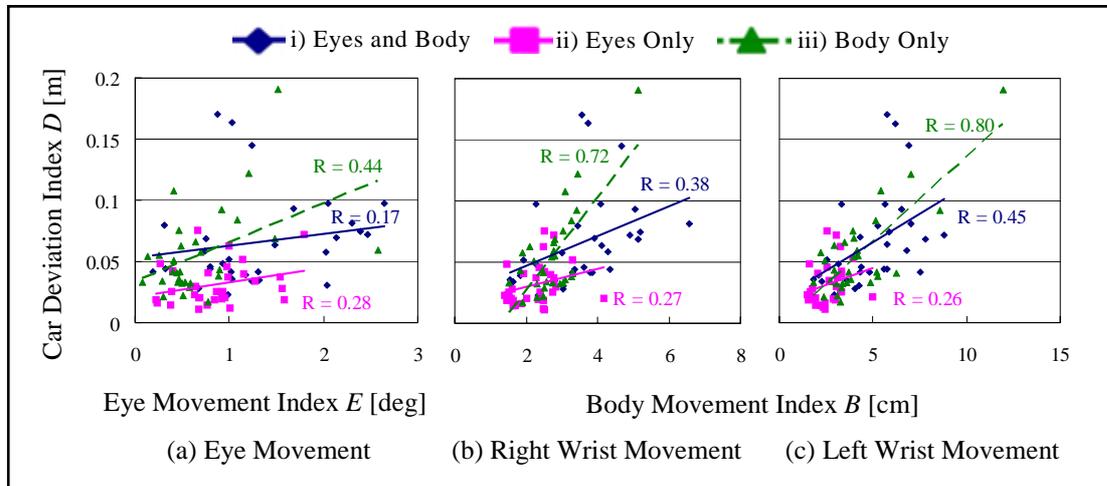


Figure 5. Relationship between Car Deviation and Eye Movement, Body Movement.

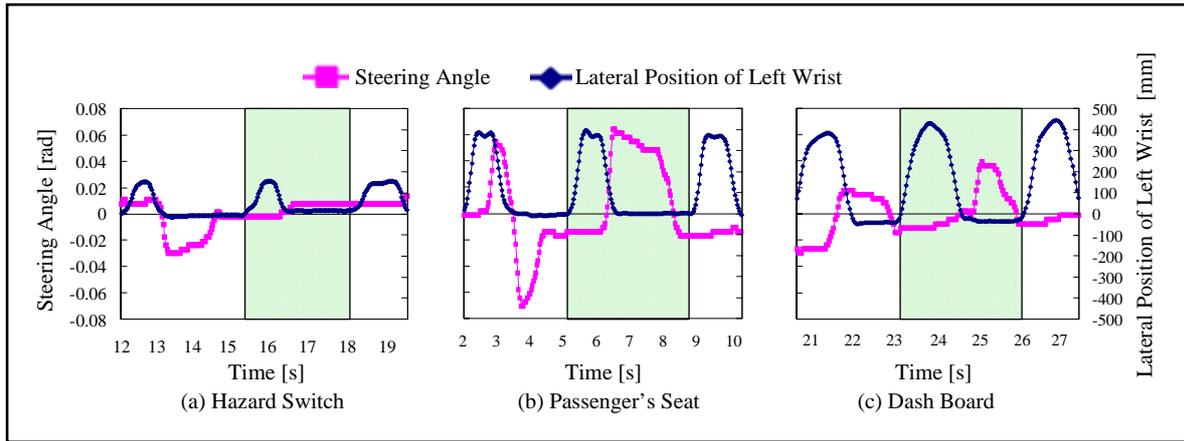


Figure 6. Time History of Left Wrist Position and Steering Angle.

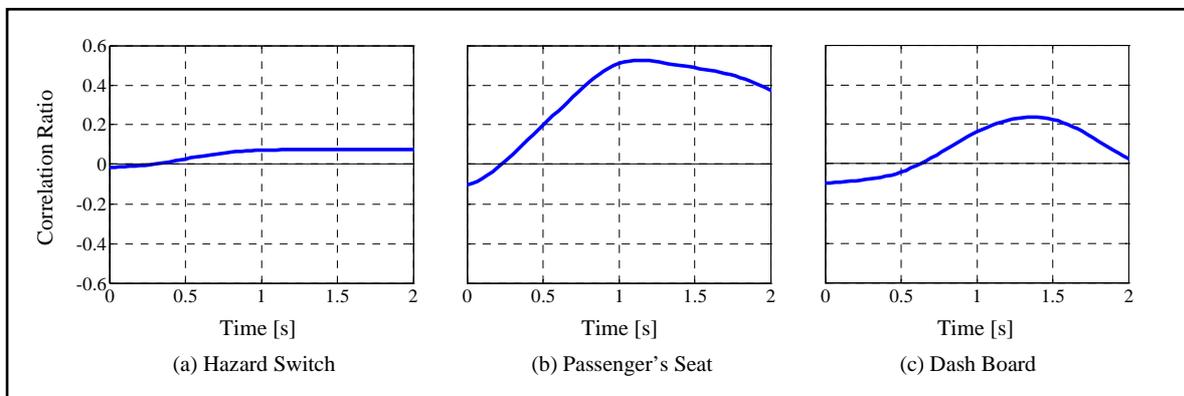


Figure 7. Cross Correlation between Left Wrist Position and Steering Angle.

that the left wrist movement according to the physical workloads influences the car lateral deviation. There are not high correlations between D and B for other body movement indices of the point.

Moreover in order to clarify the relationship between the body movements and the steering wheel angle, we investigate the cross correlation among them. Figure 6 shows the time history of the steering angle and the left wrist position for each strategy, respectively. Figure 7 shows the cross correlation of the steering wheel against the left wrist position for net area in Figure 6, respectively. In the every figure in Figure 6, the positive value represents right direction for the steering angle and the distance from the steering wheel to the left wrist, respectively. In Figure 6 (a), there is no correlation between them for the target a) Hazard Switch. In the situation of the target b) Passenger's Seat, there is a tendency that the subject steers for modification when start to returning one's left hand to the steering wheel. The timing of the adjusting steering is later in the task of the target c) than in the task of the target b). Accordingly, it is

understood that the manipulability has changed by the distance from the left hand to the steering wheel position.

EXPERIMENT OF STEERING AVOIDANCE

Experimental Procedure

In this section, we evaluate the avoidance ability using steering with the physical workloads. The situation is supposed the urgent case of sudden car emergency from left side of the straight street (see Figure 8 (a)). The long straight street includes six crosses. There is a car that may run into the street at the center of the short straight street among the crosses. One car among five cars runs into the road. As shown in Figure 8 (b), when own car runs through the line A, a car approaches from Point P and stop beside the street (Point Q). A car runs into the street suddenly at one of the every five P-Q line at random when own car runs through line B. The distance from line B and line P-Q is 20 [m]. Own car runs at

constant 60 [km/h]. Driver can avoid only by the steering toward to coming lane. The targets of physical workloads are same as previous experiments. The physical workload strategy is supposed as one condition of iii) Body Only. Six subjects of 20 to 23 years old are employed.

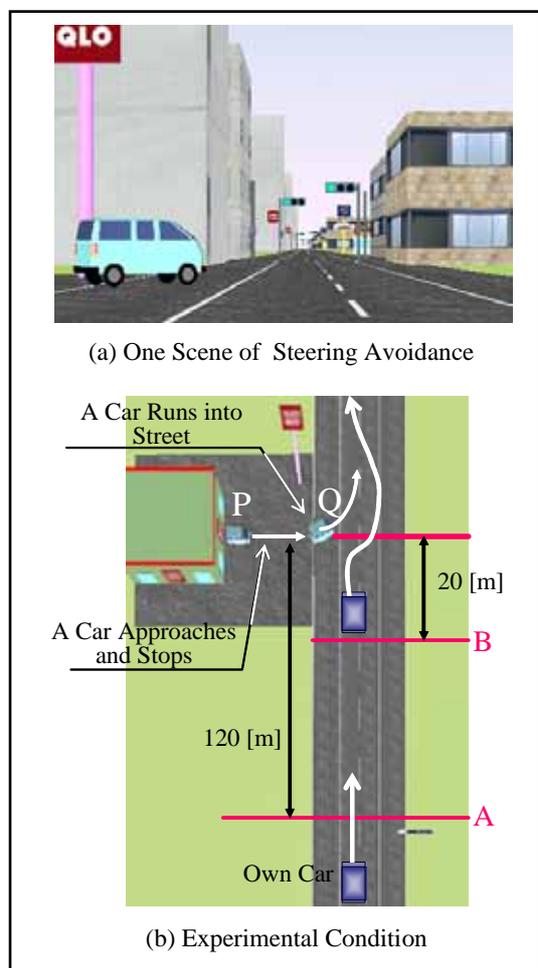


Figure 8. Outline of Steering Avoidance.

Experimental Results

Figure 9 shows the time series of averaging steering angles, after own car runs through line B. As a comparison, the series of No Task is illustrated in the figure. When a car runs into the street, drivers steer to the right for the avoidance. From the figures, there are overshoots of the steering angle after the avoidance compared with the case of No Task. The amount of overshoots becomes larger in order of the strategy i), ii), iii). This means that the maneuverability of the steering wheel becomes narrower according to the grade of the physical workloads.

Verification by the Driver Model

We verified the results of the avoidance experiments by the driver-vehicle model. Supposing the variables τ and T_{eye} in the equation (4) are constant, the variables of time constant and lag elements of every physical workload of targets are determined by the phase of a peak of cross correlation figures. The input trajectory is approximated by a sine curve. Figure 10 shows the simulation's results. According to the distance from the target to the steering wheel, the adjusting amount of steering wheel after the avoidance was increased. These tendencies coincide with the experimental results of the emergency avoidance.

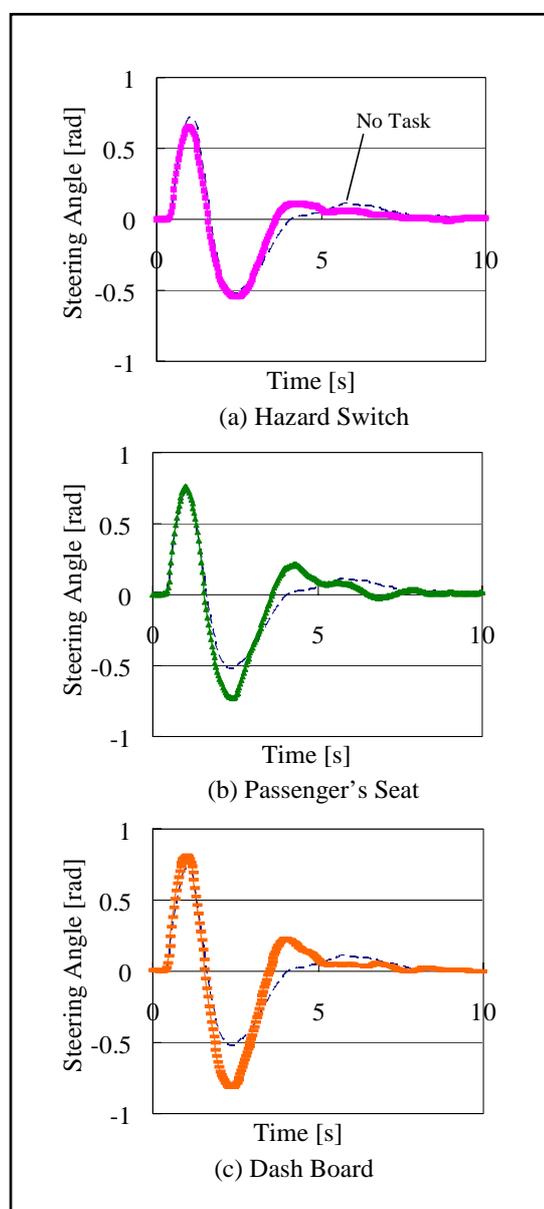


Figure 9. Steering Angle in Emergency Avoidance Compared with No Task.

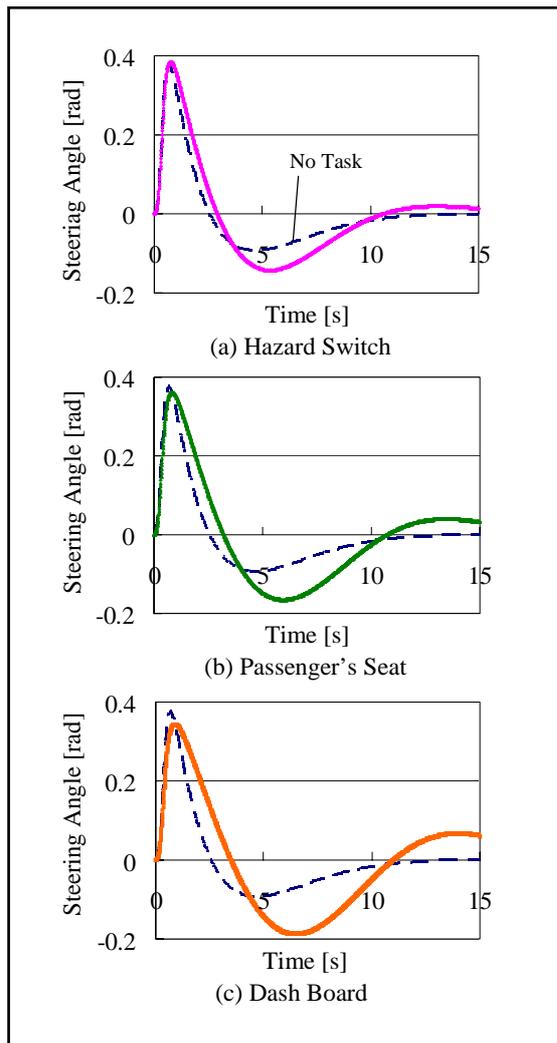


Figure 10. Simulated Steering Angle in Emergency Avoidance Compared with No Task.

CONCLUSIONS

Using a driving simulator the effect of the physical workloads on driving performance was examined for two traffic situations. We constructed the driver-vehicle model with the physical workloads. Second, to investigate the decline of the maneuverability of the steering wheel with the physical workloads, we carried out the experiments of the lane keeping and the emergency avoidance. The conclusions of this paper are as follows: (1) The driver model was consisted of the course generator and the body response according to the physical workloads. The course generator is first order lead element to foresee and estimate the car position. The characteristic of the body response is modeled by first order lag element considering to the specific target.

(2) As the results of lane keeping experiment, there are high correlations between the car deviation index and the body movement index of the left wrist position. Moreover it is clarified that the adjusting steering had been later than the movement of the left wrist, in order of the target a) Hazard Switch, b) Passenger's Seat, c) Dash Board.

(3) Experimental results of emergency avoidance, it is clarified that there are the overshoots of the steering angle after the avoidance.

(4) We studied the steering angles by the simulation, according to the delay of the steering angles against the left wrist movements as mentioned above (2). As the results, there are the overshoots of the steering angles after the avoidance coincident with the experimental results.

As a future work, we will study the more suitable model parameters based on the experiments with much more subjects and confirm the feasibility of their approach.

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