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Study on Braking Support Using Haptic Guidance for Inverted Pendulum Personal Transporter

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ABSTRACT

The inverted pendulum personal transporter has recently been actively studied. This transporter is appropriate for middle-distance movement and provides a wide field of view. According to a previous study, this transporter provides a higher safety and comfort level compared to a bicycle, particularly in crowded pedestrian areas. The transporter is already being produced, and it has spread across Europe and America. However, there have been some topple-down accidents which can be attributed to the carelessness and inappropriate operation of the personal transporter.

This study aims to evaluate the influence that braking support has on drivers and their attitude towards the usage of haptic guidance for sensing the surroundings. The haptic guidance is realized in two ways: vehicle body vibrations using driving motors and handle vibrations.

To test the acceptability to the driver, experiments are conducted on a transporter developed by the University of Tokyo. Experimental results show that for the haptic guidance associated with vehicle body vibrations, the relax score is at the normal level, but the ease to drive score is evaluated to be poor by some people. In the haptic guidance associated with handle vibrations, the ease to confirm safety and recognize danger scores are better than the haptic guidance associated with vehicle body vibrations.

Keywords: human engineering, questionnaire, driving support, personal mobility vehicle.

1 INTRODUCTION

The inverted pendulum personal transporter has been actively studied recently. It is appropriate for middle-distance movement and provides a wide field of view. According to a previous study

[1], this transporter provides a higher safety and comfort level in crowded pedestrian areas than a bicycle. Owing to this advantage, the transporter is generally used for sightseeing and security purposes. The driving theory of the transporter is inverted using the driving motor's torque, which is calculated using the angle and angular velocity to negate the moment of gravity. This transporter has already been produced by Ninebot Inc. as Segway, and it has recently spread across Europe and America. However, a few topple-down accidents have been lately reported in Vienna [2]: these can be attributed to carelessness and inappropriate operation of the transporter, as shown in Figure 1.

Typical driving assistants provide visual guidance, auditory guidance, and haptic guidance. In most cases, visual guidance can be overlooked. Auditory guidance can also be overlooked because of surrounding noise. Haptic guidance, however, communicates with users without any influence of surrounding disturbance.

This study aims to evaluate the influence that braking support has on drivers and their attitude towards the usage of haptic guidance for sensing the surroundings. The haptic guidance is realized in two ways: vehicle body vibrations using driving motors and handle vibrations. To evaluate its acceptability to users, experiments are conducted on actual vehicles. These types of guidance are evaluated based on the distance between a stop position and a barrier using an ultrasonic sensor. The acceptability is evaluated by questionnaires and vehicle stability.

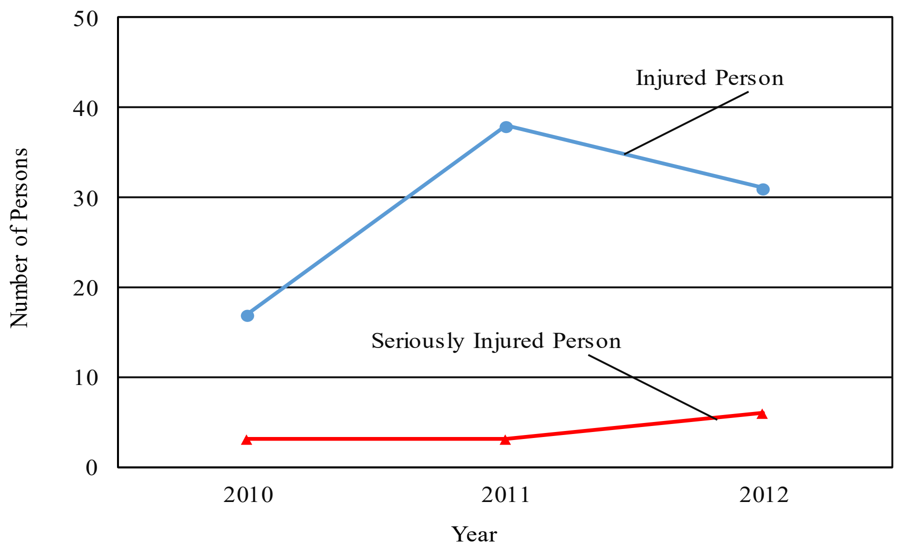


Figure 1. Personal transporter accidents in Vienna

2 EXPERIMENTAL PT MODEL

2.1 Postural control system

The experiments were conducted on the inverted pendulum personal transporter which was developed by the University of Tokyo [3].

The pitch angle and pitch angular velocities of the platform were obtained using tilt and gyro sensors. The driving torque was calculated by a controller which moved the motors and tires.

The used controller was a personal computer and the torque calculated by the controller is expressed in the following equation:

$$u = K_P\theta + K_D\dot{\theta} \quad (1)$$

where u is the torque, K_P is the proportional gain, θ is the pitch angle, K_D is the derivative gain, and $\dot{\theta}$ is the pitch angular velocity.

The gains were adjusted to be stable during transporter riding. It was confirmed that the transporter can run with constant velocity.

2.2 Elements

The transporter comprised the handle, pole, platform, motors, batteries, and tires, as shown in Figure 2. The specifications are provided in Table 1. The tilt and gyro sensors used in this study were produced by Murata Manufacturing Co., Ltd; the motors with an output of 800 W were manufactured by Koumei Co., Ltd; the motor controller was produced by Maxon Motor, and the batteries were produced by Nichido Ind. Co., Ltd.

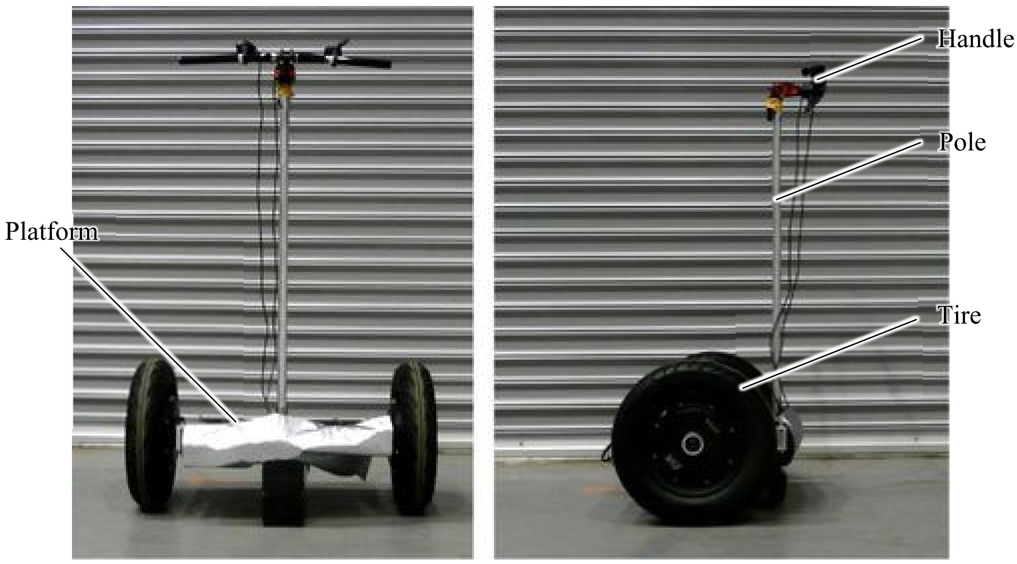


Figure 2. Inverted pendulum personal transporter

Table 1. Specifications of the inverted pendulum personal transporter

Dimensions (L × W × H)	460 mm × 840 mm × 1256 mm
Total mass	38 kg
Tire diameter	450 mm

2.3 Sensing of surroundings

In this study, the distance to a barrier was monitored and measured using an ultrasonic sensor manufactured by Max Botix Inc. The sensor was mounted on a pole at a height of 630 mm as shown in Figure 3.

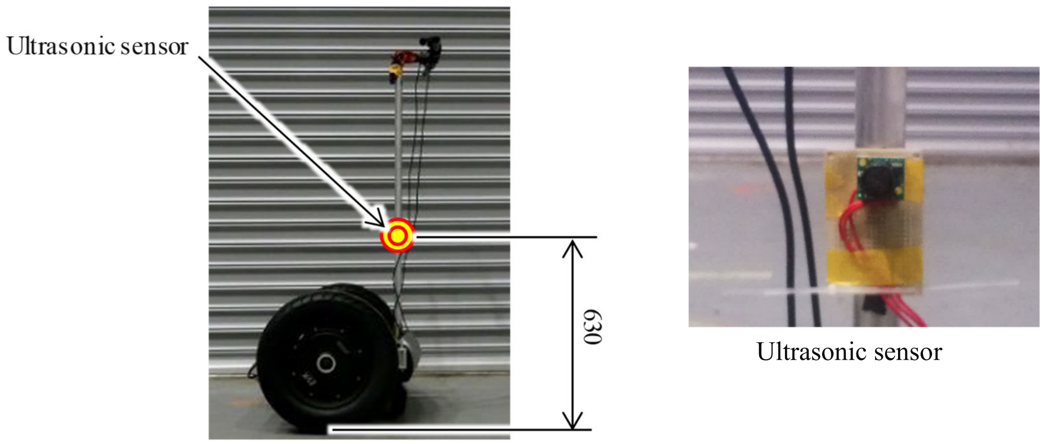


Figure 3. The ultrasonic sensor

2.4 Haptic guidance method

In this study, haptic guidance was realized in two ways: vehicle body vibrations using driving motors and handle vibrations. The ultrasonic sensor measured the distance to the barrier. If the threshold was exceeded, haptic guidance was activated.

The vehicle body vibration guidance was generated using driving motors. This method involved the suppression of motor torques at a fixed time. The vehicle body and handle vibrated from the motors' movement, and the vibration was communicated to the users as shown in Figure 4. The fixed time known as suppression control was set at 129 ms to invert by adjusting loop time T_s. To ease the utilization of haptic guidance, regular guidance sessions were conducted in structured time intervals as shown in Figure 5. However, the vehicle was considered unstable if the postural adjustment time was too short. In this study, the fixed time set for postural control was 277 ms to invert by adjusting the loop time. In the haptic guidance, the gain and non-assistant amplitudes were set at larger values, which are shown in Figure 5.

The handle vibration guidance produced by the vibration motor mounted at the pole is shown in Figure 6. This guidance method is based on eccentric rotating mass (ERM) and the guidance is also conducted if the threshold is exceeded as shown in Figure 7.

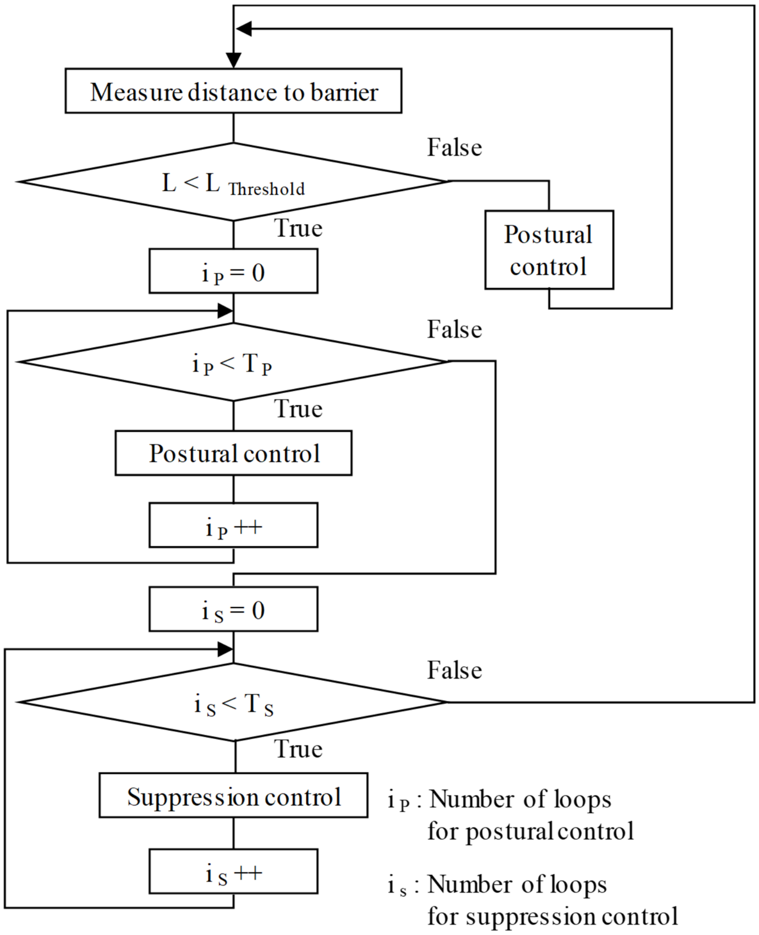


Figure 4. Flow chart for haptic guidance from driving motors

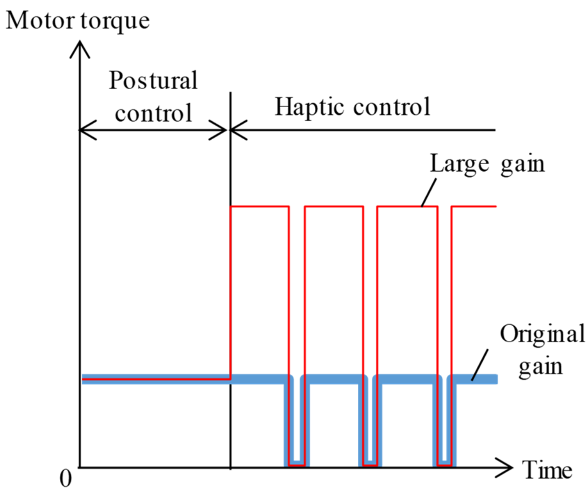
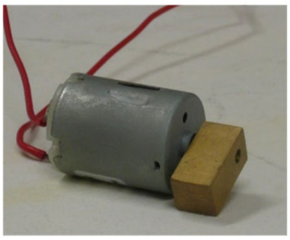
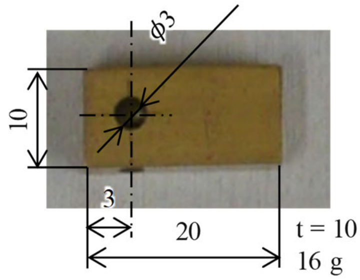


Figure 5. Transition of output motor torque with haptic guidance

The position of the ERM



ERM



Eccentric mass

Figure 6. ERM

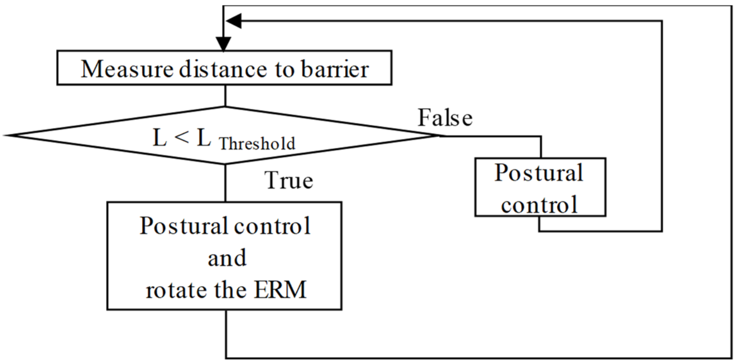


Figure 7. Flow chart for haptic guidance from ERM

4 EXPERIMENT

4.1 Evaluation conditions

Following a study by Taniguchi et al., a haptic guidance sensing efficiency test was conducted based on a less than 4 m distance to the barrier target [(4)].

Experiments were conducted with two types of haptic guidance: vehicle body vibration using driving motors and handle vibration. In non-assisted driving, the proportional gain K_P was 63, and the derivative gain K_D was 90.

The test subjects were three male persons in their 20s. In the experiments, the subjects were asked to ride the inverted pendulum personal transporter under constant velocity using non-haptic guidance and stop when they cross the landmark. The subjects were then asked to drive with haptic guidance and stop when they recognize the guidance. If the subjects were unable to recognize guidance, they drove to the front of the barrier (Figure 8 and 9).

These experiments were conducted with informed and consented subjects after receiving approval from the University of Tokyo life science ethics review committee.

Figure 8. Experimental course

Figure 9. Running with haptic guidance

4.2 Evaluation method

The last stop position was evaluated by measuring the distance to the barrier using an ultrasonic sensor. The vehicle's pitch angle was evaluated to investigate the effect of haptic guidance on the vehicle's stability. Based on subjective evaluation, the subjects answered a questionnaire set at a 7-point grading scale shown in Figure 10.

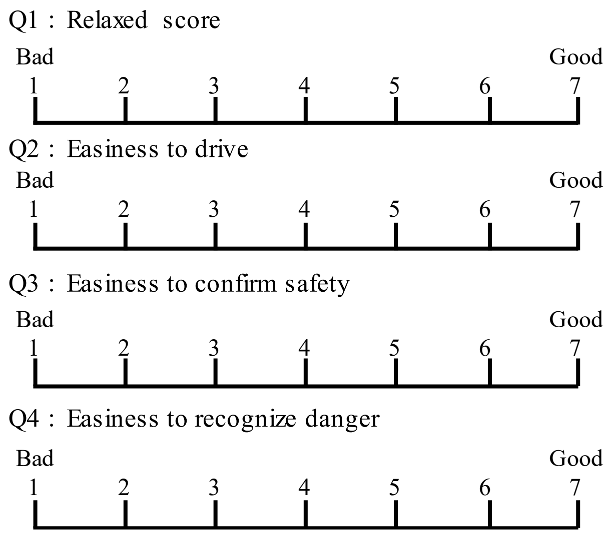


Figure 10. Questionnaire

5 RESULTS AND DISCUSSION

5.1 Evaluation of last stop position

The safety of the transporter was evaluated using the last stop position. No difference in the average value of the last stop position for either type of haptic guidance was observed, as shown in Figure 11. Comparing individual subjects, Subject 1 was able to stop at a long distance with handle vibration. On the other hand, Subject 3 was able to stop at a long distance with vehicle body vibration, as shown in Figure 12.

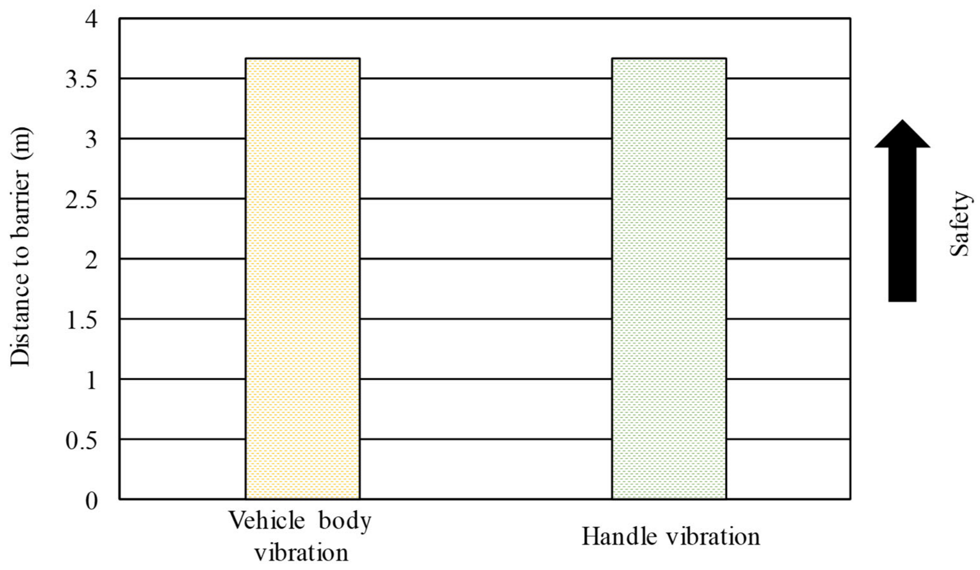


Figure 11. Average distance to barrier

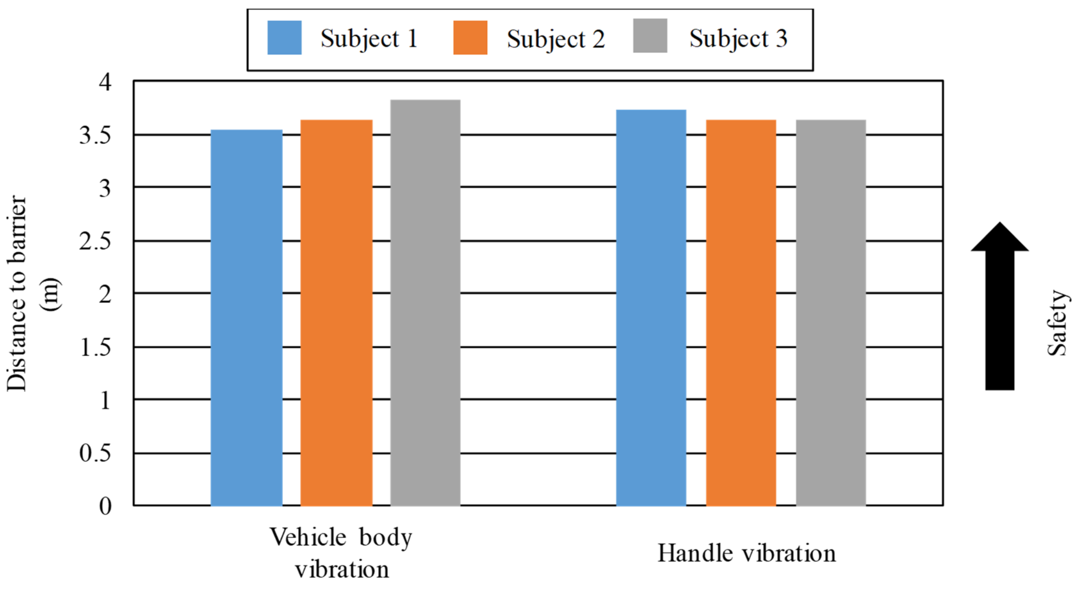


Figure 12. Distance to barrier for different test individuals

5.2 Evaluation of vehicle stability using pitch angle

The transition of the pitch angle in normal postural and haptic control is shown in Figs. 13 and 14. When the motors provide a torque, handle vibrations are generated with no distribution of the pitch angle. However, vehicle body vibrations created a pitch angle, which slowly became large after suppression control. The maximum pitch angle in normal postural and haptic control is shown in Table 2. When the motors produced a torque in the haptic guidance with vehicle body vibrations, the maximum pitch angle was 1.3 times larger than the normal postural one.

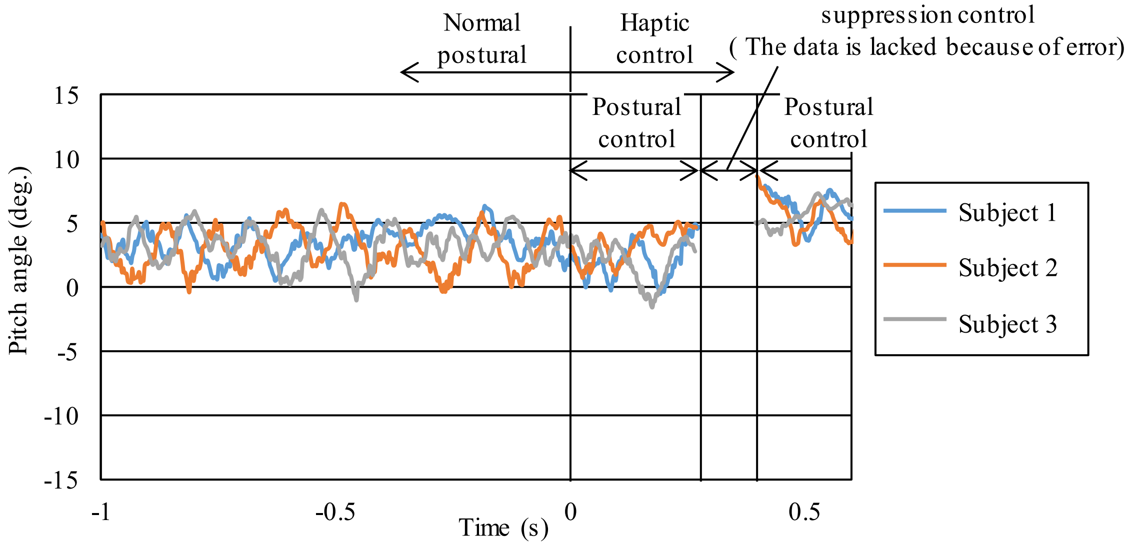


Figure 13. Transition of pitch angle in normal postural and haptic control with vehicle body vibration

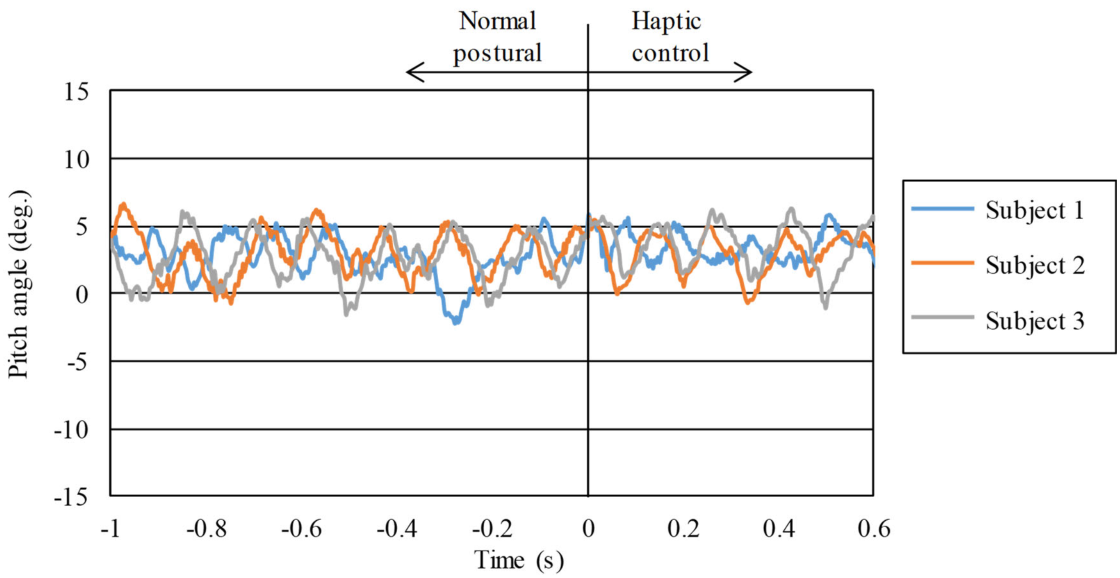


Figure 14. Transition of pitch angle in normal postural and haptic control with handle vibration

Table 2. Maximum pitch angle average

Haptic types	Postural control	Haptic control	Ratio
Vehicle body vibration	6.2 deg.	7.9 deg.	1.3 times
Handle vibration	6.1 deg.	5.9 deg.	0.97 times

5.3 Subjective evaluation from questionnaire

The influence of pitch angle transition was evaluated from relax and ease to drive scores, using the results from the questionnaire. In the relax score, the haptic guidance with handle vibrations was better scored only by Subject 3. The haptic guidance with vehicle body vibration had the same score for non-assisted driving in all subjects, as shown in Figure 15. This result demonstrated that the haptic guidance with vehicle body vibration had the same degree of relaxation when the pitch angle of transition was as described in section 5.2.

The score for ease to drive was better than in non-assisted driving. Comparing individual subjects, Subject 1 marked the relax score as worse compared to non-assisted driving. However, Subject 2 and Subject 3 marked the relax score as same or better, as shown in Figure 16. These results showed that ease to drive was poor when the pitch angle transition was as described in section 5.2. A better score was obtained by Subject 3, and the reason was related to the better stabilizing feeling experienced during short suppression control time [5].

The score for ease to confirm safety was better for vehicle body vibration than for handle vibration, as well as the score for ease to recognize danger, as shown in Figs. 17 and 18. This was attributed to the no vibration pattern felt during vehicle body vibration compared to the vibration pattern experienced during handle vibration, which limits the recognition of haptic guidance.

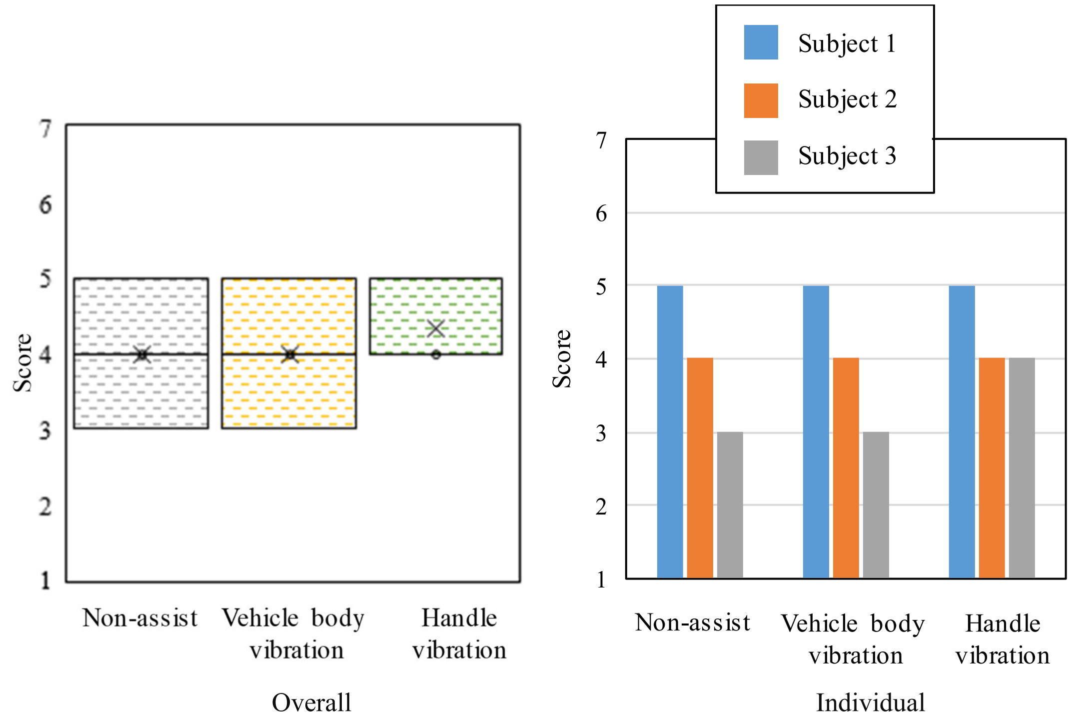


Figure 15. Relax scores

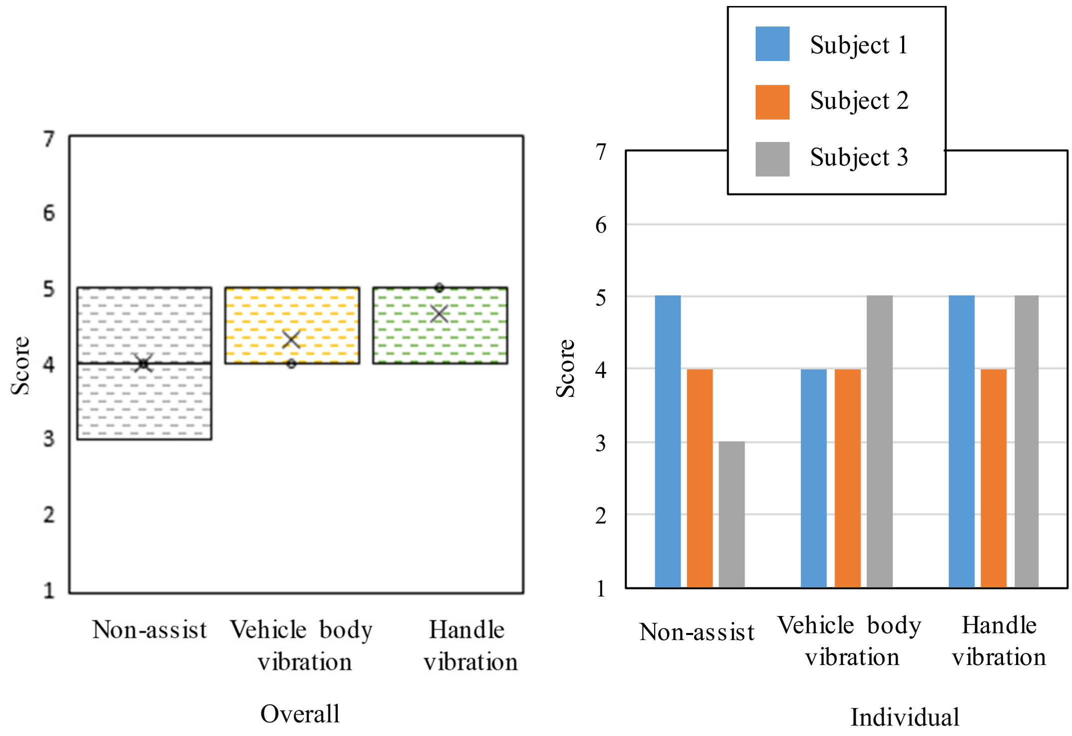


Figure 16. Ease to drive scores

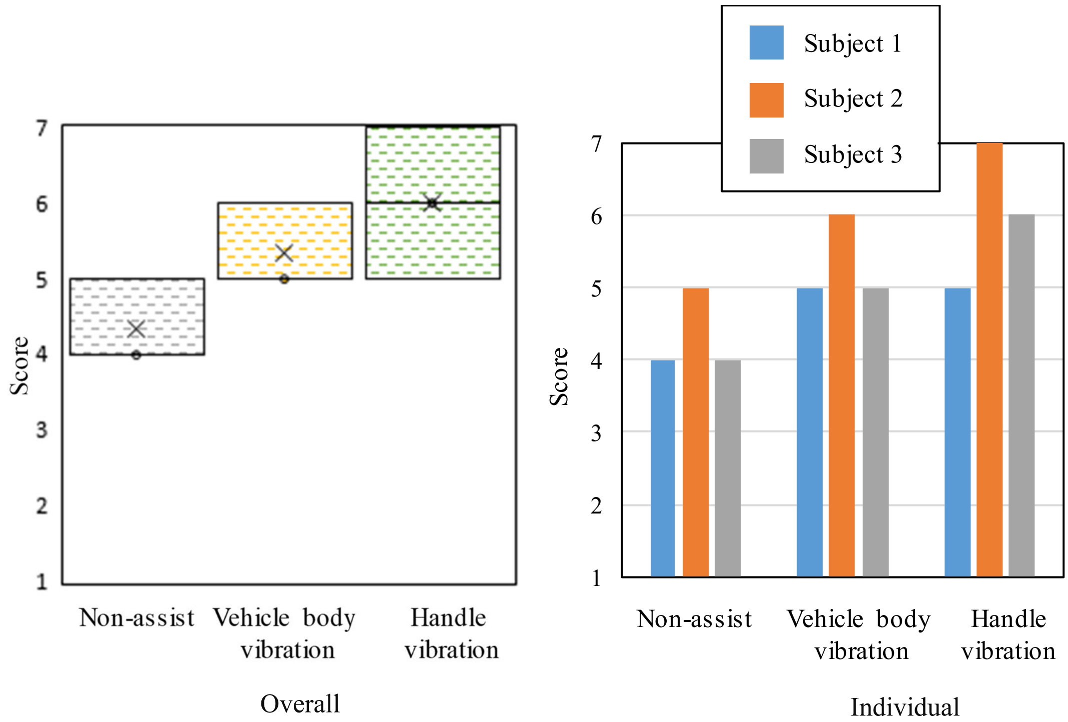


Figure 17. Ease to confirm safety scores

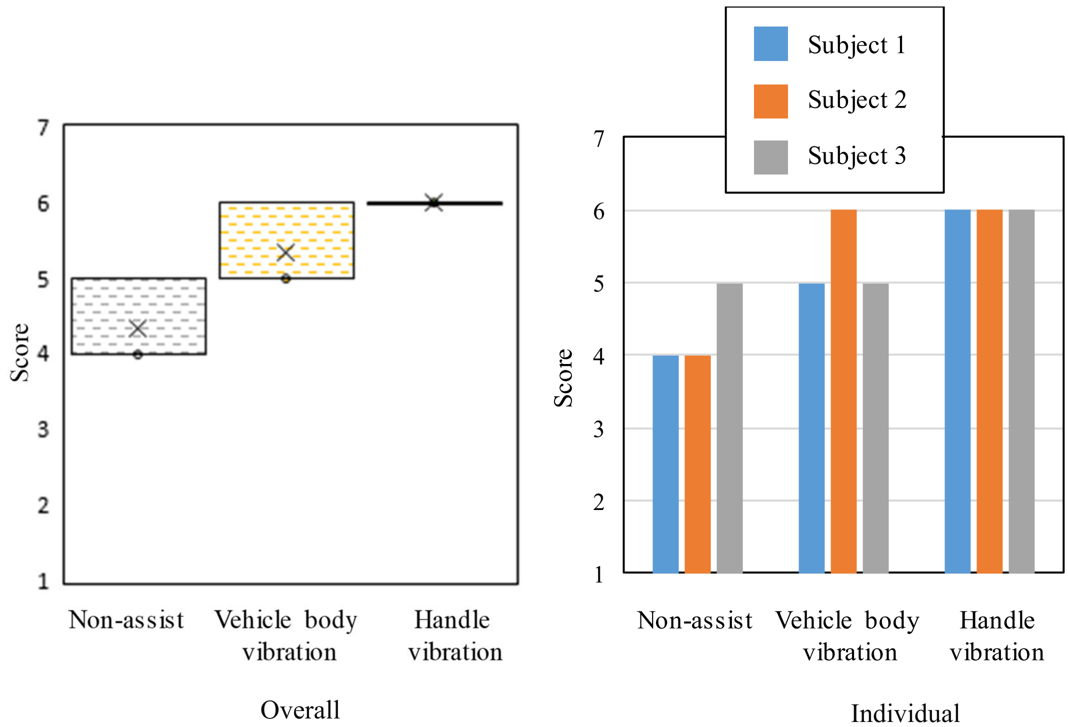


Figure 18. Ease to recognize danger scores

4 CONCLUSION

This study evaluated the influence that braking support has on drivers and the acceptability of using haptic guidance for sensing the surroundings. The haptic guidance was realized in two ways: vehicle body vibrations using driving motors and handle vibration.

The results showed that the evaluation at the last stop position was different for each tested individual. The maximum pitch angle was 1.3 times larger than the normal postural one in vehicle body vibration. As per the results of haptic guidance with vehicle body vibration, the relax score was evaluated as normal. The haptic guidance with vehicle body vibration showed the same degree of relaxation when there was pitch angle transition, but the ease to drive score was poor for some of the subjects. In the case of the haptic guidance with handle vibration, the ease to confirm safety and ease to recognize danger scores were better than for vehicle body vibration.

However, these results were obtained under limited speed and with a small number of subjects. For future studies, it will be necessary to examine and evaluate a wide range of conditions and subjects so as to improve the performance and use of transporter systems.

7 Acknowledgment

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