HapPull: Enhancement of Self-motion by Pulling Clothes

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Abstract. The realism of audiovisual media with self-motion, such as racing games and movies, is enhanced by the sensation of bodily motion. In various studies, this sensation is presented by actually moving the user's body in accordance with the audiovisual motion. However, such devices tend to be bulky, and compact devices can only simulate one sensation. In our previous study, we proposed a simple and effective system for simulating self-motion. The compact system uses DC motors and string to pull the user's clothes and thus elicit both skin sensation and deep sensation. However, the system only pulls the clothes backward. Here, we present our improved system named HapPull, which pulls the user's clothes both forward and backward and presents torque by pulling the clothes diagonally. We investigated whether users perceived the presented sensation as acceleration or velocity, and found that the physical sensation that is related to the traction force created by our system depends on the nature of the visual stimulus.

Keywords: Haptic · Pulling clothes · Self-motion

1 Introduction

In audiovisual media with self-motion, such as racing games and movies, the sense of motion is considered to be the key to realism. The sense of motion is a multisensory event that includes the vestibular sensation caused by the acceleration, deceleration and inclination of the body, the deep sensation caused by the inertia of the body, and the skin sensation caused by the wind blowing over the whole body. In various studies, these sensations are created by actually moving the user's body in accordance with the motion. However, such devices tend to be bulky, and compact devices can only present a single sensation to a limited body area.

To address this issue, we previously proposed a simple and effective system for creating self-motion by pulling the user's clothes, which elicits both skin sensation and deep sensation [1]. In a racing game, acceleration and wind are presented by pulling the body backward and fluttering the clothes. SPIDAR [2] is a representative method of

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A. D. Cheok et al. (Eds.): ACE 2017, LNCS 10714, pp. 261–271, 2018.
https://doi.org/10.1007/978-3-319-76270-8_18

moving the user's body by pulling with string, whereas we used the user's clothes as a medium for presenting force and skin sensation to a wide area of the body.

In our previous study, we developed a prototype (Fig. 1) that pulls clothes backward from the shoulders and investigated whether users perceived the sensation as acceleration or another physical quality, and found that they experienced the sensation as velocity. However, when applied to create self-motion in a car racing game, many users claimed that the traction force was not in natural accordance with velocity. There might be several reasons for these incompatible results, but we presume that a main reason is that the system cannot present deceleration because it only pulls the clothes backward. Therefore, in this study, we developed HapPull that pulls clothes both forward and backward by adding two motors in front of the body, and investigated in detail whether users perceived the presented sensation as acceleration or velocity.

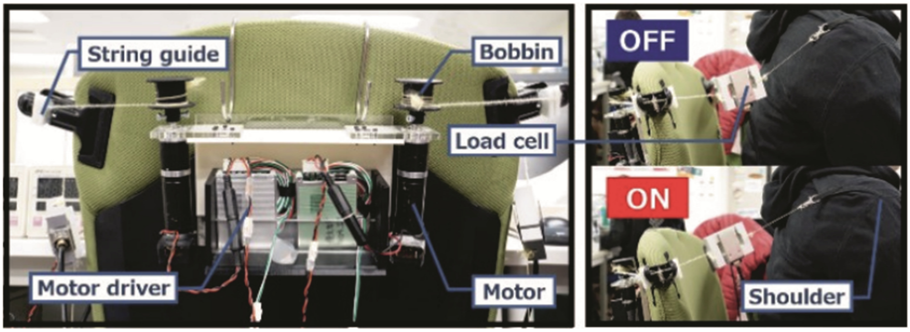

Fig. 1. Previous system [1]

2 Related Work

Vection is often used to improve the sense of self-motion with visual or auditory stimuli [3–6]. Vection refers to the illusion of self-motion created by seeing moving stimuli. However, the inconsistency between visual and bodily sensations often causes motion sickness.

While the sense of self-motion is occasionally presented using a motion platform [7–9], such systems tend to be bulky. Cheng [10] proposed a motion platform that does not require a large-scale device by carrying the user's body with another person. However, there is a risk of dropping the user or performing the wrong operation.

To cope with these issues, several studies have proposed compact systems to present part of the sensation of motion. Several studies attempted to improve self-motion by presenting tactile flow to the body using chair that vibrated in accordance with the visual contents [11, 12]. However, this method only presents skin sensation, and interpretation is necessary to relate the tactile sensation to bodily motion. A type of suit has also been developed to create whole-body vibration [13, 14], but although it is quite effective in creating a sense of immersion, it is still hard to express bodily motion.

Some studies have used compact systems that deliver electrical stimulation. Aoyama [15] simulated virtual head motion by stimulating the vestibular organs electrically. While the sensation is quite strong, the total stimulation time is limited because of safety issues. The Teslasuit [16] presents whole body tactile sensation through electrical stimulation, but again, the electrical stimulation is not safe enough for general use.

The sense of motion can also be expressed by presenting wind [17, 18]. However, creating the sensation of wind over a large area of the body typically requires a huge blower.

Our method is inspired partly by a low-cost motion platform by pulling the user's body with bandages and air cushions [19]. The acceleration force is presented by a haptic device that is used to shake parts of the user's body while seated [20–22]. In contrast to previous methods, we used string to pull user's clothes, which causes both force sensation and skin sensation to a wide area of the body.

3 System

3.1 System Configuration

HapPull (Fig. 2) is composed of a chair with a backrest, motors each with a gear head (Maxon, 25 RE φ25 mm, 10 W, 26 GP B φ26 mm, gear ratio 19:1), bobbins, Kevlar string, clips, a frame, and a microcontroller (NXP, mbed LPC1768).

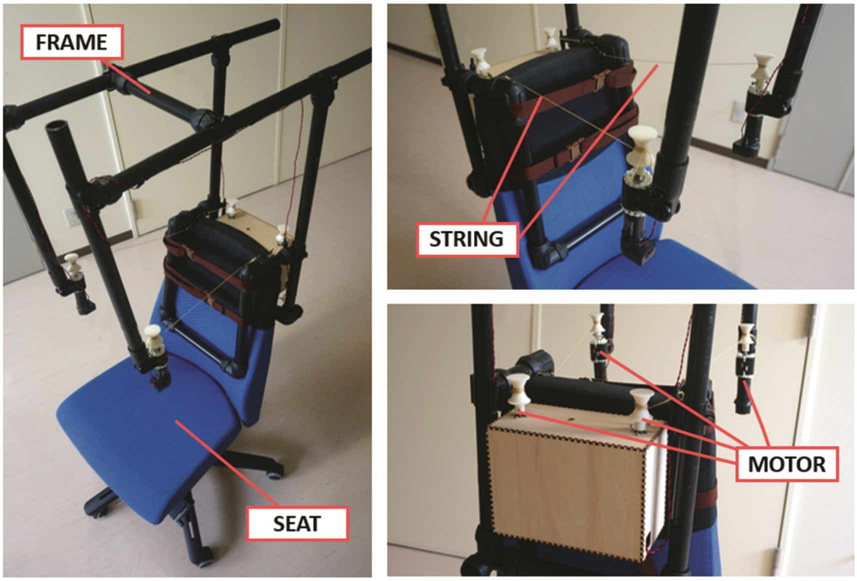

Fig. 2. System

A box containing the microcontroller is attached to the backrest of the chair. The system has four motors with bobbins for winding string, two of which are placed about

0.3 m in front of the user's body and the other two about 0.2 m from the back of the body. As shown in Fig. 3, the clips with string are attached to the shoulders of the user's clothing. The system can effectively pull the upper body by using the motors to reel in the string and pull the clothes. The microcontroller controls the motor current. Each motor can provide a force of up to about 10 kg.

Fig. 3. Method of attaching clips to the user

3.2 Sensation

Our first prototype only used two motors to present the backward traction, whereas our new prototype has two additional motors in front of the user's body. As a result, it can present translational force by strongly pulling the clothes in one direction (Fig. 4, left), vibration by vibrating the motors (Fig. 4, center), and torque by pulling on the diagonal line (Fig. 4, right). These sensations can also be combined.

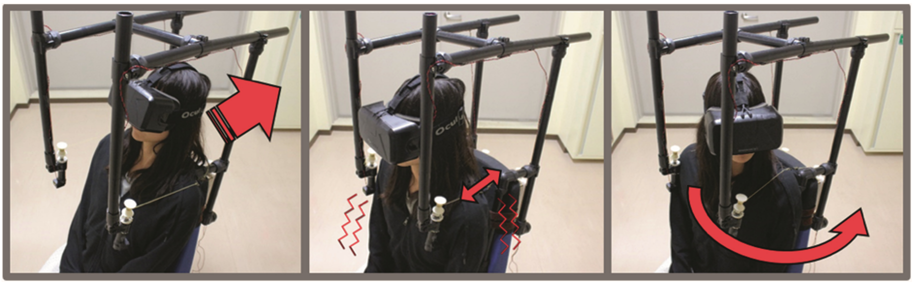

Fig. 4. Sensation induced by HapPull (left: pressure; center: vibration; right: torque)

4 Experiment

The purpose of this study was to simulate the sensation of motion by presenting a traction force to the body to create a feeling of inertia that matches the audiovisual content. We assumed that the sense of self-motion should improve by presenting the traction force in accordance with acceleration in the audiovisual content because the inertia force is physically related to acceleration. However, as mentioned in the introduction, in our previous study the users experienced the traction force as velocity, not acceleration. We presume that the main reason for this incompatibility was that our previous system only pulled the clothes backward. Another possible reason is that the experiment used a sinusoidal forward-backward motion as the visual stimulus, which we experience rarely in our daily lives. In our follow-up experiment using a car driving stimulus, many participants felt that the traction force was not in accordance with the velocity.

Therefore, in this experiment, we investigated whether users perceived the sensation presented by our new system, which can exert forward and backward force, as acceleration or velocity. We also used two types of visual stimuli to investigate whether the type of stimuli affects the results.

4.1 Methods

Because the most suitable method of presenting a traction force might differ depending on the context of the user's motion, we prepared two different visual stimuli. In the first, the visual stimulus moves forward and backward in a sinusoidal manner, as described in Eq. (1) (VA condition). In this condition, velocity is as shown in Eq. (2) and acceleration is as shown in Eq. (3). This condition can be interpreted as a reciprocating movement similar to playing on a swing. The second visual stimulus presents a repetitive forward and stopping movement, as in Eq. (4) (VB condition). This can be interpreted as a car moving forward then stopping. In this condition, velocity is a sine wave with an offset, as shown in Eq. (5). Note that velocity does not have a negative value in this case. Acceleration is a sine wave, as shown in Eq. (6). In both conditions, the frequency is set to 0.1 Hz. The optical flow of the stimulus, shown in Fig. 5, was rendered using Unity (Unity Technologies, Inc.) and presented using a head-mounted display (Oculus VR Inc., Oculus Rift Development Kit 2, resolution 1920 × 1080 (one eye 960 × 1080), horizontal angle of 90°, diagonal angle of 110°). A fixation point was positioned at the center of the visual stimulus.

$$x = A\ \sin(2\pi ft - 1/2\pi) \tag{1}$$

$$v = 2\pi fA\ \sin(2\pi ft) \tag{2}$$

$$a = 4\pi^2 f^2 A\ \sin(2\pi ft + 1/2\pi) \tag{3}$$

$$x = A(t + \sin(2\pi ft - \pi)) \tag{4}$$

$$v = A(1 + 2\pi f\ sin(2\pi ft - 1/2\pi)) \tag{5}$$

$$a = 4\pi^2 f^2 A \sin(2\pi f t) \tag{6}$$

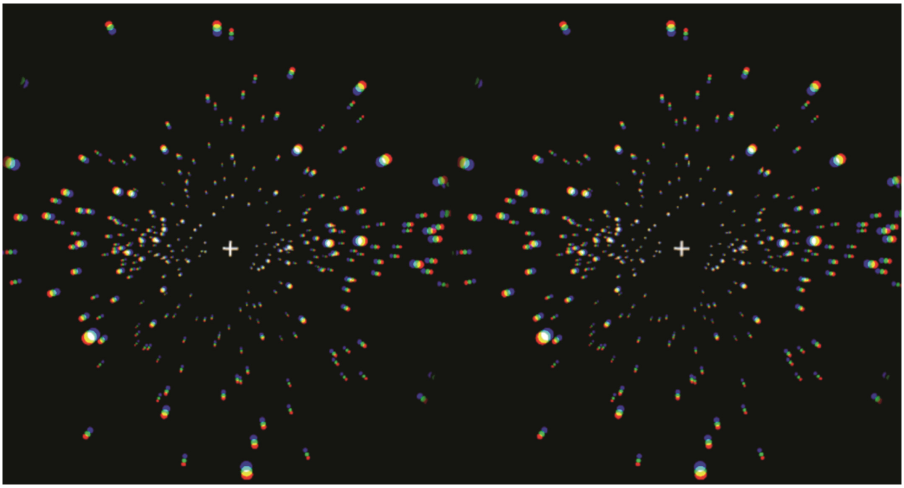

Fig. 5. Visual stimulus (left: view of left eye, right: view of right eye)

Traction force was presented under four conditions: in accordance with the acceleration (HA+ condition), in the opposite direction to the HA+ condition (HA− condition), in accordance with the velocity (HV+ condition), and in the opposite direction to the HV+ condition (HV− condition). The traction force in the VA condition is shown in Fig. 6 and that in the VB condition is shown in Fig. 7. A positive value in the graph means the two front motors are moving and pulling the body forward, whereas a negative

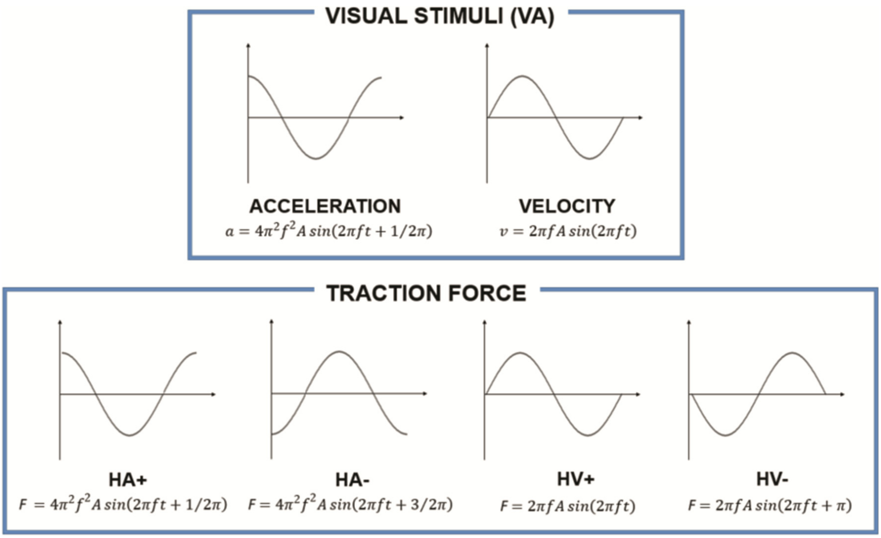

Fig. 6. Traction force in the VA condition

value means the two rear motors are moving and pulling the body backward. The maximum force was normalized and set to about 10 kg. The sinusoidal frequency was 0.1 Hz.

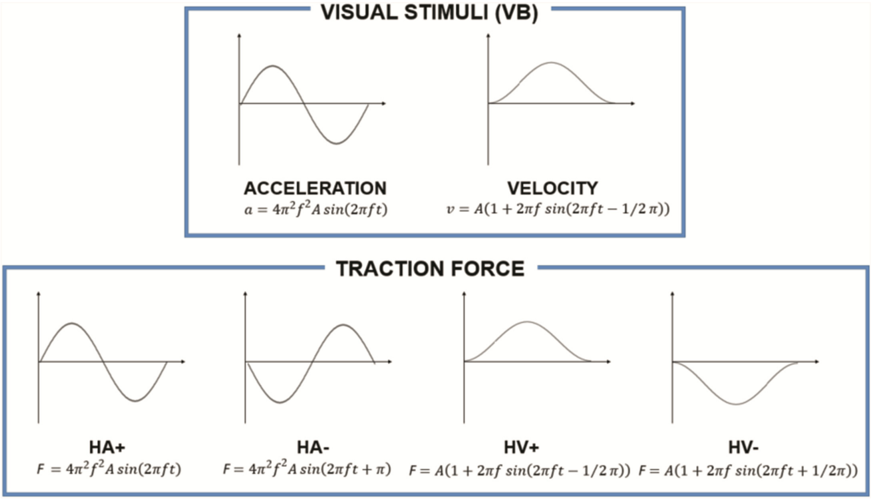

Fig. 7. Traction force in the VB condition

To control the clothing type and to facilitate the attachment of the clips, we provided the participants with a hooded sweatshirt to wear. They were instructed to sit on the chair that housed our system, and to wear the head-mounted display and noise canceling headphones (BOSE, QuietComfort15). First, the visual stimulus for the VA or VB condition was presented without traction force as a reference stimulus. Second, the visual stimulus was presented with the four traction force conditions. Each condition was evaluated on a 7-point Likert scale where the reference stimulus was scored as 4. The participants were asked to rate their subjective feeling of speed (1: very weak, 4: neutral, 7: very strong), acceleration (1: very weak, 4: neutral, 7: very strong), immersion (1: very weak, 4: neutral, 7: very strong) and incompatibility (1: very strong, 4: neutral, 7: very weak) for each condition. "Incompatibility" here means the subjective mismatch between the visual and haptic sensation. The same procedure was then repeated for the other conditions, and the order of the conditions was counterbalanced. Sixteen participants aged 20–33 participated in the experiment and each participant completed eight trials, one for each condition.

When riding in a vehicle, the body usually experiences an inertial force in the opposite direction to the acceleration. Therefore, we hypothesized that the HA− condition would be the best condition for simulating traction force.

4.2 Results and Discussion

The user feedback scores are shown in Figs. 8, 9, 10 and 11. The red lines show the median, the upper and lower boundaries of the boxes show the quartiles, and the bars show the maximum and minimum values. The horizontal axis represents each traction force condition. The Steel-Dwass test was applied to the scores.

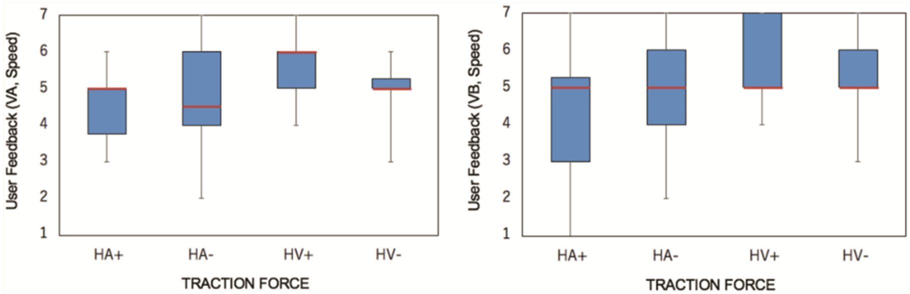

Fig. 8. Feeling of speed (left: VA condition, right: VB condition) (Color figure online)

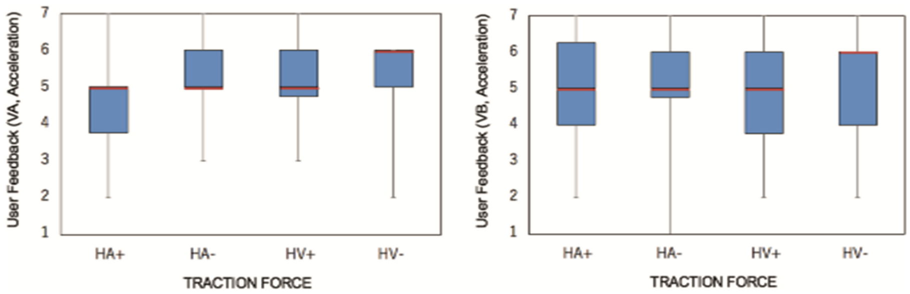

Fig. 9. Feeling of acceleration (left: VA condition, right: VB condition) (Color figure online)

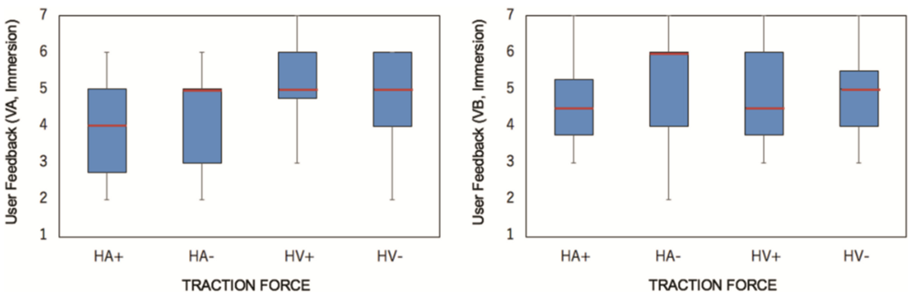

Fig. 10. Feeling of immersion (left: VA condition, right: VB condition) (Color figure online)

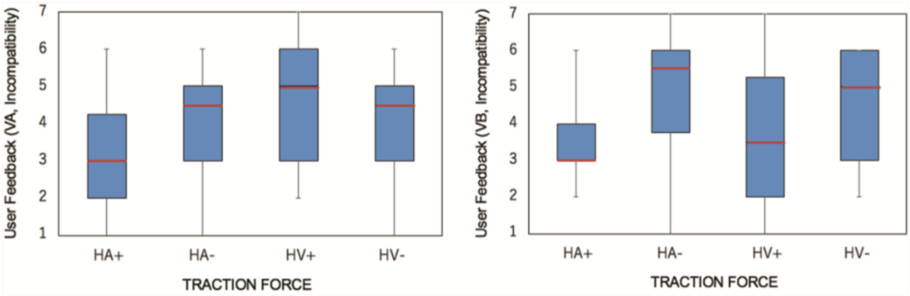

Fig. 11. Feeling of incompatibility (left: VA condition, right: VB condition) (Color figure online)

Feeling of Speed. Figure 8 shows the scores for the feeling of speed. We did not find a significant difference between conditions. However, all of the median values exceeded 4, which means that the feeling of speed was improved by our system, regardless of the presentation method.

Feeling of Acceleration. Figure 9 shows the scores for the feeling of acceleration. We did not find a significant difference between conditions. Similar to the feeling of speed, all of the median values exceeded 4, indicating that the feeling of acceleration was improved by our system.

Feeling of Immersion. Figure 10 shows the scores for the feeling of immersion. Again, we did not find a significant difference between conditions, but all of the scores were equal to or larger than 4.

Feeling of Incompatibility. Figure 11 shows the scores for the feeling of incompatibility. We did not find a significant difference between conditions for either visual stimulus. However, the scores showed a large deviation, which may have been caused by differences in the interpretation of the visual stimuli. The users' comments suggested that the traction force was interpreted either as the body's inertia itself, or as the driving force by another person. These two interpretations represent different scenarios with opposite directions of force, indicating that more realistic visual stimuli, such as a car driving scene, should be presented to prevent different interpretations. In addition, some participants provided low scores in almost all conditions, due to the discordance in the strength of the visual stimuli and the strength of the traction force created by pulling the clothes. Hence, we should adjust the strength of the traction force in accordance with the visual stimuli.

Overall, users tended to favor the VA with HV− condition. In the VB condition, they tended to favor the HA− and HV− conditions. This result was similar to our previous experiments. That is, the traction force for visual stimuli with forward and backward motion was interpreted as velocity. The traction force for visual stimuli with only forward motion was interpreted as acceleration. Therefore, the physical sensation that is related to the traction force created by our system depends on the nature of the visual stimulus.

5 Conclusion

In this paper, we improved our system by adding two motors in front of the body to pull the user's clothes forward and backward, and investigated in detail whether users perceived the presented sensation as acceleration or velocity. We also presented two types of visual stimuli, one with forward and backward motion, and the other with only forward motion and intermittent stopping, to examine the effect of the visual context.

The experimental results showed that the feelings of speed, acceleration, and immersion were improved by presenting traction force in accordance with either velocity or acceleration, compared with the condition without traction force. However, we did not find a significant difference between conditions for either type of visual stimuli. The feelings of speed, acceleration, and immersion were improved if the user felt that the haptic sensation synchronized with the visual stimuli, no matter what type of physical quality they expressed. In other words, these results may suggest the robustness of our method, although we need to conduct further studies.

We provide two examples of how our system can be applied to enrich the virtual-reality experience. One is a swing ride, which moves forward and backward like a pendulum. The user gets on the swing in the virtual space and experiences the thrill of the ride. Because our experimental results showed that the participants tended to prefer the HV+ with the VA condition, the traction force is exerted in the direction of travel in accordance with the velocity of the ride. The other example is a racing game, which moves forward then stops, as in the VB condition. The user drives the vehicle using a handle and an accelerator pedal in virtual space. Because the experimental results showed that the participants tended to prefer the VB condition with the HA− and HV− conditions, the traction force is exerted in accordance with both velocity and acceleration. Specifically, our system pulls the user's body to the rear when the vehicle starts to accelerate, presents a constant force while the vehicle moves at a constant velocity, and pulls the user's body sharply forward when the vehicle stops suddenly. The system also presents torque when the vehicle turns a curve.

As our next step, we will investigate the usefulness of vibratory sensation and torque sensation, and will apply our system to actual games.

Acknowledgements. This research was supported by the JST-ACCEL Embodied Media Project (JPMJAC1404).

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