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Vibrotactile Stimulation for a Car-based Motion Platform*

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***Abstract*—To reduce the cost of motion platforms (MPs), Virtual Reality (VR) systems with automobiles as an MP have been proposed. This produces whole-body motion by controlling the car with an accelerator and a brake. However, the system can only present body motion of up to 2 Hz, which is relatively small compared with commercially available MPs. In this paper, we propose a method of expanding the frequency range by using vibrators around the driver's seat. We developed an experimental device that imitates a car, but body motion was generated via the human hand. We compared three conditions: swing only, vibration only, and both stimuli, experienced alongside VR content. The results suggest that presenting vibration and body swing in combination significantly increases the feeling of presence, and decreases the feeling of unnaturalness.**

I. Introduction

To provide Virtual Reality (VR) content with whole-body motion at relatively low cost, VR systems with automobiles as motion platforms (MPs) have been proposed [1]. However, it is difficult for an automobile to provide high-frequency body motion. In our prototype, only low-frequency swings of up to 2 Hz can be expressed. Vibration with wide frequency components (e.g. a collision with a wall) cannot be reproduced.

In this paper, we try to solve this issue by adding vibrotactile transducers around the driver's seat of the car. There are several studies that have improved the entertainment experience by presenting vibration [2]. There are also several studies using vibrotactile feedback inside real cars [4], [5]. A motion platform with vibration has also been developed [6]. However, as far as the authors know, there are as yet no studies that have evaluated the effects of the combination of vibration and body swing.

In this research, we investigated the effect of the combination of body swing and vibration in alongside audio visual VR experience. We developed an experimental device that imitates a car (Figure 1), and presented both vibration and body swing.

II. Hardware

To safely conduct the experiment, we did not experiment with actual cars, but instead developed a device that imitates a car (Figure 1), and conducted an experiment using this device.

We designed this device based on two concepts: front-back motion is possible, and the driver's surrounding environment is the same as that in an ordinary car. We used a hand trolley (Nansin Inc. in Tokyo, Japan, DSK-101) to perform a front-back swing, and we set a wooden plate (Lumber core, W155×D46×H2 [cm]) on top of it to act as the floor of the car. We installed a gaming seat (Playseat Company) on the wooden plate for a driver's seat, as well as a handle and a pedal, which are accessories of the playseat.

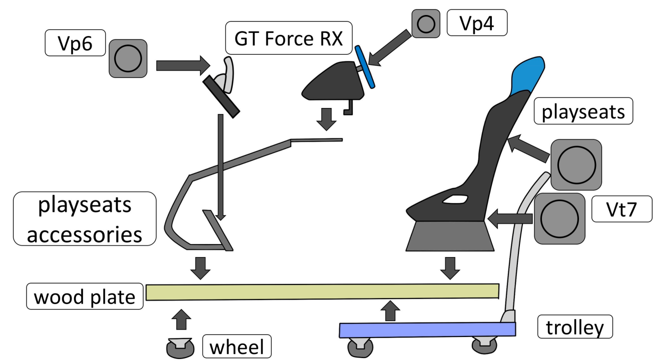

Figure 1 Overview of experimental device

To present vibration, we mounted transducers around the contact points between the human body and the device. We used different types of transducers at different locations based on the limitations of the installation area and the different weights of the body parts we wanted to actuate. The installation locations were the steering wheel (Vp 408, Acuve Laboratory, Inc.), accelerator pedal (Vp 604, Acuve Laboratory, Inc.), seat surface and backrest (Vt 708, Acuve Laboratory, Inc.). We measured the frequency characteristics of each point of a transducer while the user was seated. The strong vibration could be presented from at least 32 Hz.

III. User Study

User study was conducted using the device that we developed. Participants rode on the experimental device, and experienced VR contents with a head-mounted display (HMD) and sound, while we presented vibration and swing in accordance with the events in the VR scene. We measured the subjective evaluation of participants' VR experiences.

A. Experimental Environment

We made two videos with the Unity game engine (https://unity3d.com/). One video consisted of the car driving straight and colliding with a brick wall. The other consisted of the car driving straight and running over large stones. It was assumed that the former generates acceleration in the forward-backward direction, while the latter generates acceleration in the vertical direction. We chose these two situations to confirm the influence of the difference in swing direction between the virtual and real environments. Participants equipped earmuffs over their earphones to shut out the noise.

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When outputting a waveform from the PC to a transducer, a USB-DA converter (USB-DAC, DENON, DA-300USBS) and a pre-main amplifier (A-5VL, ONKYO, A-5VL(s)) were used to stably output low-frequency vibrations. An Oculus Rift DK 2 was used as the HMD for this experiment.

In this experiment, swing was generated by the experimenter's arms. The experimenter practiced so as to generate swinging with constant strength and constant time when people rode the equipment. As the time lag between the event in the video and the stimulation did not completely disappear with manual swinging, we recorded this time lag. Recording was performed using a microcontroller (mbed, NXP, LPC1768), an acceleration sensor, and a program in Unity. We observed the lag between the time of collision recorded by Unity and the time of the start of the swing presentation recorded by the acceleration sensor.

B. Procedure

Twelve university students outside our laboratory (5 female, 7 male) participated in this experiment. For this experiment, we adopted a method of subjective evaluation of the difference between the reference stimulus and the comparative stimulus.

After explaining the experiment to the participants, we let them experience vibration and swinging once, to prevent excessive surprises from these stimuli. Participants wore earphones, a HMD, earmuffs, grabbed the steering wheel, and then played the video. The participants experienced the video with only swinging as a reference stimulus, and immediately afterwards experienced the same video with one of three conditions. The order of the experiment was randomized.

We gave a questionnaire to each participant after comparative stimulation was completed. Assuming that the reference stimulus is 4, we asked participants to rank "presence" and "unnaturalness" on a 7-point Likert scale. We also asked participants to rank the "strength of perceived vibration" on a 7-point Likert scale without comparing it to the reference. Finally, we asked if they felt a time lag.

There were three conditions: vibration only by the vibrator, swinging only from the experimenter's arms, and vibration and swinging at the same time. As a reference stimulus, we always used a swing-only condition. As comparative stimuli, we used all three conditions. In each of the two scenes, each condition was carried out once, giving a total of six trials per participant. The stimuli were presented at the moment of colliding with the wall or at the moment of running over a stone.

C. Results

We calculated time lags for all 120 trials containing the swing condition. Almost all time lags were less than 200 ms, except for one trial (240 ms). However, there was little relation between participants' responses and actual time lags.

Figure 2 shows the evaluation of the feeling of presence and unnaturalness. A Steel–Dwass test was performed, and the results showed that in terms of presence, the combination of vibration and swing was the best in both situations, with significant differences from the other two. Moreover, the combination of vibration and swing significantly reduced unnaturalness compared with only vibration in both situations.

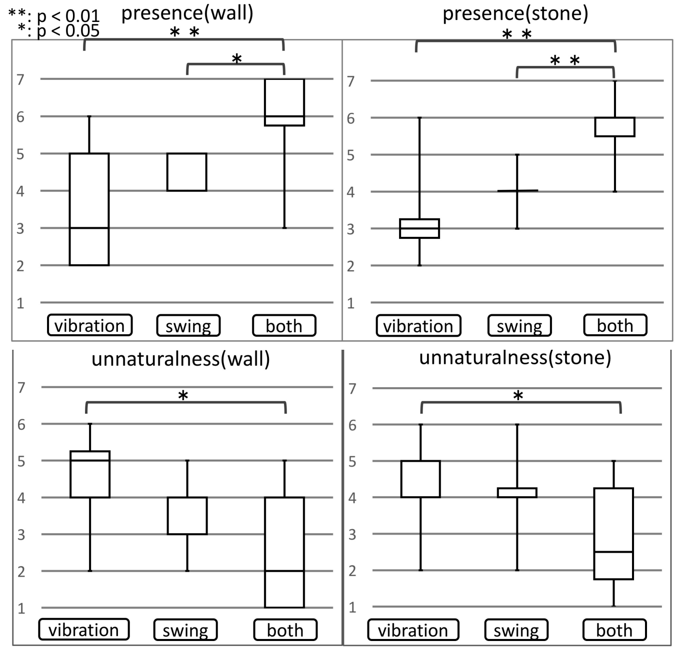

Figure 2 Evaluation of presence and unnaturalness
(1: Not at all 7: Extremely high)

IV. Conclusion

In this paper, we proposed to combine vibration and body swing to improve the experience of a VR system with an automobile as a MP. We developed an experimental device and investigated the change in the VR experience. The experimental results showed that presenting a combination of vibration and swing significantly increases presence and reduces unnaturalness, compared with vibration-only and swing-only conditions.

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