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Emotional Effects of Car-based Motion Representations with Stereoscopic Images

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Abstract

In this research, using an electric car as a motion platform we evaluated the user experience of motion representations in a virtual reality (VR) system. The system represents physical motion when it operates the car backward and forward with accompanying visual motion included in stereoscopic images in a head-mounted display (HMD). Image stimuli and car-based motion stimuli were prepared for three kinds of motion patterns, "starting", "stopping" and "landing", as experimental stimuli. In the experiment, pleasure and arousal were measured after each stimulus representation using the Self-Assessment Manikin (SAM), a questionnaire about emotions. Results showed that the car-based motion stimulus increased pleasure in the "landing" pattern.

Introduction

Virtual reality (VR) systems, which consist of a head-mounted display (HMD) and a motion platform, are expected to provide contents with a high sense of presence. Such VR systems make users feel a strong sense of motion as they represent physical motion with accompanying visual motion included in images presented through an HMD. Recently, several VR systems using appliances or persons as a motion platform have been proposed. Hashilus developed by Hashilus is a VR system that adopts a rodeo machine as a motion platform and provides horse-riding content [1]. Haptic Turk proposed by Cheng et al. is a system based on humans as a motion platform. The user lifted by the humans can play an immersive game with physical motion generated by their manual operations following instructions from the system [2]. CarVR proposed by Hock et al. is a VR system that uses a car as a motion platform to allow passengers to experience VR contents during driving [3]. One advantage of such VR systems is that they can be less costly to introduce than VR systems that use a dedicated motion platform.

The car-based VR system (CVRS) proposed by Kodama et al. is a VR system with a small electric car as a motion platform [4]. The car-based VR system represents physical motion, which accompanies visual motion represented in the stereoscopic images of an HMD, by operating the car backward and forward. Moreover, cars originally have mobility and they are utilized widely in the public to travel and transport. Thus, the CVRS can be easy to own in ordinary homes and to use outdoors unless the function for driving are removed.

Kodama et al. demonstrated that the CVRS can provide an enjoyable experience with multiple motion representations [4]. However, they provided no concrete information on how the motion representations of the car affected the user experience. The positive effects through the experience might not be obtained depending on the type of motion representation because the range of motion and the degree of freedom are limited. The effects of physical motion representations of the car need to be clarified to make the CVRS experience more comfortable.

In this research, we aimed to clarify how the physical motion of the CVRS affects the users' emotions through experiences. We focused on a relationship between motion representations of the CVRS and emotional effects of experience. Thus, in our experiment we evaluated emotional effects of the experience with extracted and simplified motion representations (Figure 1).

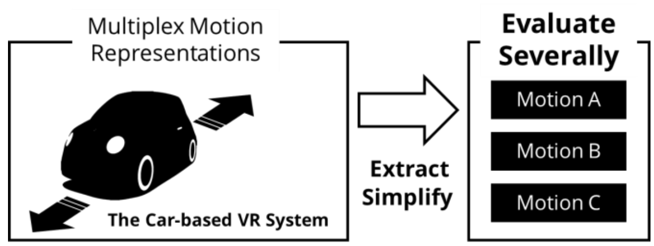

Figure 1. Concept of the experiment

Experimental Methods

Overview

Image stimuli displayed by the HMD and car-based motion stimuli of the car were created as experimental stimuli. The car-based motion stimuli accompanied the image stimuli to represent the physical motion simultaneously. In the experiment, participants were divided into two groups with or without the car-based motion stimuli. The effects by the car-based motion stimuli were analyzed by comparing results of the subjective evaluation between the groups.

Layout

Figure 2 shows the experimental layout. The experimental environment was constructed in the CVRS by Kodama et al. COMS manufactured by Toyota Auto Body Co., Ltd. was used for the base car. Oculus Rift CV1 was used for the HMD. A laptop PC that can play stereoscopic images of the HMD at 90 [fps] was installed on the trunk of the car. The PC was connected to a microcomputer in the car and control of the car driving was synchronized with the stereoscopic images of the HMD. Questionnaires used during the experiment were installed at the position of the steering wheel in front of the seat. The questionnaires were set in a holder that allowed the experimenter to extract the answered sheet quickly as participants had to frequently fill out the questionnaires during the experiment.

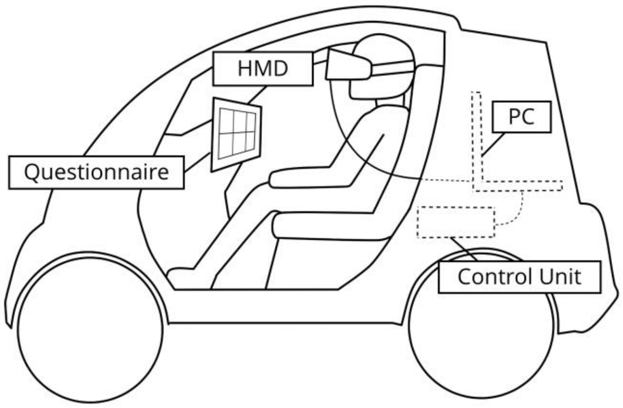

Figure 2. Experimental layout

Stimuli

Image Stimuli

Three-dimensional (3D) space composed of a black background and white wire frames was created as the image stimuli using Unity 5.4. Figure 3 shows the overview of the image stimuli. Image stimuli were created by imagining that participants were moving naturally within a cockpit-type vehicle. The 3D space of the image stimuli was composed of a cockpit (near view) in which the participant was riding and a background (distant view) to express the motion in the space. The image stimuli displayed on the HMD were stereoscopic images captured by the Main Camera object on Unity placed in the 3D space. The images containing time-synchronized visual motion representations were generated by moving the Main Camera object programmatically in the 3D space. Rectangular parallelepipeds at equal intervals in the 3D space, grid lines on the bottom surface and contour lines on the wall surface were drawn as clues to induce self-motion sensations. The reason for using only black and white is to eliminate influences of color and texture. In addition, a white frame-like object was arranged by imagining a cockpit so that participants could feel as if they were riding in a moving vehicle and recognize a state of motion.

Three kinds of motion patterns, which were “starting”, “stopping” and “landing”, were designed to be represented in the image stimuli. Table 1 shows definitions of the three motion patterns. Moreover, two conditions, A and B, were designed for each motion pattern. The top panels of Figure 4–9 show the design values of motion representations of the image stimuli. In the top panels of Figure 4–7, the vertical axis shows the speed in the forward direction (the deep direction in Figure 3) of the Main Camera object. In the top panels of Figure 8 and 9, the vertical axis shows the amplitude of the Main Camera object in the vertical direction. In addition, for each motion pattern, the condition A was designed so that participants could feel the motion gentle and moderate and the condition B was designed so that they could feel the motion steep and intense. These conditions were provided to analyze the effect of the car-based motion stimuli against the strength of motion representations. In the “starting” pattern, condition A represented the motion of starting and accelerating slowly, and condition B represented the motion of starting suddenly. In the “stopping” pattern, condition A represented the motion of decelerating slowly and stopping, and condition B represented the motion of stopping suddenly. In the “landing” pattern, condition A represented the motion of vibrating slightly in a vertical direction at landing, and condition B represented the motion of vibrating strongly in a vertical direction at landing.

In the “starting” pattern, the image stimuli were designed to fade out at the end of the stimulus presentation to exclude the “stopping” motion. Similarly, in the “stopping” pattern, the image stimuli were designed to fade in at the start of the stimulus presentation to exclude the “starting” motion.

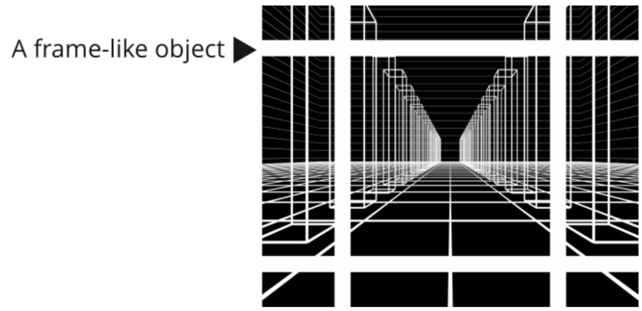

Figure 3. The overview of the image stimuli

Table 1: Definitions of the motion patterns

Motion pattern	Definition
Starting	The motion accelerating for the fixed time from the stopped state up to move forward in constant velocity
Stopping	The motion decelerating for the fixed time from the state of moving forward in constant velocity up to stop completely
Landing	The motion falling from high altitude and vibrating in the vertical direction at landing

Car-based Motion Stimuli

The car-based motion stimuli were implemented to accompany each of the image stimuli motion representations by operating the car backward and forward. However, the car-based motion stimuli could not be directly reflected in the motions represented by the image stimuli. The motions that moved about a maximum of 40 [m] were represented in the image stimuli. In contrast, the CVRS was supposed to operate within the range of 5 [m] in the back and forward directions. Therefore, the car-based motion stimuli were presented only at the times when self-motion sensations were particularly induced by the image stimuli. The car-based motion stimuli were adjusted by trial and error by five developers upon the implementation.

The bottom panels of Figure 4–9 show the design voltages of the car’s accelerator. In the “starting” pattern, the car was controlled to move forward during the accelerating motion of the image stimuli. In the “stopping” pattern, the car was controlled to move backward during the decelerating motion of the image stimuli. In the “landing” pattern, the car was controlled to move backward during the falling motion of the image stimuli and change to move forward immediately at the landing motion of the image stimuli. As the car operated with a delay of about 200 [ms] after the PC command, the voltage input of the accelerator was earlier than the acceleration, deceleration or landing in the image stimuli.

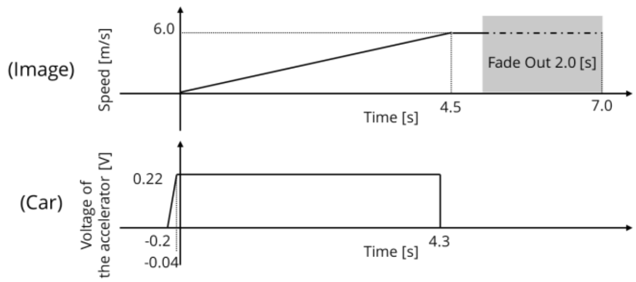

Figure 4. Design value of the "starting" A condition

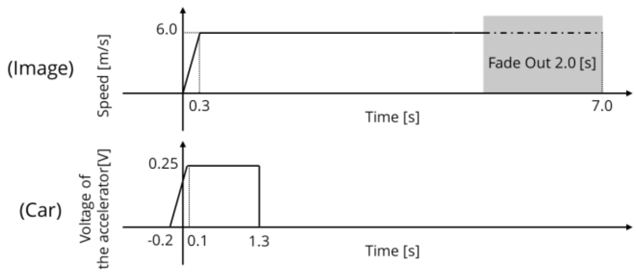

Figure 5. Design value of the "starting" B condition

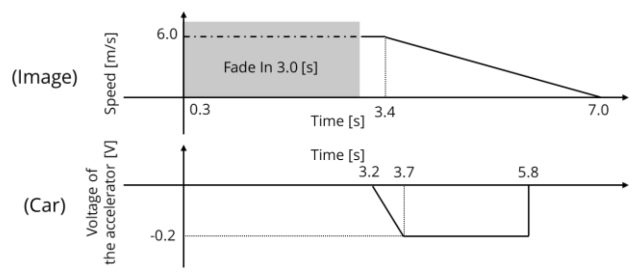

Figure 6. Design value of the "stopping" A condition

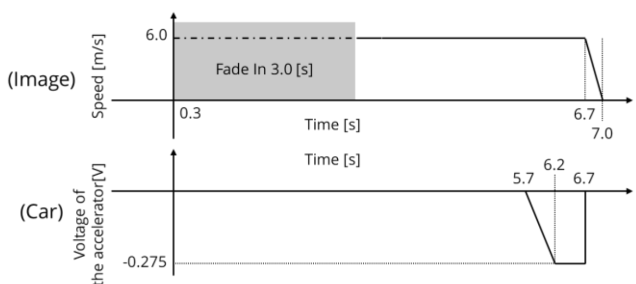

Figure 7. Design value of the "stopping" B condition

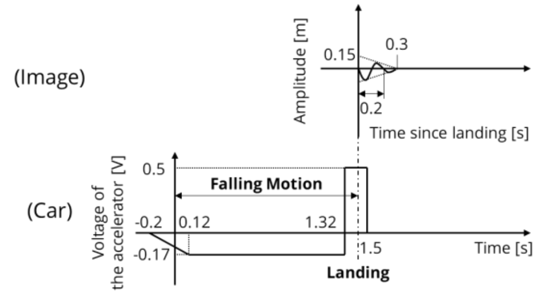

Figure 8. Design value of the "landing" A condition

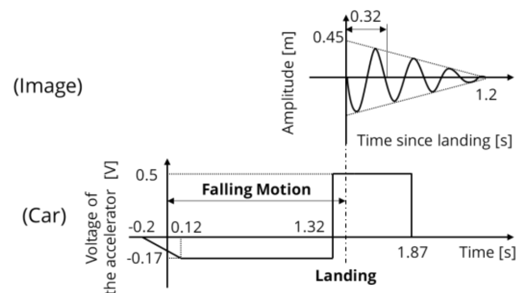

Figure 9. Design value of the "landing" B condition

Procedure

Figure 10 shows the experimental procedure. Informed consent was obtained at the beginning of the experiment. All the participants were seated on the seat in the car and experienced the experimental stimuli of all six conditions in a random order. Participants answered a questionnaire after experiencing an experimental stimulus of one condition and removing the HMD following an instruction from the experimenter. Before starting the experimental stimuli, a practice trial was conducted. In the practice trial, participants practiced the process from experiencing a stimulus to answering a questionnaire using a practice stimulus that was not included in the motion representations used for the experiment. An oral interview was conducted after participants completed all six conditions and had answered the questionnaires. In the experiment, the process from the practice trial to the oral interview was defined as one set, and two sets were conducted in total.

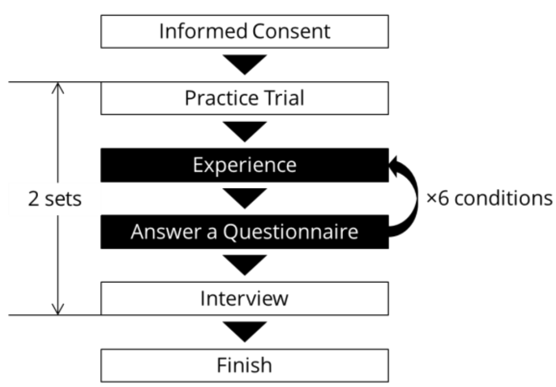

Figure 10. Experimental procedure

Evaluation

Self-Assessment Manikin (SAM)

The Self-Assessment Manikin [5], which allows respondents to evaluate their own emotion intuitively, was adopted as the questionnaire that the participants filled out immediately after experiencing an experimental stimulus. Figure 11 shows the SAM. The SAM used in the experiment evaluated pleasure and arousal in nine stages. Participants answered by marking the parts that applied to their own emotions. Pleasure and arousal correspond to Russell's circumplex model [6] (Figure 12), then types of emotion at the experience can be estimated.

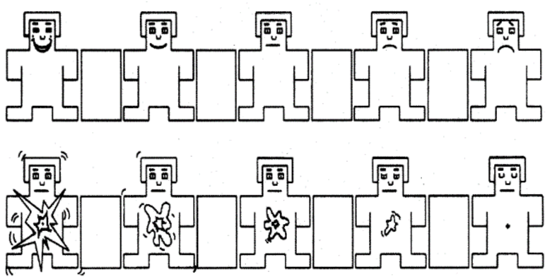

Figure 11. Self-Assessment Manikin (SAM) [5]

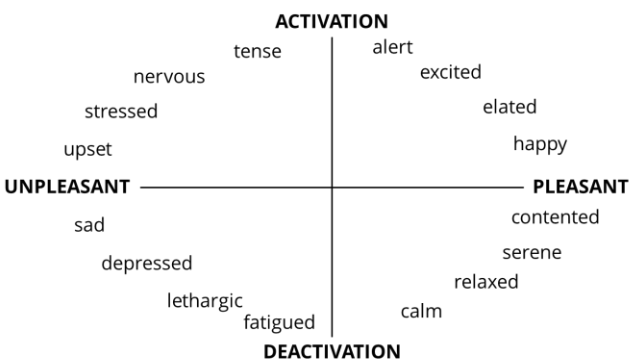

Figure 12. Russell's circumplex model [6]

Oral Interview

An oral interview that asked questions about comfort and impressions of the experience was conducted to compare the responses with the results of the SAM. In the interview of the second set, questions asking about impressions of the overall experimental stimuli, including the first set, were added. The main questions in the oral interview were as follows:

1. Did you notice the difference between two motions (A and B) of any motion pattern? If so, which of two experiences of the motion pattern(s) that you noticed the difference did you feel more comfortable? Please tell me the reason.
2. What was the most comfortable experience overall? Please tell me the reason.
3. What was the most uncomfortable experience overall? Please tell me the reason.
4. If you felt unnatural during the experience, what was the experience? How did you feel at the time?

(These questions below were asked in the second set only.)

5. What was the experience in which your impressions and comfort changed from the first to second set? Please tell me the reason.
6. What was the most impressive experience overall? Please tell me the reason or comment.
7. Please tell me if you have comments or opinions about the experiment.

Participants

Participants were 30 men and women aged in their 20s–60s with normal eyesight. Participants were employees of Toyota Central R&D Labs., Co, Ltd. and were recruited using internal bulletin boards. Spectacle wearers were excluded because the HMD was attached and removed frequently in the experiment. Half of the total 30 participants experienced the experimental stimuli with the car-based motion stimuli, the others experienced them without the car-based motion stimuli.

Results

Self-Assessment Manikin (SAM)

Figures 13 and 14 show the average scores of pleasure and arousal. Error bars of these figures show standard errors. Analysis was performed based on the presence of the car-based motion stimulus and the condition since the order effect by the number of sets was not indicated.

Pleasure

The two-way ANOVA, regarding the presence of the car-based motion stimulus as a between-subjects factor and the condition as a within-subjects factor, was performed on the pleasure score. Before the ANOVA was performed, the adjustment of degrees of freedom by ε of Greenhouse-Geisser based on the results of Mendoza's multi-sample sphericity test was performed. The main effect of the car-based motion stimulus ($F(1,58) = 6.888$, $p < .05$) and the interaction ($F(2.69, 156.22) = 3.432$, $p < .05$) between the factors was significant. The simple main effect of the car-based motion stimulus at "landing" A and "landing" B conditions was significant according to the result of the simple main effect test ($F(1,58) = 9.498$, $p < .01$; $F(1,58) = 8.735$, $p < .01$). In addition, the simple main effect of the condition was also significant when the car-based motion stimulus was presented.

Arousal

The two-way ANOVA, regarding the presence of the car-based motion stimulus as a between-subjects factor and the condition as a within-subjects factor, was performed on the arousal score. Before the ANOVA was performed, the adjustment of degrees of freedom by ε of Greenhouse-Geisser based on the results of Mendoza's multi-sample sphericity test was performed. The main effect of the condition ($F(3.81, 221.02) = 24.04$, $p < .01$) was significant. However, the main effect of the car-based motion stimulus and the interaction between the factors was nonsignificant. Performing multiple comparisons on the condition using Holm's method, significant differences between the A and B conditions were shown in the "stop" and "landing" pattern ($p < .05$). Although many other combinations had significant differences, descriptions of them are omitted in this paper because the motion patterns are different from each other.

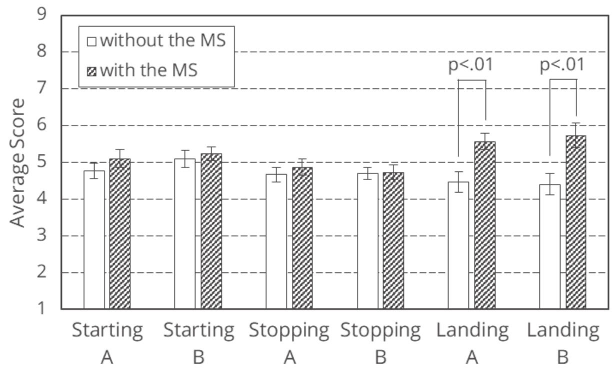

Figure 13. Average score of pleasure (the MS means the car-based motion stimuli)

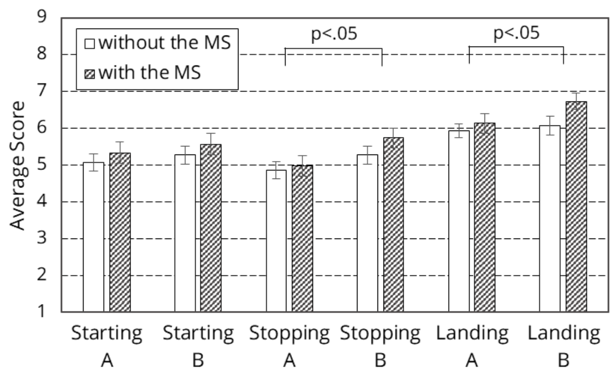

Figure 14. Average score of arousal (the MS means the car-based motion stimuli)

Bubble Charts

Figures 15–20 show bubble charts of the SAM whose horizontal axis shows the pleasure score and vertical axis shows the arousal score. The size of each plot shows the number of responses from the participants. 'MS' is the car-based motion stimuli. The color of the plot shows the presence of the car-based motion stimulus and the overlapping parts are colored grey.

Figures 15 and 16 show bubble charts of the "starting" pattern. In the "starting" pattern, the change of the distribution in condition A was not shown by the car-based motion stimulus. In condition B, participants who indicated high pleasure and high arousal tended to increase with the car-based motion stimulus.

Figures 17 and 18 show the bubble charts of the "stopping" pattern. In the "stopping" pattern, the change of the distribution in condition A was also not shown by the car-based motion stimulus. However, participants who indicated high pleasure and high arousal in condition B tended to increase with the car-based motion stimulus.

Figures 19 and 20 show the bubble charts of the "landing" pattern. In the "landing" pattern, participants who indicated high pleasure and high arousal in both condition A and B increased with the car-based motion stimulus.

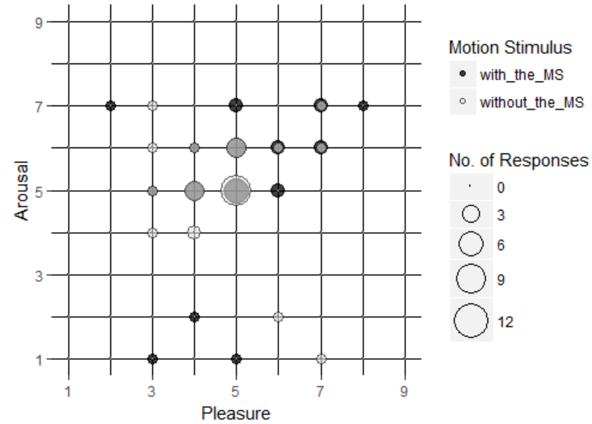

Figure 15. Bubble chart of the SAM in the "starting" A condition

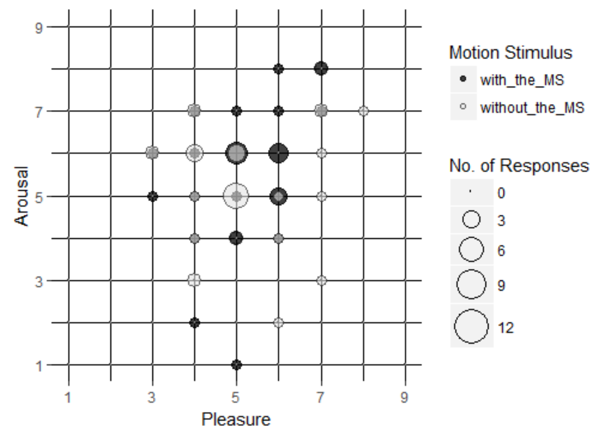

Figure 16. Bubble chart of the SAM in the "starting" B condition

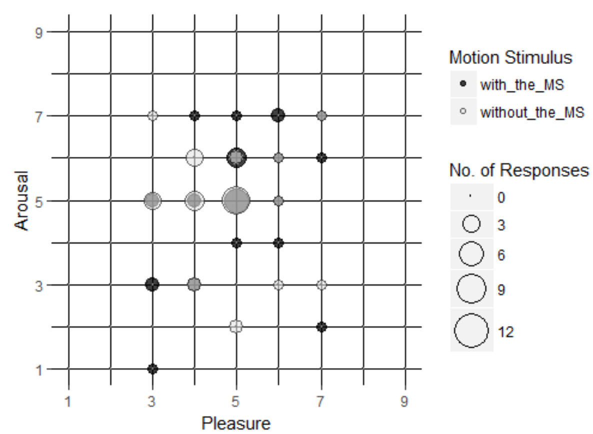

Figure 17. Bubble chart of the SAM in the "stopping" A condition

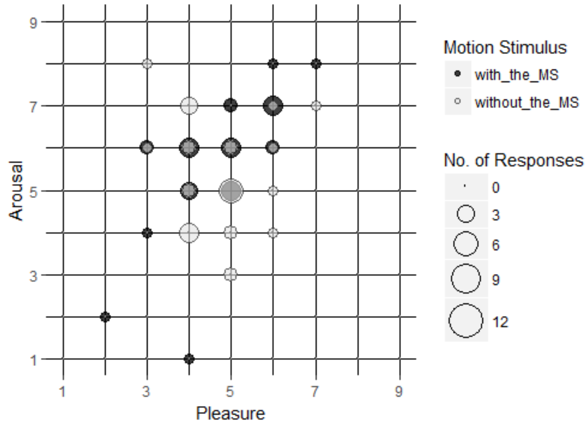

Figure 18. Bubble chart of the SAM in the “stopping” B condition

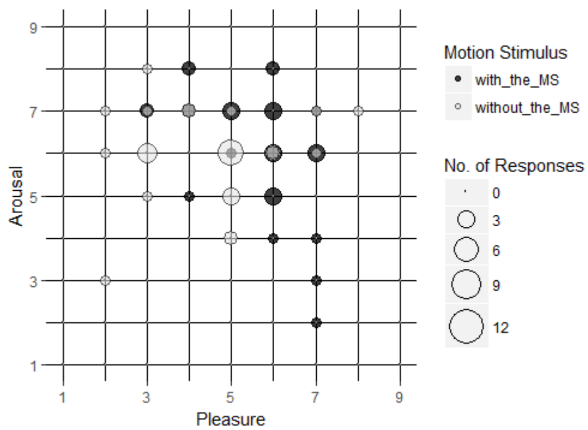

Figure 19. Bubble chart of the SAM in the “landing” A condition

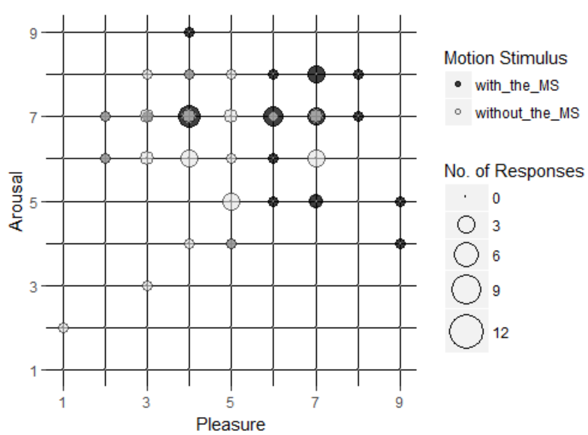

Figure 20. Bubble chart of the SAM in the “landing” B condition

Interview

Figure 21 shows the number of participants who stated each condition as the most comfortable at least once, answering the question: "what was the most comfortable experience overall?" In the same way, Figure 22 shows the number of participants who stated each condition as the most uncomfortable at least once, answering the question: "what was the most uncomfortable experience overall?" The data in these figures were compiled for each condition even if participants had stated nothing or multiple conditions as the most comfortable or uncomfortable.

Without the car-based motion stimulus, the “starting” pattern was answered by more participants as “the most comfortable” than the other patterns. Further, the “stopping” and “landing” patterns were answered by several participants as “the most uncomfortable”. Some participants who answered that the “starting pattern” was “the most comfortable”, commented “I felt natural and comfortable”. Participants who had answered that the “stopping” pattern was “the most uncomfortable” commented “I felt myself moving even after stopping in the image stimuli”. For the “landing” pattern, some participants who had answered that it was “the most uncomfortable” pattern commented “it was too thrilling” or “I felt myself floating or weightless momentarily”.

In contrast, with the car-based motion stimulus, the “landing” pattern was answered by more participants as “the most comfortable” than the other patterns, and the “stopping” pattern was answered by several participants as “the most uncomfortable”. Some participants, who answered that the “landing” pattern as “the most comfortable”, commented “it was fun because I have never experienced before” and “I felt realistic”. On the other hand, one of participants, who answered that the “stopping” pattern was “the most uncomfortable”, commented “I felt myself floating”.

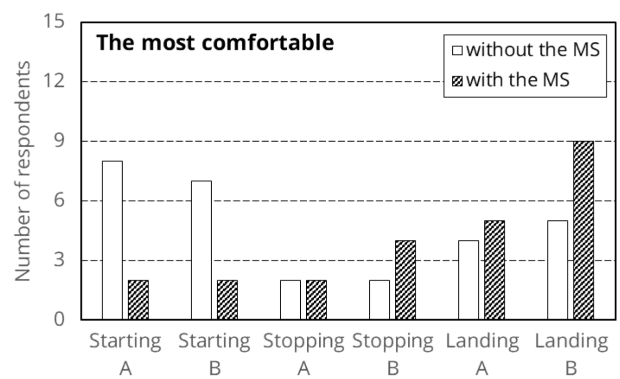

Figure 21. Number of participants who stated as the most comfortable, answering the question: "what was the most comfortable experience overall?"

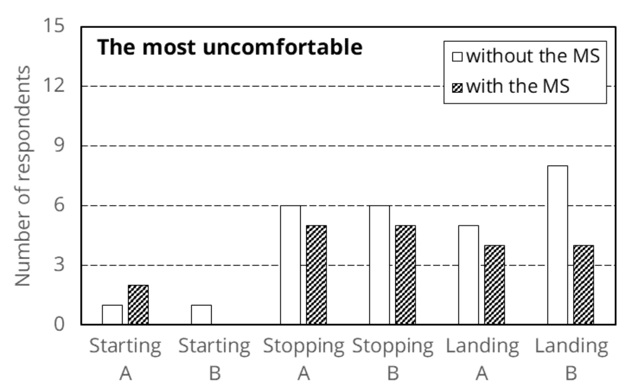

Figure 22. Number of participants who stated as the most uncomfortable, answering the question: "what was the most uncomfortable experience overall?"

Figure 23 shows the number of participants who stated that they had felt unnatural for each condition at least once, answering the question: “if you felt unnatural during the experience, what was the experience?” Without the car-based motion stimulus, more than half of the participants indicated that they felt unnatural about the “stopping” and “landing” patterns. In contrast, with the car-based motion stimulus the number of the participants who felt unnatural about these patterns decreased.

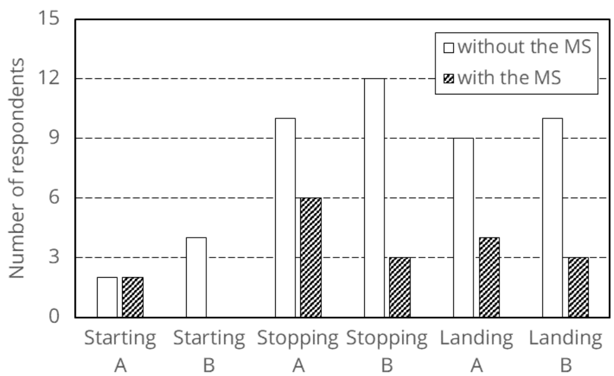

Figure 23. Number of participants who had stated that they felt unnatural

Discussion

In this section, the effects of the car-based motion stimulus are discussed for each motion pattern from the results of the SAM and the oral interview.

Starting

In the “starting” pattern, no significant increase due to the car-based motion stimulus was indicated. Without the car-based motion stimulus, the average score of pleasure was relatively high and the number of participants who felt unnatural was only a few. Therefore, for this pattern the car-based motion stimuli did not provide any improvement of the effect for participants.

In addition, participants who indicated high pleasure and high arousal tended to increase with the car-based motion stimulus in condition B. In comparison with Russell’s circumplex model, the car-based motion stimulus was suggested to cause emotions such as “excited” or “happy”.

Stopping

In the “stopping” pattern, no significant increase due to the car-based motion stimulus was indicated. From the oral interview, several participants indicated unnaturalness as a reason for their uncomfortableness through the experience with and without the car-based motion stimuli. Thus, this suggested that the physical “stopping” motion could not be completely represented by the car. However, it was suggested the car-based motion stimulus alleviated the unnaturalness because the number of participants who felt unnatural decreased in this group.

Moreover, participants who stated high pleasure and high arousal were inclined to increase with the car-based motion stimulus in condition B, as well as the “starting” pattern. The car-based motion stimulus was suggested to cause emotions such as “excited” or “happy”, referring to Russell’s circumplex model.

Landing

In the “landing” pattern, the pleasure score increased significantly with the car-based motion stimulus. This suggested that the car could have represented the physical “landing” motion properly. Moreover, it could be considered from the high arousal score and the oral interview that the “landing” pattern is more rarely experienced by general people than the “starting” and “stopping” pattern. This feature might induce a strong unnaturalness when the stimulus presented without the car-based motion stimulus. In contrast, when the stimulus is presented with the car-based motion stimulus, it might provide an extraordinary experience and raise the pleasure score.

Additionally, participants who showed high pleasure and high arousal seemed to increase with the car-based motion stimulus in both the condition A and B. Comparing the results with Russell’s circumplex model, the car-based motion stimulus was suggested to induce emotions such as “excited” or “happy”.

Furthermore, the results suggested that the car-based motion stimulus improved the user experience even if the motion axis of the car was different from the motion axis of the images. The first reason might be that the suspension system of the car contributed to present the physical motion vertically. The second reason might be that the users, who had not experienced the “landing” motion in real life, had an illusion that the “landing” motion was real.

Conclusion

In this research, we evaluated the user experience of physical motion representations of a CVRS accompanied by visual motion representations in stereoscopic images of a HMD. In the experiment, using the SAM, pleasure and arousal were measured for three kinds of motion patterns, “starting”, “stopping” and “landing”.

From the results of the experiment, two main pieces of information were obtained. First, no significant increase in the pleasure score due to the car-based motion representation was indicated in the “starting” and “stopping” patterns. However, it was suggested that the unnaturalness was alleviated in the experience with the car-based motion representation. Second, the pleasure score increased significantly due to the car-based motion representations in the “landing” pattern. The reason suggested for this is that the extraordinariness of the “landing” pattern assisted in making the user experience more positive by using the car-based motion representation.

In the future, we will advance the study of new kinds of motion patterns to provide rich VR experiences.

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Author Biography

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