Part XV

Symposium 3—The Future of Vection

An Introduction to Symposium 3: The Future of Vection

Symposium Organizer: Takeharu Seno

In this symposium, we will first introduce "What is Vection." This introduction will be followed by four presentations from leaders in the field of vection research. The symposium will provide an overview of the important controversies and new findings in the field.

SELF-MOTION PERCEPTION FACILITIES AT YORK UNIVERSITY

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York University has a long history of research in the perception of self-motion and orientation using purpose-built apparatus. Recently we developed and installed new facilities including new, more capable versions of Ian Howard's tumbling room and sphere devices: (1) The wide field stereoscopic environment (Fig. 1) is a projected, computer-generated, virtual environment that completely fills the participant's visual field with edgeless, high-resolution imagery. (2) The new tumbling room (Fig. 2) allows for full 360 degree rotation of the observer or the visual environment with near perfect visual fidelity. The room walls, floor and ceiling can be removed allowing for locomotion in a cylindrical environment. (3) The sphere environment (Fig. 3) allows for presenting full-field visual motion displays in pitch, roll or yaw while in a wide range of postures with respect to gravity. This presentation will overview the capabilities and illusions elicited in these devices as well as experiments to cross-validate the devices.

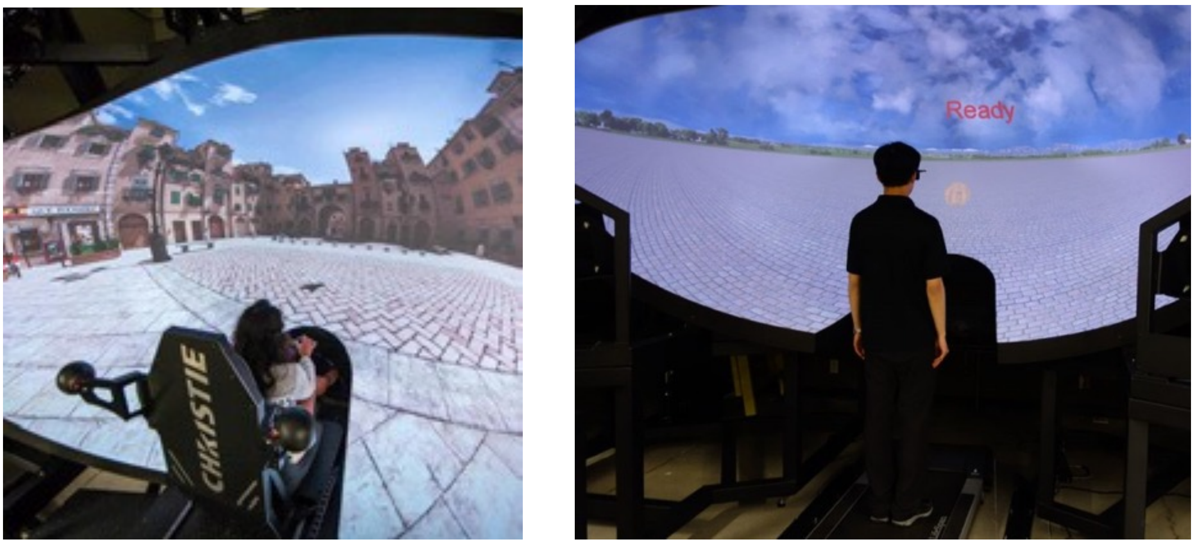

Fig. 1. The Wide-field Immersive Stereoscopic Environment is a projected, computer-generated, virtual environment. It is driven by eight overlapping, blended and calibrated projectors to provide high-contrast, high-resolution virtual imagery over the viewer's entire visual field. It can be used in seated (left) and standing/treadmill (right) configurations. The user's head and limbs can be tracked and the correct perspective projection for the user's vantage point presented in real time.

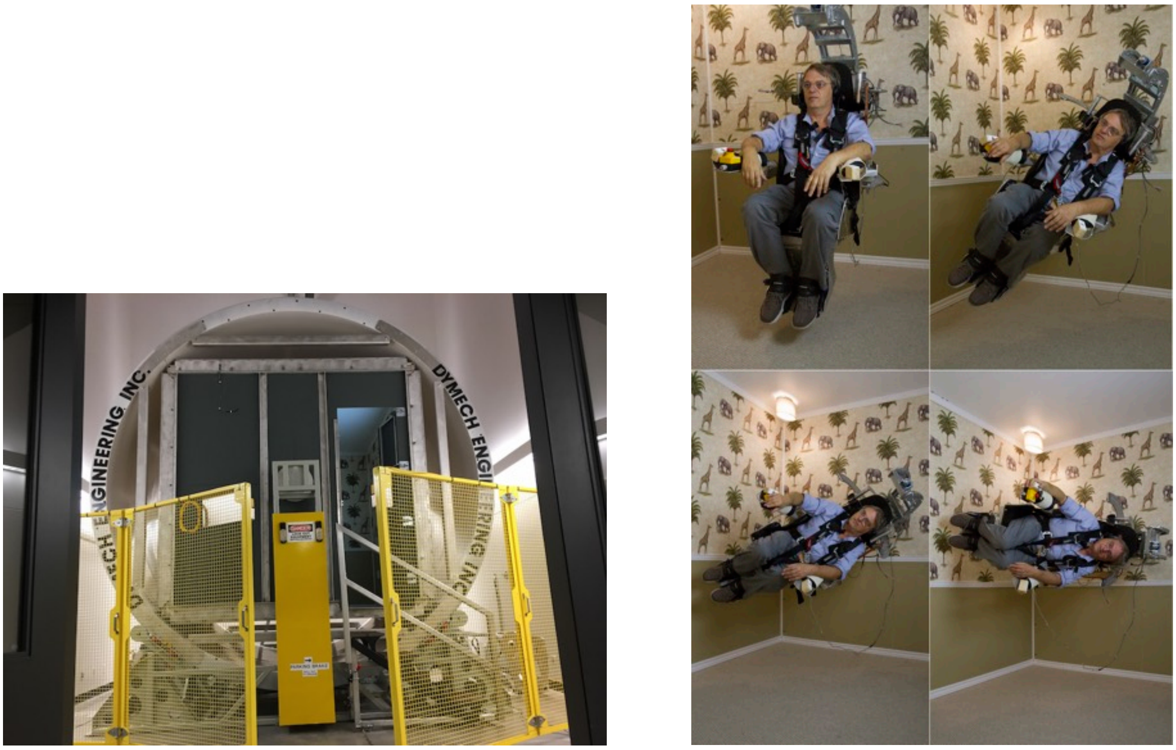

Fig. 2. The Tumbling Room enables motorized rotation of either the room or the observer (or both). In either case, under continuous rotation the observer typically perceives full 360-degree self-rotation (right). The room walls, floor and ceiling can be removed providing a continuous locomotion interface as the room turns. Imagery can be projected on the interior surface of the cylinder in this mode.

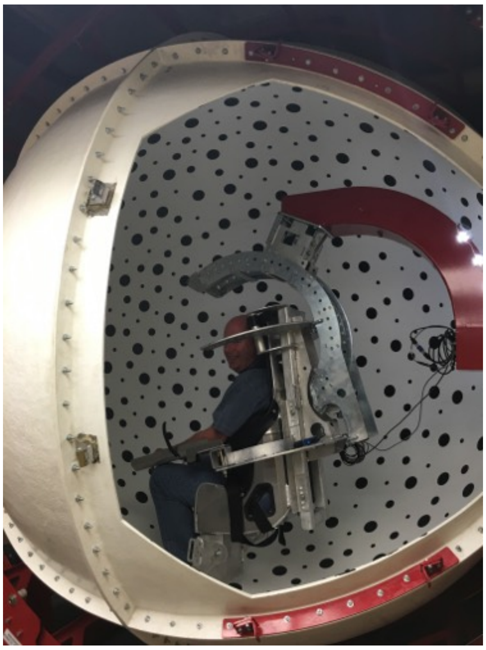

Fig. 3. The Sphere (shown here with access door removed) can provide full-field rotational optic flow to an observer oriented in a variety of postures. In various configurations yaw, pitch and roll vection can be produced.

PHENOMENOLOGICAL APPROACH TO VECTION

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Visually induced illusory self-motion perception (vection) has been studied in various methods and in various filed of science. For example, experimental Psychological methods have a long history. Also, brain imaging studies have revealed brain areas for vection induction. In this study, we newly introduce Phenomenological approach to vection research. Phenomenological approach is very usefulness and important to know vection more. We recorded the oral reports for 40 seconds when the participants observed vection stimulus and perceived vection. Thirteen volunteers participated in this study. There were two directional conditions, i.e. expansional and contracted optical flows. Two trials were repeated in each condition. We counted the frequencies of uttered words from various viewpoints. Phenomenological analyses suggest what will be the important topics in future vection study. Also, they proved us the validity of the experimental Psychological approach used in some previous vection studies.

INDIVIDUAL DIFFERENCES IN POSTURAL STABILITY PREDICT BOTH VECTION AND SIMULATOR SICKNESS

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Abstract

Evidence is mounting that differences in postural responding can be used to predict who will become sick and experience strong self-motion when exposed to global optical flow (e.g., Apthorp et al., 2014; Stoffregen & Smart, 1998). In this study we initially measured fluctuations in centre of foot pressure (CoP) when participants were standing quietly with their eyes open. They were next repeatedly exposed to two different types of self-motion display. As expected oscillating optic flow induced stronger vection and more sickness than the smooth self-motion display. Participants who had displayed lower CoP recurrence rates and had larger sway areas when standing quietly were more likely to later: (1) experience stronger vection; and (2) report motion sickness. We propose that CoP recurrence rates could serve as a useful diagnostic tool for evaluating who will benefit the most/least from exposure to virtual environments.

When people are exposed to visual self-motion simulations, there can be striking individual differences in both the incidence of motion sickness and the symptoms they experience (Keshavarz, Hecht & Lawson, 2015). However, Stoffregen and his colleagues have shown that we can predict who will become sick (even before any exposure to visual motion) based on the individual differences in their spontaneous postural stability (see Smart et al., 2002; Stoffregen & Smart, 1998). Two recent studies also appear to show that these individual differences can be used to predict some future experiences of vection (i.e., visually induced illusions of self-motion—see Apthorp, Nagle & Palmisano, 2014; Palmisano et al., 2014). This study extends this recent vection research. It examines whether postural instability can be used to predict both the strength of the vection and the likelihood of motion sickness when participants are exposed to two different types of radially expanding optic flow display—simulating smooth forwards linear motion either with or without additionally bob and sway head motions. The study also compares the predictive power of both traditional summary CoP measures of postural stability (sway path and sway area) and new dynamic Recurrence Quantification Analysis (RQA) based measures (recurrence rates).

Method

Participants. Fifteen female students (mean age 20.9, SD = 1.6 years) participated in this study at the University of Wollongong. All had normal or corrected-to-normal vision and reported feeling well at the start of the experiment. They had not consumed alcohol in the last 24 hours and were not taking prescription medication. Experimental protocols were in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

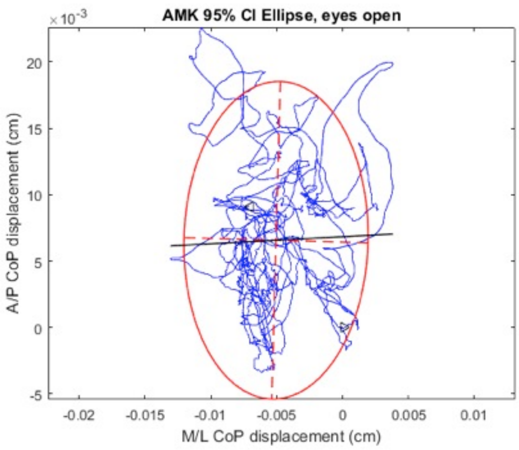

Fig. 1. Sway path (blue) and sway area (red ellipse) for participant AMK.

Displays. We examined two types of vection inducing display: (1) *smooth* radial flow; and (2) *oscillating* radial flow—simulating constant forwards self-motion with/without simulated head oscillation. Each optic flow display was presented for 30s. The dependent variables measured on each of these trials were: (a) the verbally rated vection strength from 0 (no vection) to 10 (strong vection); and (b) a verbal rating of sickness from 0 (no sickness) to 20 (to frank sickness) (using the Fast Motion Sickness Scale—see Keshavarz & Hecht, 2011).

Visual motion stimuli. Each display simulated self-motion through a 3-D cloud consisting of 3000 blue circular objects (cloud dimensions were 12.3 m wide × 5.8 m high and 13.1 m deep). All of the optic flow displays simulated 1.1 m/s forwards self-motion. Half of the displays also simulated combined horizontal (Amp 4.4 cm; freq 1 Hz) and vertical (Amp 2.2 cm; Freq 2 Hz) viewpoint oscillation.

Sway analyses. **Sway path length** was calculated as the total distance travelled by the CoP over each 60 s period of standing quietly (see blue trace in Fig. 1). **Sway area** was calculated as the 95% confidence ellipse around the region covered by the CoP over this same period (see red ellipse in Fig. 1).

Recurrence quantification analysis (RQA) was also conducted on the anterior-posterior and medial-lateral axis CoP data (using the Recurrence quantification toolbox for Matlab; see Li et al., 2004). The specific parameters used for the RQA were an embedding dimension of 8, a delay of 15, a minimum line length of 2, and a threshold of 0.6. Two (time-time) recurrence plots were produced for each 60 s period of eyes-open standing—one for sway along the anterior-posterior axis and the other for sway along the medial-lateral axis (see the left and right plots in Fig. 2. respectively). The **recurrence rate** (0-1) in each case corresponded to the correlation sum of the CoP (with the black regions in these plots indicating recurrent points).

Results

Display type effects on vection and sickness. As expected based on previous research, adding simulated viewpoint oscillation to radial flow displays was found to significantly

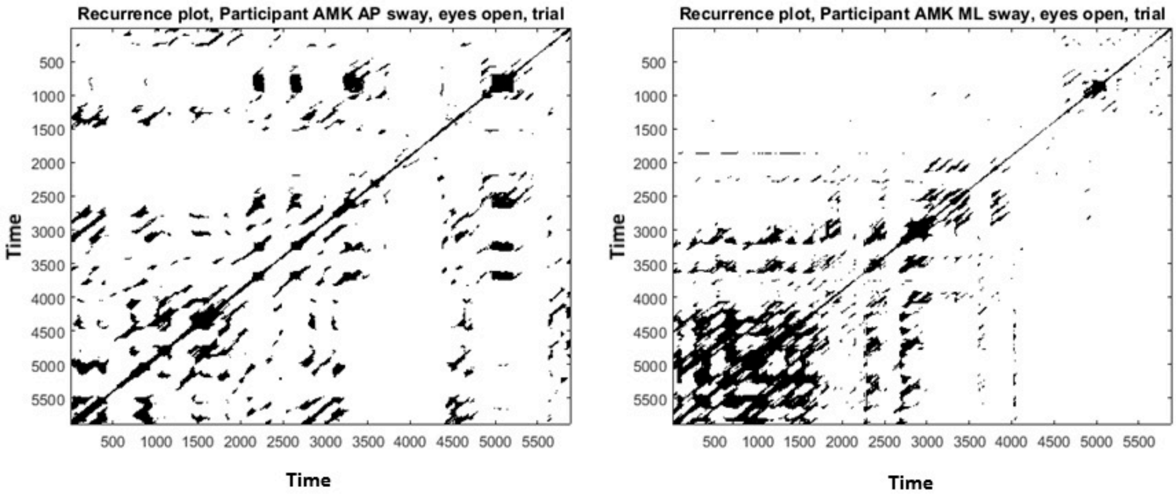

Fig. 2. Anterior-Posterior (left) and Medial-Lateral (Right) axis recurrence plots for participant AMK.

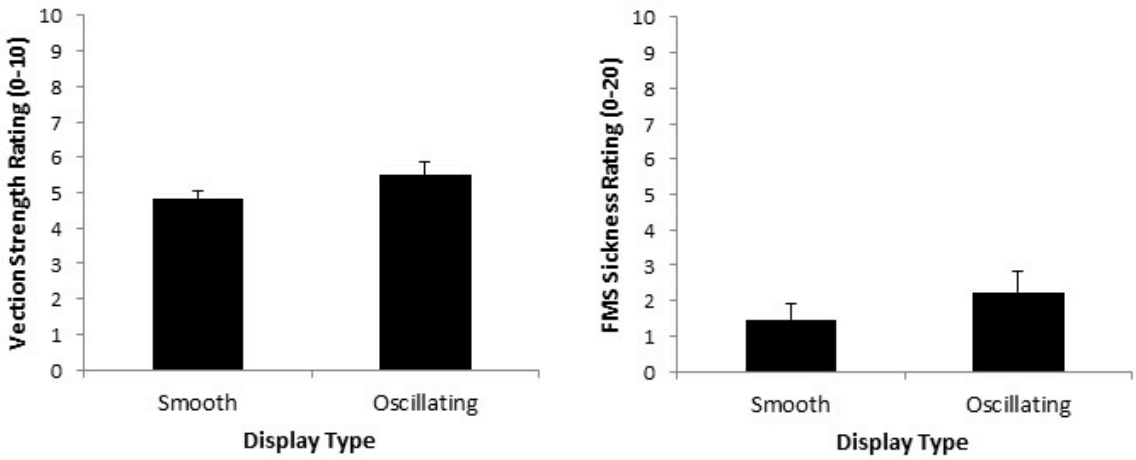

Fig. 3. Anterior-Posterior (left) and Medial-Lateral (Right) axis recurrence plots for participant AMK.

increase vection strength ratings ($t_{15} = 2.62, p = 0.02$) and increase sickness symptoms ($t_{15} = 2.59, p = 0.021$ see Fig.3 left and right) (see Palmisano et al., 2007; 2008; 2011).

Predicting vection from sway measures. Individual differences in sway path did not reliably predict the strength of either smooth or oscillating vection (both linear regressions analyses conducted were $p > 0.05$). As in earlier research by Apthorp et al. (2014), sway area was found to predict the strength of smooth ($R^2 = 0.37, t_{14} = 2.64, p = 0.02$), but not oscillating ($R^2 = 0.07, t_{14} = 0.91, p = 0.38$), vection. By contrast, the RQA based sway measures were able to reliably predict both types of vection (see Fig. 4.). Anterior-posterior recurrence rates were found to significantly predict the strength of the vection induced by smooth radial flow ($R^2 = 0.33, t_{14} = -2.53, p = 0.025$; Fig. 4 Left). Medial-lateral recurrence rates were found to significantly predict the strength of the vection

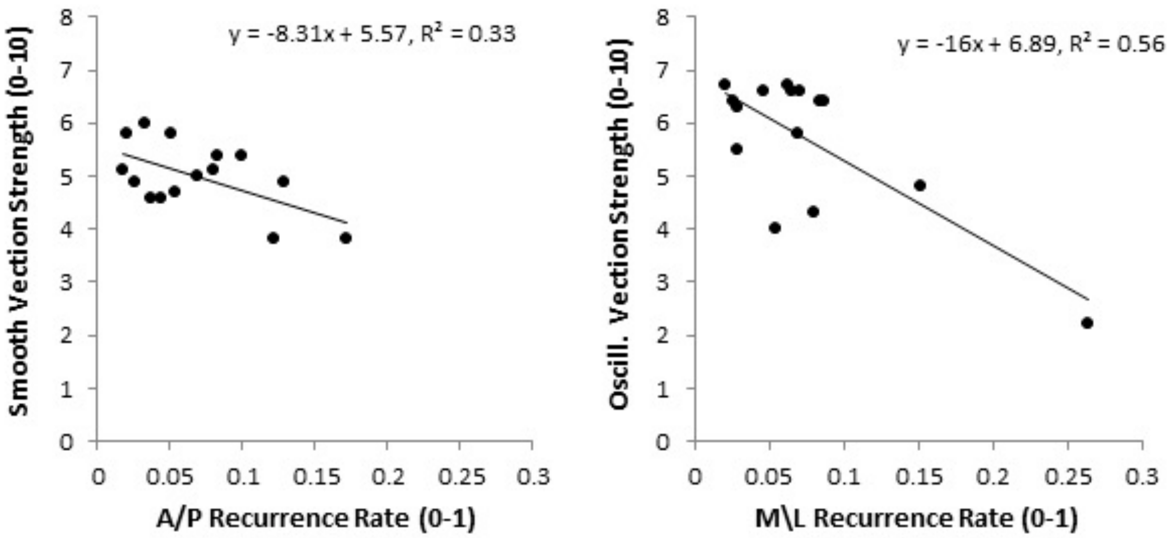

Fig. 4. Relationships between recurrence rates and vection strength ratings for smooth (left plots) and oscillating radial flow displays (right plots). The top plots show recurrence rates along the medial-lateral axis. The bottom plots show the recurrence rates along the anterior-posterior axis.

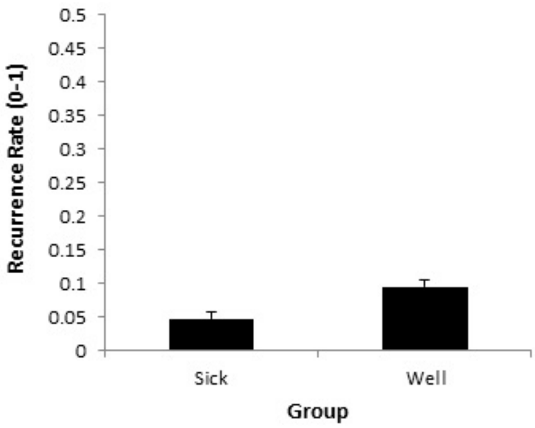

Fig. 5. Mean anterior-posterior recurrence rates during quiet stance for Well and Sick participants. Error bars depict standard errors of the mean (SEMs).

induced by oscillating optic flow ($R^2 = 0.56, t_{14} = -4.056, p = 0.01$; Fig. 4 Right).

Predicting sickness from sway measures. A between-subjects t-test revealed that participants who eventually became sick ($M = 0.05, SD = 0.013$) had significantly lower anterior-posterior recurrence rates than those who remained well ($M = 0.09, SD = 0.016$), $t_{14} = -2.36, p = 0.03$ (see Fig. 5.). While differences in sway path length also appeared to predict these 'sick' and 'well' groups ($t_{14} = -2.17, p = 0.047$), sway area did not ($t_{14} = -1.38, p = 0.19$).

Discussion

Recurrence rates were the most reliable predictor of future vection experiences and motion sickness. In this experiment recurrence rates predicted the strength ratings for both smooth and oscillating types of vection. Recurrence rates were also found to predict the likelihood of sickness when exposed to visual motion stimulation. Specifically, lower recurrence rates tended to be associated with stronger vection experiences and the increased likelihood of experiencing motion sickness. These findings suggest that individuals who display greater spontaneous instability (less recurrence) will be more prone to experiencing both vection and sickness. Consistent with this notion, the sway path lengths and sway areas of these individuals also tended to be larger (even if these effects did not always reach significance). Taken together these findings suggest that vection and visually induced motion sickness might be indirectly related to each other via the person's postural responses to the visually simulated self-motion.

Acknowledgements

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EFFECTS OF FOOT-STIMULATION (VIBRATIONS AND A WATER-FLOW) ON VECTION

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Abstract

The effects of foot-stimulation (vibrations and a water-flow) on the visually induced self-motion perception (vection) were examined in two experiments. The strengths of vection (latency, duration and magnitude) were measured when foot stimulation and/or visual oscillation were added to the visual optic flow simulating a forward self-motion. In Experiment 1, the vibrations were presented to observer's sole. It was very large individual differences in the effects of foot-vibration on vection. In some observers, vection could be facilitated by the foot-vibrations, in others it was inhibited. In Experiment 2, a water-flow from the front was presented to observer's feet. Although the foot-water-flow made the vection duration longer in all observers, the foot-water-flow facilitated or inhibited vection dependently on each observer's characteristics. These results suggest that the integration process between visual inputs and foot-stimulations might vary among individuals.

While vision contributes to the recognition of external world, vision play a major role in the self-motion perception and the body control. Mere exposure to a retinal optical flow induces an illusory self-motion perception, called vection (Palmisano, Allison, Schira, & Barry, 2015). Many sensory organs contribute to the self-motion perception. Vection can be facilitated by the combination of visual input and other sensory input (Shulte-Pelkun, Riecke, & Bülthoff, 2004; Riecke, Väljamäe, & Schulte-Pelkun, 2009; Seno, Ogawa, Ito, & Sunaga, 2011). Shulte-Pelkun et al. (2004) showed that the vection was facilitated by adding the vibration of seat and floor to visual stimulus. To examine effects of foot-stimulation (vibrations and a water-flow) on vection, we measured the strengths of vection when foot stimulation and/or visual oscillation were added to visual optic flow simulating a forward self-motion.

Method

Apparatus

Experiments were conducted in a dark room. The visual stimuli projected by a CRT projector (Christie Digital Systems, Marquee 8500/3D) were presented on a 100-inch rear-screen. The spatial resolution of the display were 1024 × 784 pixels and the refresh rate was 60 Hz. Observers sat at viewing distance of 0.7 m and fixed his/her head using a chin rest. The chromaticity of the visual stimuli was designed to provide dichoptic stimulation with red-blue anaglyph glasses. The foot stimuli (vibration and water-flow) were presented using an electric massager (Twinbird Inc., EM-B705BR) and an electric

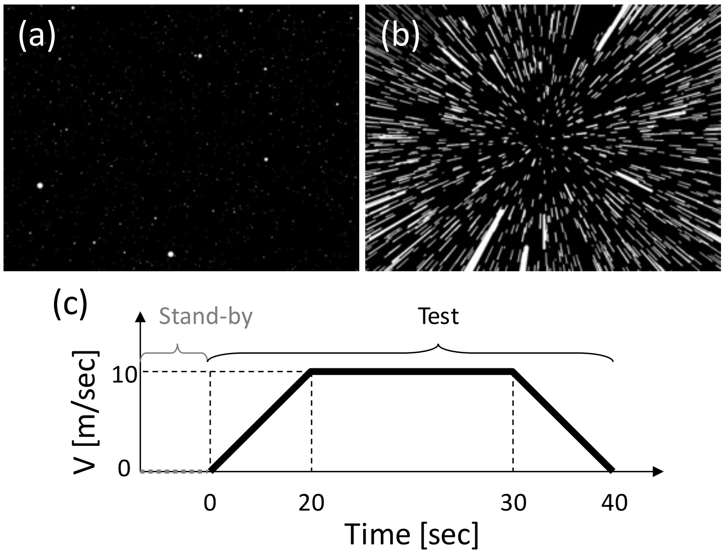

Fig. 1. Test stimulus. (a) Random-dot, (b) Expanding optic flow, (c) Translation profile.

foot bath machine (Alinco Inc., MCR7914), respectively.

Stimuli

Figure 1 (a) and (b) shows the visual stimuli. The discs were randomly placed in a virtual three-dimensional space spread from a screen to 28 meters away with the diameter of 9.9 cm and the density of 0.022 discs/m^3. The size and binocular disparity of discs were changed as a function of the distance from observers. The visual angle of the stimuli was 111 deg × 95 deg. The expanding optic flow simulating observer's forward translation were added to discs. This optic flow was started with an observer's key press, and the velocity of translation was modulated with the profile shown as Figure 1 (c).

In "with visual oscillation" condition, sinusoidal vertical oscillation was added to visual stimuli with the temporal frequency of 12.5 Hz and the amplitude of 5 cm (in a virtual space). Therefore, the closer dots moved larger.

In "with foot vibration" condition, the vibration was presented to observer's soles with the temporal frequency of 12.5 Hz. In the case of presenting both foot vibration and visual oscillation simultaneously, authors got the impression that the vibration and oscillation were synchronized even though they were not actually.

In "with foot water-flow" condition, the water-flow was presented to observer's feet in a toe-to-heel direction. In addition to the water-flow, micro-bubbles were emitted by a foot bath machine. The micro-bubbles were made for massaging one's soles. Although the detailed parameters of water-flow and micro-bubbles were unspecified, authors convinced that the water flowed from their toe to heel, and got the impression that the bubbles had an effect similar to but weaker than the foot vibration.

Procedure

We measured the vection strength using three vection indices, 1) subjective magnitude, 2) duration, and 3) latency. In one trial, firstly visual oscillation and/or foot stimulation were presented under the "with visual oscillation" and/or "with foot stimulation (vibration or water-flow)" conditions ("Stand-by phase" in the experimental profile shown as Figure 1 (c)). Secondly, observer pressed a key and started the optic flow display if they could ready for a trial.

We defined forty seconds from the beginning of a trial as the test duration. Observer responded the presence or absence of the self-motion perception using a key-press during the test duration. We also defined the time from the beginning of a trial to the first response as vection latency, and the sum of the time observer responded as vection duration. Finally, observer responded the subjective vection magnitude, ranging 0 (only discs moving) to 100 (only subject moving).

Experiments were divided into two parts, 1) foot vibration and 2) foot water-flow. Each part was designed on the two-by-two conditions composed of foot stimulation (without, with) and visual oscillation (without, with). We repeated each condition four times. The order of conducting four conditions was counterbalanced over the observers.

Subjects

Totally, 27 volunteers participated in the experiments. In preliminary experiment, two volunteers responded the very strong vection (magnitude = 100) regardless of experimental conditions, and two did not respond the vection at all (magnitude = 0). These four volunteers did not go on to the main experiment. Since another two volunteers always kept pressing the response key (latency = 0 sec or duration = 40 sec) in every trial, we decided that these two volunteers did not well know the procedure of the experiments, and omitted these two observers' data into analysis.

There were 18 volunteers who participated in the foot vibration experiment [mean age: 23.4 ± 4.2 (SD); range: 21–37 yr]. There were 16 volunteers (13 of 16 individuals who took part in the foot vibration experiment, and 3 individuals were new) who participated in the foot water-flow experiment [mean age: 22.6 ± 2.6 (SD); range: 21–33 yr]. No one except for the three (foot vibration experiment) or two (foot water-flow experiment) authors was aware of the purpose of the experiment.

Data Analysis

Vection data were analyzed with a three-way analysis of variance (ANOVA). The factors were 'Individuals', 'Foot stimulation (without, with)', and 'Visual oscillation (without, with)'. For all multiple comparison tests, Ryan's method was used.

Results and Discussion

Foot Vibration

The results for the three vection indices in the foot vibration experiment are shown in Figure 2 and Table 1. Figure 2(A) shows the vection magnitude. Under the control (without foot vibration and visual oscillation, NoVib-NoOsc for short) condition, middle-magnitude vection occurred. When either of foot vibration or visual oscillation was presented (Vib-NoOsc or NoVib-Osc), vection was inhibited. When both foot vibration and visual oscillation were simultaneously presented (Vib-Osc), vection magnitude was as much as that for NoVib-NoOsc condition. Three-way ANOVAs for vection magnitude

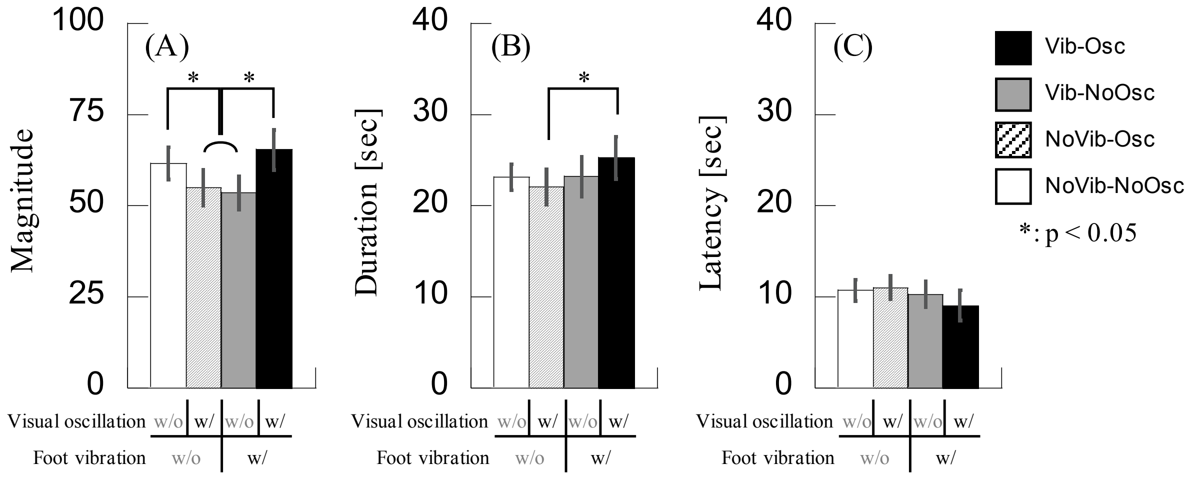

Fig. 2. Three vection indices in foot vibration experiment. (A) Magnitude, (B) Duration, (C) Latency.

Table 1. 3-way ANOVA results in foot vibration experiment.

		Magnitude		Duration		Latency	
	df	F	p	F	p	F	p
A: Individuals	17	16.700	****	14.405	****	7.015	****
B: Foot vibration	1	0.337		3.288	+	1.514	
C: Visual oscillation	1	1.660		0.005		0.085	
A*B	17	1.706	*	1.292		1.337	
A*C	17	4.096	****	2.550	****	1.592	+
B*C	1	22.557	****	3.978	*	1.804	
A*B*C	17	2.263	***	2.169	**	1.031	

+: p<0.1, *: p<0.05, **: p<0.01, ***: p<0.005, ****: p<0.001

confirmed a significant main effect of 'Individuals' ($P < 0.0001$) but not 'Foot vibration' and 'Visual oscillation' (respectively, $P > 0.1$). The interactions among 'Individuals', 'Foot vibration', and 'Visual oscillation' were significant ($P < 0.05$).

Figure 2 (B) shows the vection duration. The longest was Vib-Osc condition, followed in order by Vib-NoOsc, NoVib-NoOsc, and Vib-NoOsc condition. The results of three-way ANOVAs were similar to that for vection magnitude.

Figure 2 (C) shows the vection latency. The shortest was Vib-Osc condition, followed in order by Vib-NoOsc, NoVib-NoOsc, and Vib-NoOsc condition. Three-way ANOVAs for vection latency confirmed a significant main effect of 'Individuals' ($P < 0.0001$) only. As described above, the vection strength differed greatly in individuals. Especially, the effect of foot vibration and visual oscillation depended on individuals. To focus the individual differences, Figure 4 (A) shows the each individual vection magnitude data. These vection magnitude were normalized by the data of the control (NoVib-NoOsc) condition. Plus and minus values correspond to the vection facilitation and inhibition, respectively.

The visual oscillation (NoVib-Osc condition) hardly facilitated vection. This is inconsistent with previous studies showing that the visual oscillation facilitates the vection (Palmisano, Gillam, & Blackburn, 2000; Palmisano, Bonato, Bubka, & Folder, 2007; Palmisano, Allison, & Pekin, 2008; Nakamura, 2010; Nakamura, 2013). The difference between our experiment and previous studies was the amplitude and frequency of the visual oscillation. Previous studies used the visual oscillation with relatively lower frequency and larger amplitude ([Palmisano et al. (2007), 1.8–7.4 Hz, 4.5 deg], [Palmisano et al. (2008), 1/7 Hz, 37 deg], [Nakamura (2010), 1 Hz, 12 deg], [Nakamura (2013), 1 Hz, 7.5 deg]). The visual oscillation we used was relatively higher frequency (12.5 Hz) and smaller amplitude (2.9 deg at maximum). These parameters of the oscillation might be not effective for vection facilitation.

The foot vibration (Vib-NoOsc condition) inhibited vection for six observers (#4, 6, 11, 14, 15). This is inconsistent with previous studies showing that the vibration stimulus facilitates the vection (Farkhatdinov, Ouarti, & Heyward, 2013; Riecke, Schulte-Pelkum, Cainard, & Bülthoff, 2005). While previous studies used the vibration with the higher frequencies ([Farkhatdinov et al. (2013), 90 Hz (sinusoidal) and 70–110 Hz (chirp)], [Riecke et al. (2005), 15–90 Hz (the broad-band vibration of the seat and floor)], the frequency we used was very low (12.5 Hz). It may need the vibration with the higher frequency to facilitate vection. On the other hand, after the experiment, some observers reported that they had to pay attention to the sounds that the foot massager emitted. The foot device generating sounds might decrease the observers' immersion to the visual stimuli and inhibit the vection.

The simultaneous presentation of foot vibration and visual oscillation (Vib-Osc condition) had different effects on each observer. The foot vibration and visual oscillation facilitated vection for four observers (#1, 2, 4, 6) but inhibited vection for two observers (#17, 18). In the third experiment of Riecke et al. (2005), three out of twenty-four observers reported that the vibration did not match the velocity profile of the visual motion. For these observers, vection was inhibited. Although our result is consistent with that of Riecke et al. (2005) in that the ways to associate the vibration and visual motion differs in individuals, there were few observers who showed the vection facilitation in our experiment. The difference between two studies might be due to the difference of visual stimulus. Riecke et al. used the photorealistic image of the Tübingen market place including a cobbled pathway. It seemed relatively easy for their observers to imagine that the vibration occurs when the vehicle she/he ride run on the cobbled pathway. However, it was difficult for our observers to evoke that the vibration occurs when observer's body translation with the randomly-distributed discs we used. This discrepancy should give rise to the difference between two studies.

In the foot vibration experiment, it is revealed that simply adding the foot vibration or equalizing the frequencies of the foot vibration and the visual oscillation cannot facilitate the vection.

Foot Water-Flow

The results for the three vection indices in the foot water-flow experiment are shown in Figure 3 and Table 2. Figure 3 (A) shows the vection magnitude. Under the control (without foot water-flow and visual oscillation, NoWF-NoOsc for short) condition,

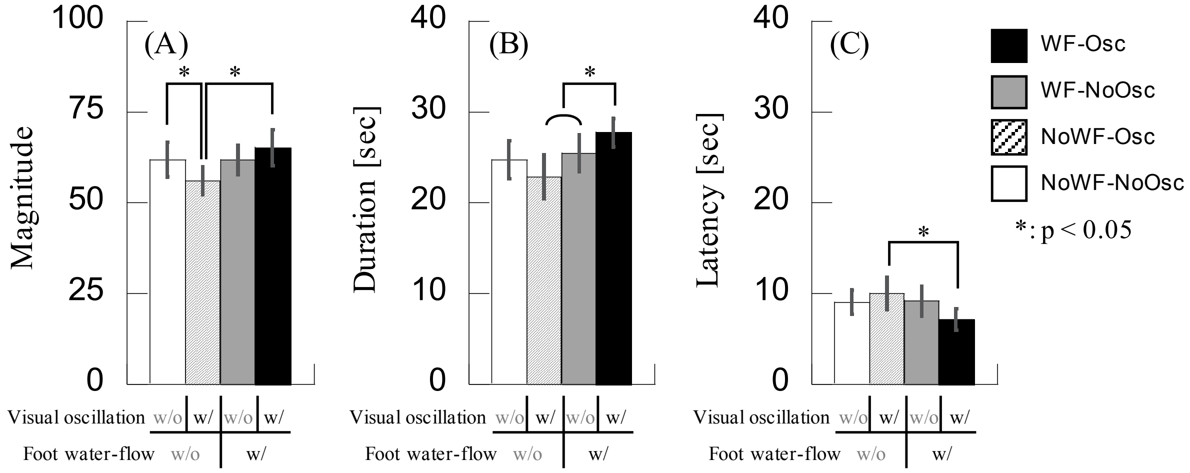

Fig. 3. Three vection indices in foot water-flow experiment. (A) Magnitude, (B) Duration, (C) Latency.

Table 2. 3-way ANOVA results in foot water-flow experiment.

		Magnitude		Duration		Latency	
	df	F	p	F	p	F	p
A: Individuals	15	8.189	****	22.685	****	13.152	****
B: Foot water-flow	1	4.681	*	13.618	****	3.397	+
C: Visual oscillation	1	0.357		0.059		0.465	
A*B	15	3.753	****	2.195	**	1.101	
A*C	15	3.915	****	2.475	***	1.44	
B*C	1	4.810	*	7.921	**	4.216	*
A*B*C	15	1.828	*	2.091	*	1.701	+

+: p<0.1, *: p<0.05, **: p<0.01, ***: p<0.005, ****: p<0.001

middle-magnitude vection occurred. When visual oscillation was presented (NoWF-Osc), vection was inhibited. When both foot water-flow was presented (WF-Osc), vection magnitude was as much as that for NoWF-NoOsc condition. When both foot vibration and visual oscillation were simultaneously presented (WF-Osc), largest magnitude vection occurred. Three-way ANOVAs for vection magnitude confirmed a significant main effect of 'Individuals' ($P < 0.0001$) and 'Foot water-flow' ($P < 0.01$) but not 'Visual oscillation' (respectively, $P > 0.1$). The interactions among 'Individuals', 'Foot water-flow', and 'Visual oscillation' were significant ($P < 0.05$).

Figure 3 (B) shows the vection duration. The longest was WF-Osc condition, followed in order by WF-NoOsc, NoWF-NoOsc, and WF-NoOsc condition. The results of three-way ANOVAs were similar to that for vection magnitude.

Figure 3 (C) shows the vection latency. The shortest was Vib-Osc condition, followed in order by WF-NoOsc, NoWF-NoOsc, and WF-NoOsc condition. Three-way

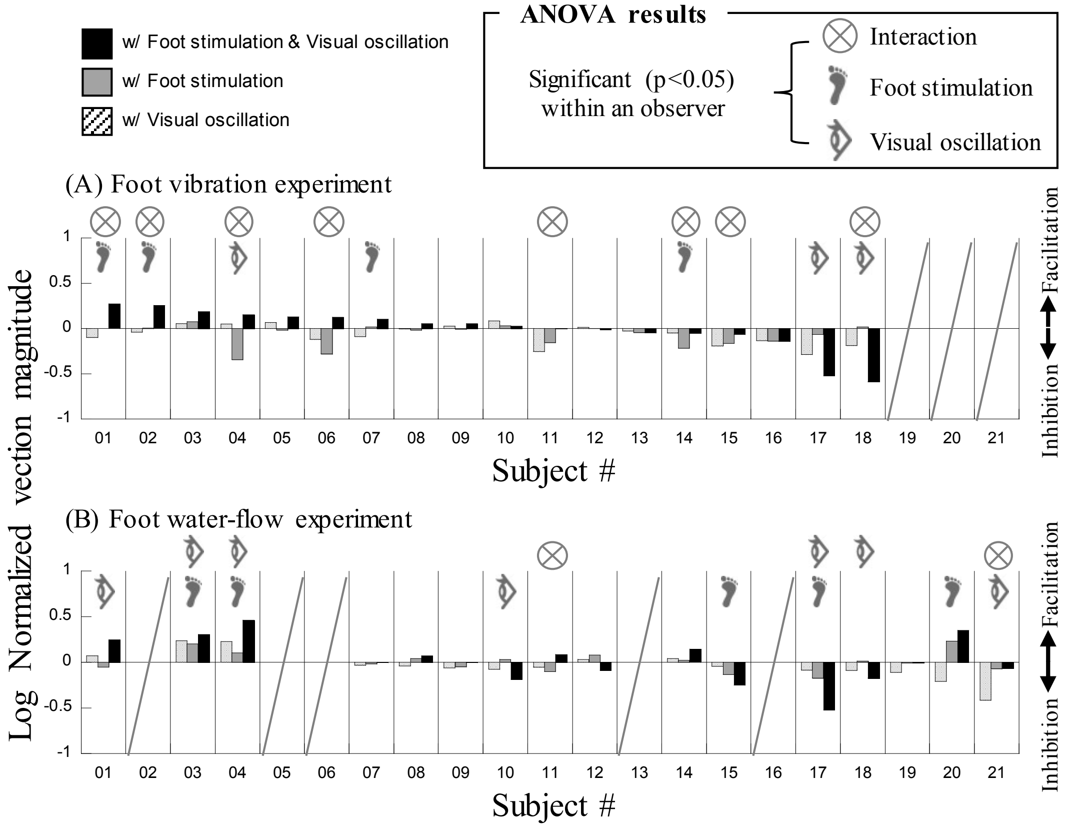

Fig. 4. Three vection indices in foot water-flow experiment. (A) Magnitude, (B) Duration, (C) Latency.

ANOVAs for vection latency confirmed a significant main effect of 'Individuals' ($P < 0.0001$) only.

The water-flow slightly enhanced vection magnitude and elongated vection duration on the whole data of the all observers. However, the effect of foot water-flow and visual oscillation differed greatly in individuals as well as the foot vibration experiment. To focus the individual differences, Figure 4 (B) shows the each individual vection magnitude data.

The visual oscillation (NoWF-Osc condition) hardly facilitated vection except for two observers (#3, 4). This is inconsistent with the foot vibration experiment.

The foot water-flow (WF-NoOsc condition) inhibited vection for three observers (#3, 4, 20). As well as the foot vibration experiment, since the foot bath machine generated relatively loud sounds, this might decrease the observers' immersion to the visual stimuli and inhibit the vection. On the other hand, while the water-flow's strength was constant, the simulated forward translation speed was changed. Due to this discrepancy, vection might be not facilitated.

The simultaneous presentation of foot water-flow and visual oscillation (WF-Osc condition) had different effects on each observer. The foot water-flow and visual oscillation facilitated vection for four observers (#1, 2, 4, 20) but inhibited vection for four observers (#10, 15, 17, 18). The observers that the vection was facilitated or inhibited were roughly consistent with the foot vibration and water-flow experiment. The way in which observers integrate the foot and visual stimulation may not depend on the type of foot stimulus.

Summary

The effects of foot-stimulation (vibrations and a water-flow) on the visually induced self-motion perception (vection) were examined. The strengths of vection were measured when foot stimulation and/or visual oscillation were added to the visual optic flow simulating a forward self-motion. In Experiment 1, the vibrations were presented to observer's sole. It was very large individual differences in the effects of foot-vibration on vection. In some observers, vection could be facilitated by the foot-vibrations, in others it was inhibited. In Experiment 2, a water-flow from the front was presented to observer's feet. Although the foot-water-flow made the vection duration longer in all observers, the foot-water-flow facilitated or inhibited vection dependently on each observer's characteristics. These results suggest that the integration process between visual inputs and foot-stimulations might vary among individuals.

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