Tactile Apparent Motion Presented from Seat Pan Facilitates Racing Experience

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Abstract. When moving through the world, humans receive a variety of sensory cues involved in self-motion. In this study, we clarified whether a tactile flow created by a matrix of vibrators in a seat pan simultaneously presented with a car-racing computer game enhances the perceived forward velocity of self-motion. The experimental results show that the forward velocity of self-motion is significantly overestimated for rapid tactile flows and underestimated for slow ones, compared with only optical flow or non-motion vibrotactile stimulation conditions.

Keywords: Tactile flow, Optic flow, Multisensory integration.

1 Introduction

In chair-like vehicles, humans generally detect velocity information using visual cues and detect acceleration and angular acceleration information using mechanical cues (vestibular and tactile sensations). The authors have been focusing on developing multisensory displays, such as vestibular and tactile displays, to facilitate self-motion perception in a vehicle-based VR system [2,18,3], which present multiple modality stimuli to produce a subjective realistic experience [12].

A stationary observer often feels subjective movement of the body when viewing a visual motion simulating a retinal optical flow generated by body movement [22]. Gibson concluded that a radial pattern of optical flow is sufficient for perceiving the translational direction of self-motion [9]. In virtual reality environments, not accurate speed but differences in locomotion speed are perceived from an optical flow [4,5]. The self-motion generated by the optic flow is further facilitated by adding a sound moving around the user [17], a constant flow of air to the user's face [19], or simple vibrotactile cues from a seat [16,7]. Even when tactile and visual stimuli indicate motions in different directions, sensitivity to motion can be improved [10]. When consistent somatosensory cues are added to

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the hand (a sustained leftward pressure on a fist for rightward visual rotation), the cues also facilitate vection [15].

The conventional tactile seat vibration approach has been used for directing visual attention or displaying directional information [21,11,13]. For example, Tan et al. developed a 3×3 tactile matrix display built into a back rest or seat to provide directional or way-finding information [21]. Hogema et al. conducted a field study with an 8×8 matrix of tactors embedded in the seat pan in car to indicate eight different directions [11]. Israr and Poupyrev proposed an algorithm to create a smooth, two-dimensional tactile motion for a 4×3 tactile matrix display and applied it to computer games [13]. Our approach is different from these previous studies in that we focus on the tactile seat vibration approach to create a forward velocity change of self-motion.

The actuators in most tactile matrix displays are arranged sparsely. However, the apparent motion, the illusory perception of motion created by the discrete stimulation of points appropriately separated in space and time, can be experienced between pairs of touches, as well as pairs of lights or sounds. With the stimuli generating optimum apparent motion, the user would not perceive two discrete tactile stimuli but rather a single moving tactile stimulus between the two, regardless that the tactile stimulus is not actually moving on the surface of the skin [6,8]. The tactile apparent motion is elicited with two main parameters: stimulus duration and the inter-stimulus onset interval (ISOI, often referred as stimulus onset asynchrony: SOA [14]) between onsets of subsequent tactile stimuli [20]. Both parameters determine the velocity of illusionary movement. In our study, we used seat vibration to provide a velocity cue of self-motion, which was varied by changing the ISOI between the onsets of sequentially activated rows of vibrators.

2 Experiment: Tactile Flow with Car Racing Video Game

To test the feasibility of enhancing perceived forward velocity of self-motion in a virtual environment, we conducted an experiment using ten-second videos of a car-racing computer game with our tactile feedback device. We also evaluated the perception of moving forward velocity using an expanding radial flow motion in peripheral vision and a tactile flow from a seat pan. In both experiments, participants viewed optical stimuli while gazing at a fixation cross and sitting on a tactile stimulator on the seat pan and rated their perceived forward velocity by using the method of magnitude estimation.

2.1 Method

Six participants (three males and three females; 18-35 years old) participated. Recruitment of the participants and the experimental procedures were approved by the NTT Communication Science Laboratories Research Ethics Committee, and the procedures were conducted in accordance with the Declaration of Helsinki. None of the participants was aware of the purpose of the experiment.

The tactile stimulator is composed of twenty voice-coil motors arranged in a 4 × 5 grid and an aluminium plate (196-mm long × 245-mm wide × 3-mm thick, A5052P) with holes. The voice-coil motor is a full-range speaker (NSW2-326-8A; Aura Sound Inc.), and presents stronger stimuli in a wider area than conventional eccentric rotating mass vibration motors. Each voice-coil motor was attached to pin-arrays made of ABS resin and vibrated sinusoidally at 50 Hz for 200 ms of stimulus duration. The pins popped up from the holes and vibrated vertically. Five voice-coil motors in the same lateral line were driven together by a computer with D/A boards (DA12-16(PCI) and DA12-8(PCI); CONTEC Co., Ltd.) and a custom-made circuit (including an amplifier). They were sequentially activated with a constant interval, which created a tactile motion from front to back. We varied the ISOI (100, 200, or 300 ms) to change the velocity of the tactile flow. In the conditions where the ISOIs were greater than the stimulus duration (200 ms), there was a blank interval between tactile stimuli. In addition, we used two control conditions for tactile flow: a non-motion random vibration (five vibrators out of twenty randomly and successively activated with a 200-ms duration and 200-ms ISOI); no vibration (i.e., vision-only condition).

Participants were seated on the center of the tactile device. One side of the tactile device was parallel to the monitor. They were instructed to keep their heads on a chin rest as shown in Fig. 1. The participants observed the stimulus binocularly. Participants wore an earmuff (Peltor Optime II Ear Defenders; 3M, Minnesota, USA) to mask the sound of the tactile device. Subjects were instructed to watch the fixation cross shown at the center of the stimulus display during the trial. The standard stimuli consisting of visual motion were presented for ten seconds. After a two-second pause, the test stimuli consisting of visual and/or tactile motion were presented for ten seconds. During the experiment, the experimental room was darkened. No lighting other than the monitor was present in the room.

A recorded video of a car-racing computer game (TORCS; The Open Racing Car Simulator [1]) was presented as a visual stimulus. The video gives a first-person perspective while driving the car on a straight stretch of a racing track. The playback speeds of the video were changed (133%, 100%, or 66%), and then the length of the videos were set to identical lengths (ten seconds). A fixation cross was always shown at the center of the video, and the participant was instructed to gaze at it during the trial. In the video, there were some cues related to optical flow, such as road texture, signboards on a wall, and some buildings. Figure 2 shows the temporal sequence of the experiment. The participants' task was to estimate the velocity of self-motion. Two trials were conducted for each condition. The presentation order of the fifteen conditions (five tactile conditions × three video playback speeds) was pseudo-randomized.

Visual stimuli of control condition were radial expansions of approximately 1,000 random dots in each frame, simulating a translational motion. The dots had a diameter changing from six pixels (corresponding to 0.5 degrees) to thirty pixels (2.5 degrees) according to the distance from the center. The visual stimulus images (1,024 × 768 pixel resolution at 60-Hz refresh rate) were presented on

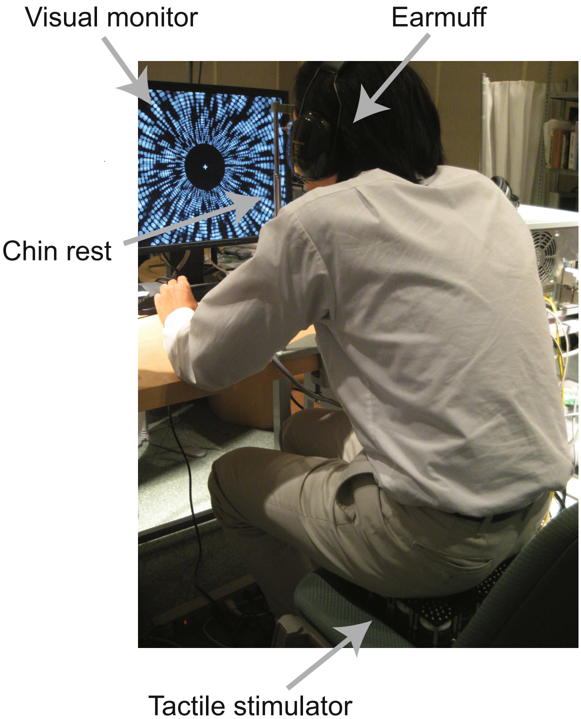

Fig. 1. Configuration of the experimental apparatus. The subject was instructed to sit on the tactile stimulator and gaze at the fixation cross at the center of the monitor. The distance between the monitor screen and the subject's face was 30 cm. Experiments were performed in a darkened room.

a 21.3-inch LCD screen (Iiyama Inc.). The images subtended a visual angle of 72 deg (horizontal) $\times$ 57 deg (vertical) at the viewing distance of 300 mm. The central circular area of the diameter of 20 degrees was masked with a black background in such a way that the moving dots were presented only outside the circular border. The velocity of the expanding optical flow was changed from 80% to 120% of the standard stimulus.

2.2 Results and Discussion

Figure 3 shows the averaged values (geometric mean) obtained by magnitude estimation. The perceived velocity of self-motion was facilitated by both the velocities of the tactile motion and the video playback, which is consistent with the result of the control condition using the random dot pattern. At 133% video playback speed, the perceived velocity of self-motion increased as the ISOI of the tactile flow decreased (i.e., increased with the speed of the tactile flow). In addition, the perceived velocity under the random vibration condition was

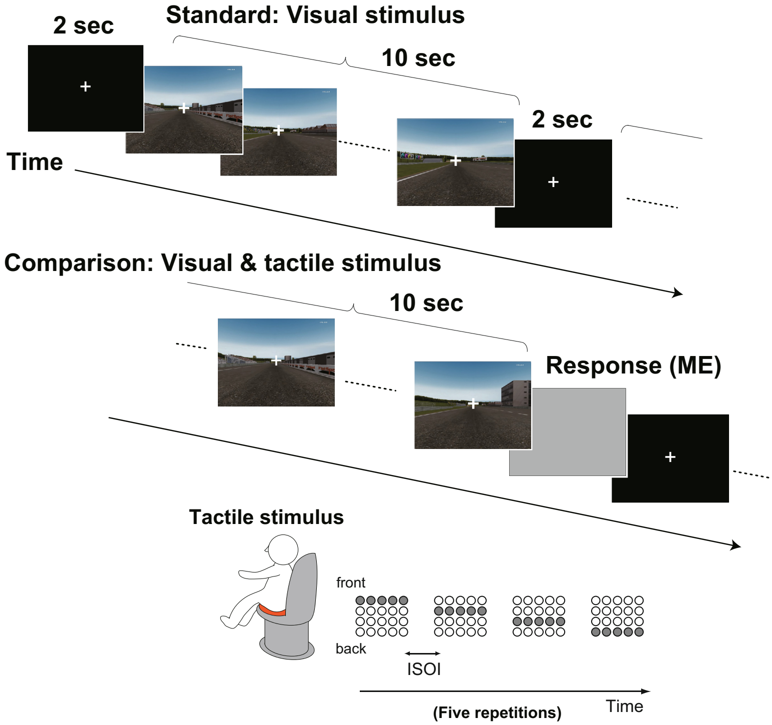

Fig. 2. Temporal sequence. A 10-sec video of a car-racing computer game was used as a visual stimulus. The video playback speed was altered. The tactile stimulus was consisted of four successive rows of vibration. The inter-stimulus onset interval (ISOI) between the tactile rows was varied to measure the effect on the perceived velocity of self-motion. Participants had to report numerically their perceived velocity relative to the standard in a magnitude estimation.

smaller than others at 133% video playback speed, perhaps because the tactile stimuli of random vibration were not consistent with self-motion. On the other hand, at 66%, there was not any clear difference across the tactile conditions.

To quantitatively evaluate the difference between the conditions, we conducted a two-way repeated measures ANOVA for magnitude estimation values. The analysis revealed significant main effects of the video playback speed condition [$F(2,10)= 33.68$, $p <.001$, $\eta_p^2=.87$]. But the main effect of the tactile condition was not found [$F(4,20)= 2.01$, $p=.13$, $\eta_p^2=.29$, n.s]. There was no significant interaction between the video playback speed condition and tactile condition [$F(8,40)= 0.27$, $p=.97$, $\eta_p^2=.05$, n.s]. These results indicate that tactile apparent motion on a seat pan did not facilitate the perceived forward velocity of self-motion in a racing game application as much as it did with expanding random dot pattern stimuli. Future work includes conducting further experiments with more participants to show the effect more correctly.

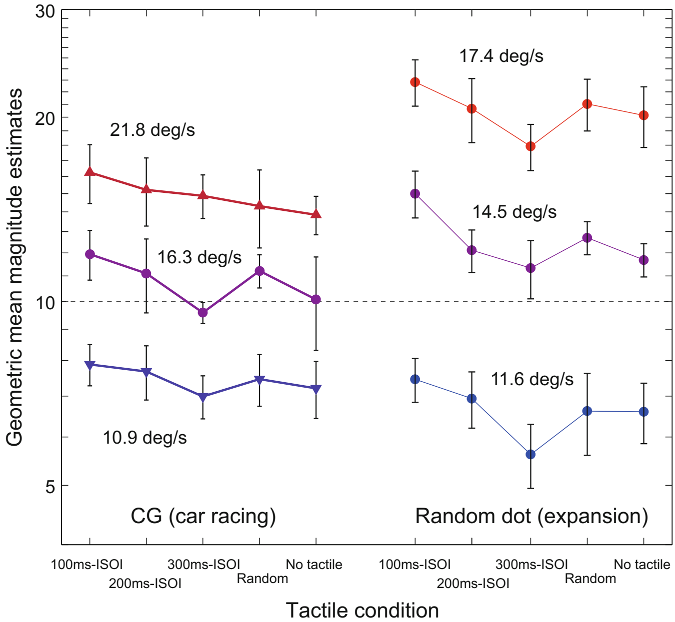

Fig. 3. Magnitude estimation for forward velocity as a function of ISOI of the tactile stimuli (left: CG, right: random dot pattern). Each dot represents the geometric mean value across participants. Error bars show SEs.

3 Conclusion

In this paper, we have shown experimentally a change in perceived forward velocity of self-motion caused by changes in the speeds of the tactile apparent motion on a seat pan. When visual and tactile flows that simulate forward moving are presented simultaneously, the quicker tactile motion stimuli enhanced the perceived forward velocity of self-motion and the slower ones inhibited it. In contrast, almost no change in velocity perception was observed when a tactile stimulus without motion cues was presented together with an optic flow. Finally, we confirmed that the method using tactile flow on the seat pan can be applied in a car-racing computer game. So far, the method seems to change the perceived velocity a bit but not to function as well as when a simple expanding optic flow is presented.

Future work will investigate whether it is possible to change the perceived velocity by changing the stimulus duration or the intensity of tactile stimuli. We will also examine the effect of the perceived change in moving velocity with contraction of the random dots or backward motion of tactile flow.

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