Sensory Integration Model of Pedestrian by Vection and Somatosensory Stimulation

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Abstract
In this study, we clarify the integration mechanism of sensory information of vision and somatosensory sensation in walking. In this experiment, we evaluated the possibility of affecting walking by attenuating a somatosensory sensation by giving vibration stimulation to the feet, and by presenting optic flow to the peripheral visual field to generate a self - motion sensation of vision superiority. Experimental results confirmed that walking in the direction opposite to the self - motion sensation is presented by presenting the optic flow and vibration stimulation. Based on the results of this experiment, we propose that sensory devices such as vision and somatosensory sensation are not exclusive in walking, but are integrated by superposition.

Keywords: Pedestrian Guidance, Vection, Somatosensory, Sensory Integration, Peripheral Vision Display

1 Introduction

In recent years, development of walking navigation technology to avoid various risks during using mobile devices has been desired. As a current walking navigation technology, it depends on visual information obtained from explicit instruction information such as signs and arrows. However, there are many illusions such as "When sending wind to the face of a stationary subject watching a image, the illusion that the subject is moving forward is strengthened[5]", "When a next train starts to move, the stationary subject feels moving in the opposite direction ". Not only explicit information but also possibility of pedestrian guidance by implicit input from various sensor such as vision, somatosensor, tactile, equilibrium, etc. are conceivable. However, it is not necessarily clear from the viewpoint of the integration between these senses and the characteristics of the sensory-motor system as to how these implicit stimuli influence our walking.

As an example, a research using optic flow in a direction 90 degrees orthogonal to the traveling direction was reported, and it was impossible to induce walking such as detecting a statistically significant difference although induction of standing condition was possible[8]. Watanabe and colleagues have succeeded in causing a certain amount of walking induction effect by presenting of optic flow causing lateral self-movement sensation to peripheral visual field and suppressing of self-movement sensation of somatosensory [6]. In this regard, Lishman reports that vision, somatosensory, vestibular, etc. have an influence on self-movement sensation but vision prevails over other senses[3]. However, if "exclusive integration" gives visual dominance over other senses, pedestrian guidance should be possible without reduction processing of self-motion sensation caused by somatosensory. However, there are no such reports in Watanabe's research. They presented lateral optic flow stimulation to own forward walking, whereas Lishman deals only with forward and backward movements (opposite self-motion perception). Differences in this experimental condition are conceivable.

In addition, Watanabe used eight compact disk type motors weighing less than 1g as a vibration stimulus device, but each motor was independent, the vibration phases did not match and the gain of vibration was small. To realize effective guidance, it is considered necessary to present stronger vibrations such as using a single vibration motor. Furthermore, because the fixed motion capture device was used to measure the subject 's movement, the measurement range was narrow. And the induction effect could be confirmed but it was not clear how long the effect of the phenomenon would continue[6].

Therefore, in this research, we measure the pedestrian guidance that improves precision and reliability. Improvements from previous research are as follows.

1. Extend walking time from a few seconds to a few tens of seconds (because walking is slightly unstable for a few seconds of walking start).
2. Change from "toe" to "heel" as the position measurement part (it seems that fluctuation in the lateral direction is small).
3. Switch an optic flow in the lateral direction of striped stimulus figure so as to move an optic flow of rectangular stimulus figure from forward direction to lateral direction (to make the figure of forward and backward movement and the lateral movement the same).
4. Two panels placed on the side are not used for stimulus presentation (as it is an optic flow of rotational motion rather than optic flow of lateral movement).
5. Late the speed of visual stimulus from 157 deg/s to 65.5 deg/s.
6. Changed from 1g small disk type vibration motor to 1 larger vibration motor.
7. Change to image measurement that extracts the difference value (slope gradient) for each step on the same side from the absolute position measurement by motion capture.
8. Compare the data for a relatively long period before and after optic flow presentation.

By conducting experiments based on these improvements, we aim to elucidate the relationship between sensory consciousness related to pedestrian guidance and self - motion sensation and walking control.

2 Sensory Integration Affecting Walking

Walking behavior is not just a foot movement.At least our senses accompany our walking.

- Interaction between the ground and the foot (force sensation of the sole)
- Physical perception in which a foot moves and supports the body (somatosensory)
- Optic flow of the object in the visual field due to its own movement (vision)
- Perception of body swaying and tilting (equilibrium)
- Perception of sound accompanying movement (hearing)

We control the walking movement as a whole of them and realize the intended movement.

There is no problem if self-motions obtained from each sensation are consistent with each other, but inconsistency often occurs. As another example of presenting an optic flow different from self-motion sensation, Dichigans and colleagues presented various motion visual stimuli in a state where the subject was stationary and investigated the occurrence of self-movement[1]. As a result, when a motion visual stimulus is presented in the central visual field, the motion of objects is observed, and the self-motion sensation hardly occurs. But when the motion visual stimulus is presented to the site including the peripheral portion of the visual field, a self-motion sensation (vection[4]) occurs. And in the case where the movement speed of the visual stimulus was fast (> 90 deg/s), a feeling of both the object and the self-movement occurred. There are reports that it is better to have a lower speed to generate a self-motion sensation, and that a longer stimulation presentation time is better to generate a self-motion sensation.

There are many studies from diverse sensory inputs to decision of walking behavior, but at present many of them are limited to phenomena reports, and few are going into the internal process of action decision. Therefore, in this research, we aim at elucidating the internal processes leading from sensory input to behavior decision by more detailed experiments, especially the characteristics of sensory integration in self-motion sensation.

3 Pedestrian Guidance Experiment Using Peripheral-Vision Display and Vibration Device

We evaluated a method for inducing a change in walking direction by presenting an optic flow stimulus to control subject's gaze direction and self-motion sensation, together with a vibratory stimulus to the leg. The presentation of optic flow stimulus creates an illusion that the body is moving in a opposite direction to that of the flow.

3.1 Methods

We used HMD type peripheral-vision display (Fig.1) as a visual stimulator and "Bururu"(Alfax) as body sway stimulation device.

Peripheral-vision display has six liquid crystal panels (four 3.5-inch panels on top and bottom, two 2.5-inch panels on left and right). The pixel number of six liquid crystal panel eachs is 320×240. Left and right panels are disposed 30 degrees outside the stable fixation field of 90 degrees, and top and bottom panels are disposed 30 degrees outside the stable fixation field of 40 degrees.

We create visual stimuli which displayed images of three types on a PC, and output the HMD through three screen output adapters. Through two distributing the stimuli, and then output each of six panels. In this experiment, in order to provide optic flow of left and right for pedestrians using four vertical panels except for output of left and right panels. In addition,

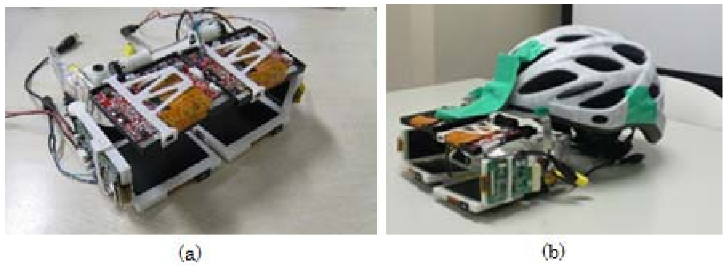

Figure 1: HMD type peripheral-vision display. (a) peripheral-vision display, (b) peripheral-vision display that is mounted on a helmet

for avoiding the deviation of view field by vibration during walking, and we fixed the panels on a helmet.

3.2 Visual and Vibration Stimulus

Optic flow was presented in each panels and flow was drawing blue dots with a black background (blue: black = 1:3). In peripheral vision away 25 deg or 45 deg from the center, a higher sensitivity was shown to short wavelength light such as blue (100,000 times the sensitivity of the blue of central vision and 10,000 times as compared to that of the highest sensitivity)[7]. So we used optic flow stimulation of blue and black. Visual stimuli is moved constant speed in a direction of either up, down, right and left (466pixel/sec, 65.5deg/sec).

Calf type of "Bururu" (16x13x4 cm, 95g, 30Hz) are worn to tibialis anterior muscle and foot type (11x9x4 cm, 80g, 30Hz) are worn to extensor digitorum brevis muscle of a subject.

Subject walks in front wearing vibration devices "Bururu" and HMD device. Presentation timing of visual stimuli are following two. During whole walking distance, we presented radial optic flow that occurs when a pedestrian to move forward (control condition). As another condition, we presented right and left optic flows (optic flow when traveling from 5 seconds later during about 8th step) to arrive (target condition) (Fig.2).

Note that we presented a stimulus to 5 seconds later as a time of stable walking in this experiment. Subject was conducted four times above two conditions. In step forward right foot twice and other step forward left foot, walking distance was 15m. Then we used as experimental data to 22 steps from start walking. Subject wore markers on their malleolus and we analyze this experiments using a movie that was taken by a video camera put on 2m back from the start line. The vibration stimulus was presented simultaneously with the commencement of walking. Subjects were three 20 years old male.

4 Results

In experiments coordinates of landing points of each step was measured from a walking movie. Furthermore, we got from the center line of every step by geometric computation method (distance of i-th = d_i). Even going to walk forward, subject do a little tilted walk along a straight line. Because there are variations in each trial, tilted walk was uniformalization. We evaluated a difference value between previous foot position and current foot position on the same side.

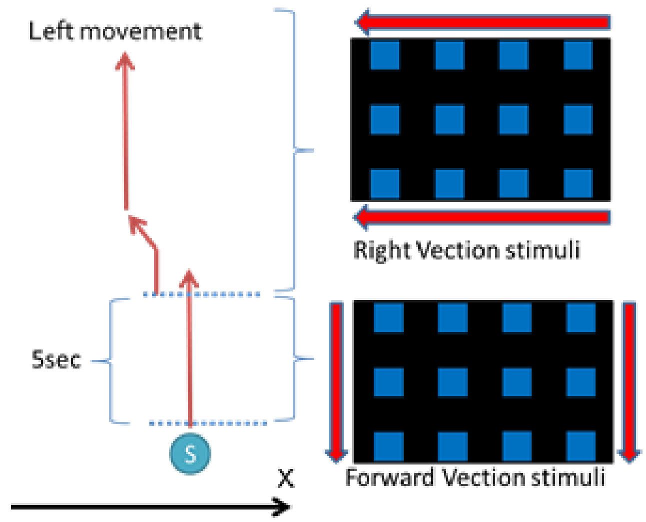

Figure 2: Visual stimuli and presentation timing in target condition

$$\delta_i = \frac{\sum_{i=1}^{N}(d_i - d_{i-2})}{N} \tag{1}$$

$$\Delta_i = \delta_i^{left} - \delta_i^{straight} \tag{2}$$

When lateral vection occurs by switching to a optic flow in the horizontal direction and inclination of walking direction is changed, a difference value is moved in the vertical direction. This should not change the difference between a value of without vection (control condition). The difference between control data should relieve an average distortion various caused by walking. It should be noted that we try out for unstable very few steps after the start.

Fig.3 shows difference values with left and right data of four traials average values in number of each steps($N = 4$). X-axis is number of subject's steps, Y-axis is difference value (δ_i) between previous foot position and current foot position on the same side (Eq.1). Further we got a diference (Δ_i) of two conditions. One condition is presented stimuli in right or left direction (δ_i^{left}) and second condition is not presented stimuli ($\delta_i^{straight}$) (Eq.2).

Before 8th step, optic flow was stimulied onset time of 5 seconds after the start, behavioral changes have been observed 2 steps late (10th step). It was almost same as latency time of Watanabe et al[6].

Significant variation was obtained as three subject's result of evaluating t-test($p > 0.005$) between four data (6, 7, 8, 9th steps) before walking changes and four data (10, 11, 12, 13th steps) after walking changes. In subject A, an average of before 4 steps is -7.8cm and the standard deviation is 3.7cm, an average of after 4 steps is -1.6cm and the standard deviation is 4.1cm. It was significant at $p < 0.05$ (t-test). Result of subject B is likewise 5% significance, result of subject C is not 5% significant but induce effect from average and variance was evaluated (Table.1).

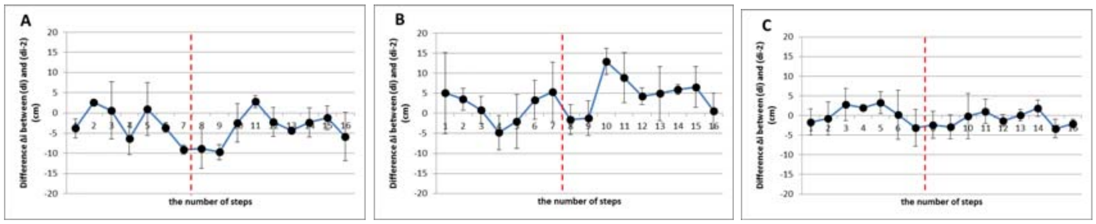

Figure 3: Average difference of the left and right direction in three subjects (X: the number of steps, Y: the average difference values of the left and right direction). Optic flow timing is showed by red dotted line.

Table 1: Average of pre-stimulus and post-stimulus (before $\mu 1$ and after $\mu 2$) (cm) and standard deviation (before $\sigma 1$ and after $\sigma 2$) (cm) and significance (t)

	$\mu 1$	$\mu 2$	$\sigma 1$	$\sigma 2$	t
A	-7.8	-1.6	3.7	4.1	4.4
B	1.5	7.7	6.1	6.1	2.8
C	-2.1	-0.1	4.7	3.6	1.3

5 Discussion

From the experimental results, it was shown a influence of presented stimulation in 4 steps after stimulus presentation. In pedestrian guidance, since self-motion sensory integration is likely to be related deeply, an overview of its previous research below.

Lishman et al[3] have reported visual would prevail if the three senses conflict, but the body movement is only forward and back movement. There is Dichigans et al[1] intended for self-motion of left and right direction. They examined the effects of location, size and movement speed of stimulus for the case where subjects are stationary. It is said that display speed of a stimulus will not occur self-motion sensation in 90-120deg/sec over there. Limit of object smooth tracking is 60deg/sec, 10.5deg/sec is used in self-motion sensation by vertical upward movement[2]. In view of these results, there is a possibility too fast speed of stimuli in this study (65.5deg/sec). In previous studies, it has not been treated that a direction of self-motion sensation is to be different directions in each sense.

In our experiments, subject's movement was "diagonally forward left and right". Cognitive system of this action is presumed as follows. All self-motion sensation are facing forward consistently for 5 seconds before optic flow stimulation. It is considered that self-motion direction by where left and right optic flows to the peripheral visual field is presented after 5 seconds, subject's feeling was changed to "left and right obliquely forward". If the goal of subjects is moving forward, instructions diagonally forward left and right is issued reflexively as correcting a new self-motion sensation to compensate for current self-motion. So the output of vection and other self-motion sensation, while it is not exclusively visual dominance in previous study, it is considered that integration by superposition.

Sensory integration process in pedestrian guidance is considered to be as shown in Fig.4. In our experiments, movement of subjects was "diagonally forward left" on (c) for straight line with no optic flow presentation (d). Self-motion sensation before the presentation of left direction optic flow (a) after 5 seconds is forward (d) without contradiction. By presenting optic flow in a lateral direction (a), subject's self-motion direction obtained from direction (b) by vison and (d) by vestibular is added vectorially. So subjects obtain a illusion of "right obliquely forward" self-motion sensation. The goal of the walking are "move forward (d)", correction amount of the sensory (g) is required in subject's brain. Therefore to "instruction to correct a new self-motion sensation (f)" and "instruction forward (d)" is added, new instruction of "walking to left diagonally forward (c)" is emitted reflexively. In other words, vection and the output of self-motion sensation from other sensory is unlike visual dominance, it is considered to have been superimposed integrated (e).

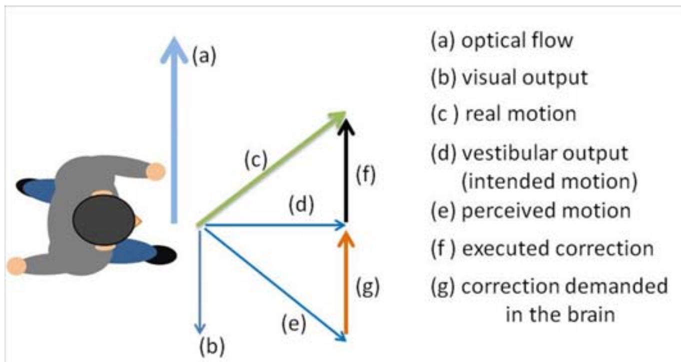

Figure 4: Pedestrian guidance model by integration between multiple senses.

And in this study, induce effect was confirmed, but the effect was temporary, pedestrian came back in a straight line trajectory in a few seconds after stimulus. If subject has changed walking trajectory by self-motion sensation, the effect should be kept be straight, but it is shown that there is a fixed action in opposite direction from this experimental results. One reason might be that there is a hierarchical control system in walking. There are three goals of uprightness, straight and purpose direction at least in control of our walking. It is considered to have intervened in the reflection system to realize upright walking in this study. However, different control of straight and purpose direction are working at the same time to walk, it is not possible to ignore them. Additional experiments are needed to elucidate this, it is necessary to consider as one possibility.

6 Conclusion

In this study, by verifying induce effects of walking by intervention in vision, somatosensor and other self-motion sensation, we examined a sense and motor system of walking. This experiments with relatively wide space finely tuned conventionally, it was discussed the relationship between various self-motion sensation. Specifically, unlike visual dominance in previous study, output of vection and other self-motion sensation is considered to have been integrated by superposition.

We have experiments based on a hypothesis that pedestrian was induced continuously as the intervention in reflection system walk upright. Analyzes the mechanism in detail by experiments with plurality directions stimulation and other sensory stimuli, we have a plan of brain function measurement with a focus on motor areas.

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