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Short Note

Stimulus Meanings Alter Illusory Self-motion (Vection) — Experimental Examination of the Train Illusion

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Abstract

Over the last 100 years, numerous studies have examined the effective visual stimulus properties for inducing illusory self-motion (known as vection). This vection is often experienced more strongly in daily life than under controlled experimental conditions. One well-known example of vection in real life is the so-called 'train illusion'. In the present study, we showed that this train illusion can also be generated in the laboratory using virtual computer graphics-based motion stimuli. We also demonstrated that this vection can be modified by altering the meaning of the visual stimuli (i.e., top down effects). Importantly, we show that the semantic meaning of a stimulus can inhibit or facilitate vection, even when there is no physical change to the stimulus.

Keywords

Train illusion, vection, meaning

1. Introduction

Exposure to a visual motion field that simulates the retinal optical flow generated by self-movement commonly causes the perception of the subjective movement of one's own body. This phenomenon is known as 'vection' (Fischer and Kornmuller, 1930). For example, when a person inside a stationary train observes a train on an adjacent track beginning to move, they are likely to perceive that it is their own train that is moving in the opposite direction, whereas observers standing outside on the platform looking at the train rarely experience any illusion of self motion. This phenomenon is known as the 'train illusion', and provides a good example

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of vection in everyday life. This illusion was described anecdotally by William James (*Principles of Psychology* (p. 735), 1918). The present study provides the first systematic study of the train illusion (here generated in the laboratory *via* virtual computer graphics techniques, as opposed to the real world situation).

A large number of vection studies have been carried out to examine the effects of manipulating stimulus properties (i.e., size, position of the visual field, speed, luminance, depth, etc.; see Dichgans and Brandt, 1978; Seno *et al.*, 2009). However, a systematic examination of the 'train illusion' situation has not been conducted. Evidence from everyday life suggests that the semantic meaning of motion stimuli may play an important role in vection (the semantic meaning is one example of top down effect). For example, the latency of vection (i.e., the delay between the initial exposure to visual motion stimulation and vection induction) has been examined in a number of previous studies (e.g., circular vection, Kennedy *et al.*, 1996). These have typically reported a latency of 4 to 12 s (e.g., linear vection, Bubka *et al.*, 2008), which is considered to constitute the typical vection latency range. However, the 'latency' of vection is thought to be very short in the train illusion. It is plausible that the 'latency' of vection is particularly short in this situation because we understand/expect that trains are often in motion. In contrast, when viewing abstract experimental displays (moving dot patterns), vection typically cannot be obtained without a significant delay. We hypothesized that this discrepancy may be caused by the effect of stimulus meaning.

Recent research has demonstrated that higher level cognitive and attentional factors can influence vection. For example, Kitazaki and Sato (2003) found evidence that unattended motion dominates vection. A related study by Seno and colleagues (2011) reported that an additional attentional task decreased vection strength.

Other studies provide evidence that vection can be altered by the observer's knowledge and expectations. In several early vection studies subjects were positioned on a moveable platform. Demonstrating platform motion to the subject prior to the experiment (even though the subject was always stationary during the experiment) appeared to facilitate vection (Andersen and Braunstein, 1985; Berthoz *et al.*, 1975), although there was no quantification of the effect that was described in the papers. More recently, Lepecq and colleagues (1995) examined the vection induced in seated 7- to 11-year-old children. They found that vection latency was shortened by showing subjects that their chair could physically move (compared to when it could not). In a related study by Wright and colleagues (2006), upward and downward vection was also facilitated by the knowledge that upward and downward body movements were possible. Similarly, Palmisano and Chan (2004) found that vection was more likely to occur and induced faster when their subjects were moved on a chair (feet off the ground) and told to expect vection prior to testing (as opposed to conditions where they were placed behind a heavy table, had their feet placed firmly on the ground throughout the experiment and were told to expect object motion).

The observer's interpretation of the visual stimuli has also been shown to alter vection strength. Riecke *et al.* (2006) showed that a computer generated natural scene could induce stronger vection rather than scrambled or inverted scene stimuli. Naturalistic stimuli induced stronger vection than non-naturalistic stimuli (Schulte-Pelkum *et al.*, 2004). These studies indicate that cognitive level processing (understanding the meanings of the stimulus) can affect vection strength.

Based on the above studies, we speculated that manipulating the stimulus meanings of the motion display could significantly alter the observer's vection experience (even when the physical properties of the motion display were either held constant or taken into account). We induced the train illusion using a virtual simulation, and tested this hypothesis by analyzing the strength and the time course of vection in a variety of different conditions. The virtual simulation of the standard train illusion consisted of a static in-train foreground texture and a moving background train texture. A number of other variants of this original train illusion simulation were also tested (see supplemental materials and Fig. 1, or download them from http://prosody.c.u-tokyo.ac.jp/~fukuda/trainillusion.html). Specifically, we tested two types of motion stimuli (train and grating) and three types of scene foreground (train, uniform-grey-shaped-train, no-foreground).

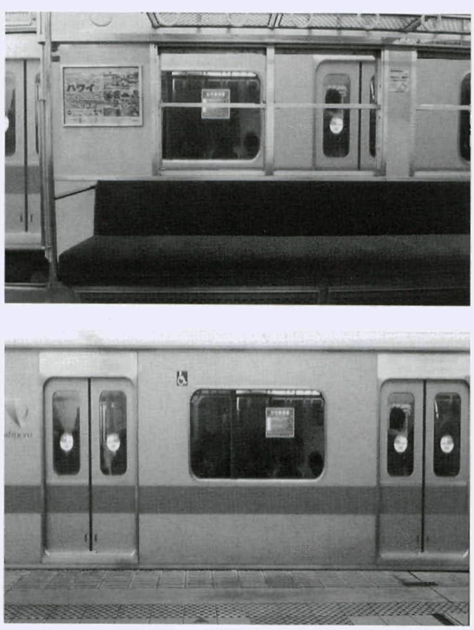

Figure 1. The virtual scenario of the train illusion. The upper panel shows the train illusion condition, and the lower panel shows the platform condition. This figure is published in colour in the online version.

2. Method

2.1. Apparatus

Stimulus displays (pixel resolution, 1024 × 768; refresh rate, 75 Hz) were generated and controlled by a computer (Apple MB543J/A), and rear projected onto a Plasma display (3D Viera; Panasonic). The experiments were conducted in a darkened room.

2.2. Subjects

The subjects comprised 14 adult volunteers, who were graduate or undergraduate students (aged between 20 and 28 years; seven males and seven females). All subjects reported normal or corrected to normal vision (some wore eyeglasses) and were free from any diseases affecting the vestibular system. All of these subjects had experienced vection prior to participating in this experiment (either in other vection experiments or in demonstrations during psychology lectures). None of them was aware of the purpose of the experiment. All 14 volunteers participated in the three experiments.

3. Ethics Statement

Our experiments were pre-approved by the ethics committee of Kyushu University, and informed consent was obtained for each subject.

4. Stimuli

In Experiment 1, we produced a virtual situation of the train illusion consisting of a moving train and static in-train textures (see supplemental materials and Fig. 1). We produced two types of motion stimuli (train and grating) and three types of foreground (train, uniform-grey-shaped-train, no-foreground). These six conditions were repeated four times in a random order. In the train illusion condition, we presented an image of a Japanese train with its doors opened. No people were visible in the train. Through the window and the opened door, the train or grating could be seen. The profile of the speed change of the train was as follows; over the first 0–7 s, the train or grating smoothly sped up, then moved at constant speed from 7 s to 30 s (0.6 cycles/s in the grating condition). The grating was moved in the same profile of the train. The spatial frequency of the grating was 0.7 cycles/deg, with a contrast of 100%. The 0.7 cycles/deg was set in accord with the spatial frequency of the windows of the train texture. The mean luminance of the stimulus was 25.54 cd/m^2. Stimulus presentation lasted 30 s. The viewing distance was 57 cm. The stimuli subtended 72 deg (horizontal) × 54 deg (vertical) visual angles. The images (i.e., train, windows, doors, etc.) were approximately the same size as the objects would appear in the real world.

In Experiment 2, we additionally presented the train illusion condition with the door of the foreground train closed and a uniform-grey moving grating in the background (Table 1). In Experiment 3, we presented the moving background train or grating beyond a texture-mapped station platform (instead of the in-train texture) (see Fig. 1). Participants were seated on a chair and viewed the stimuli binocularly. Participants' heads were not fixed (no chin-rest).

5. Procedure

Subjects were instructed to press one button when they first perceived vection in each trial, and to keep it pressed as long as the experience of vection continued. The cumulative duration of button-pressing was considered to represent the duration of vection. The latency of the first button-press was considered to represent the latency of vection.

The instructions were as follows: 'Please press the corresponding button while you are perceiving horizontal self-motion. If this decision becomes difficult, or if self-motion perception disappears, please release the button'. We were careful not to give subjects any suggestions about our hypotheses, because there is evidence that vection can be modulated by instructions/cognitive bias (e.g., Lepecq *et al.*, 1995; Palmisano and Chan, 2004). Subjects were allowed to rest between the trials. The length and timing of the rest periods were freely determined by the subjects for ethical reasons (to avoid motion sickness).

Experiments 1 and 2 were conducted on the same day. All conditions in both experiments were presented in a random order. Experiment 3 was conducted after finishing Experiments 1 and 2. Each condition in all experiments was repeated four times.

6. Results

The results revealed that vection latency was significantly shorter in the train illusion condition (Fig. 2). Although the average latency was not zero, in 16.7% trials the latency was shorter than one second. Thus, we believe that the train illusion scenario was realized using virtual computer graphics. Vection latency was shorter and duration was longer in the train illusion condition than in the other conditions, although the grating had similar spatial frequency as the train windows. Figure 3 shows the time course of button pressing for all conditions. It reveals that the time course of vection in the train illusion condition seems to be different from that in the other condition. We conducted a statistical comparison between the train illusion condition and the other stimulus condition using paired t-tests for two consecutive time bins. Significant differences were observed from 2 to 9 s and 11 s after stimulus onset (black bar under the x-axis in Fig. 3), indicating that vection in the train illusion condition was stronger than that in the other stimulus condition in the early phase of its time-course.

We hypothesized that both top-down (including semantic meaning) and bottom-up processes might be responsible for modulating our vection data. If this was the

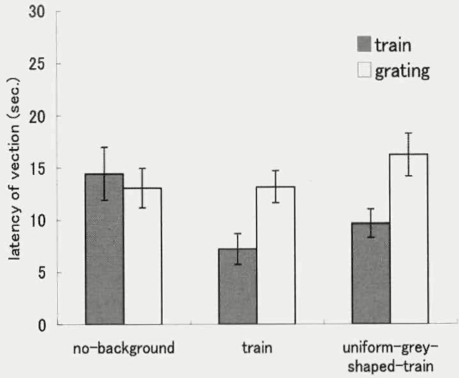

Figure 2. The results of latency. The horizontal bar indicates three types of the foreground. In the train illusion condition (in-train foreground with a moving train), latency was significantly shorter than the other conditions. The error bars indicate SEs.

case, then time course of vection might be best represented by independent components. To test this hypothesis, we applied Independent Component Analysis (ICA, Bell and Sejnowski, 1995; Comon, 1994) to our data. ICA can separate sequential data consisting of mixed signals from different sources into statistically independent component source signals. As a result, we found three source signals by ICA. The first component peaked at 10 s, while the second component increased its response over time, and the third component exhibited no particular features. The first component was displayed the most clearly in the train illusion condition. In this condition, vection started suddenly after stimulus presentation, peaked around 10 s later, and vanished after that peak (drop-outs of vection). This component corresponded closely to everyday experience of the train illusion. The second component was displayed most clearly in the other stimulus conditions, which has an ordinary/typical laboratory experiment type vection time course. The third component seemed to reflect noise. These results of ICA are consistent with the notion that vection can be influenced by two independent sources: stimulus meanings and the physical properties of the stimulus.

Two-way analyses of variance (ANOVA) of vection latency revealed a significant main effect of motion component (train or grating) ($F(1, 13) = 5.56$, $p < 0.05$), and a tendency toward a main effect of the foreground texture (nothing, train, grey) ($F(2, 26) = 2.933$, $p = 0.071$) and an interaction between the two factors ($F(2, 26) = 2.701$, $p = 0.086$), though these effects did not reach statistical significance. Multiple comparisons (Tukey's honestly significant difference test) revealed significant differences between the train foreground and the other foreground conditions in vection latency ($p < 0.05$). It was revealed by the Shapiro-Wilk test that obtained latency data were normally distributed. We did not use the participants as the factor.

We found that the vection time course changed when the train's door was opened or closed (Fig. 4). The results revealed a significant difference in vection dura-

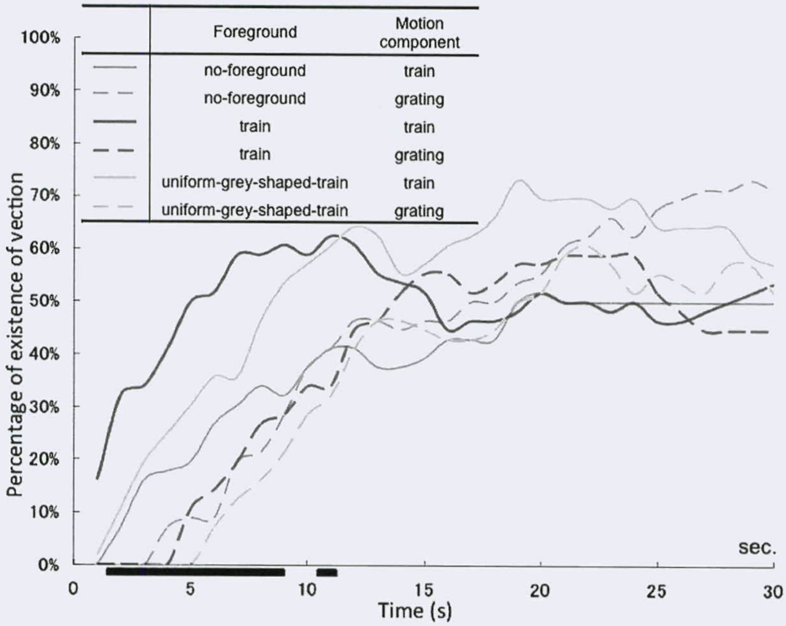

Figure 3. The time courses of vection. The vertical bar indicates the frequency of vection existence over 56 trials (14 subjects × 4 trials). 100% in a certain period indicates that all subjects perceived vection in all trials for that period. The red solid line indicates the train illusion condition (in-train texture with a moving train). The wave form of the red solid line is different from other conditions. The black bar under the x-axis depicts the range in which the difference between train/train and no-foreground/grating conditions was significant ($p < 0.05$ by paired t-test). This figure is published in colour in the online version.

tion between these two conditions ($t(13) = 9.70$, $p < 0.01$) but no difference in the latency of vection ($t(13) = 0.07$, $p > 0.05$). Regarding bottom-up visual properties, the area of motion field was larger in the opened-door condition. Thus, if vection was mediated primarily by bottom-up stimulus properties, then we would have expected it to be stronger in the opened-door than in the closed-door condition. However, the duration and latency of vection were found to be longer and shorter, respectively, in the closed-door condition. These findings indicate that the closed-door might make the observer more likely to believe that they were on a moving train. In contrast, the opened-door is likely to have inhibited such a belief, because the doors of a moving train would not normally be open. Thus, cognitive factors consistent with our subjects experiences of being on a moving train facilitated vection. This finding is in accord with the notion that the meaning of a stimulus can facilitate vection, and that vection can be modulated in a top-down fashion.

When we used a platform texture as the foreground and the train exterior as the background, vection was strongly inhibited, exhibiting a longer latency and shorter duration. The same motion components in the platform condition strongly induced vection when the platform texture was converted to a uniform grey back-

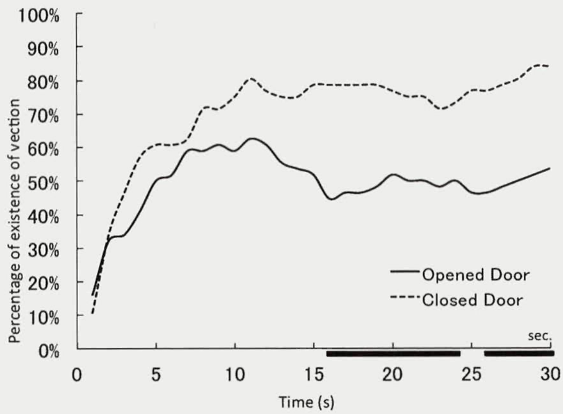

Figure 4. The time course of vection. The solid line indicates the opened door condition and the dashed line indicates the closed door condition. Comparison between opened door condition and closed door condition was made by paired t-test for two consecutive time bins. Black bar under x-axis depicts the range that the difference between opened door and closed door condition was significant ($p < 0.05$).

ground (Figs 5 and 6). Thus, the meaning of the platform inhibited vection. Two-way ANOVA revealed significant main effects of the background texture (platform or uniform-grey) (latency, $F(1, 13) = 35.41$, $p < 0.01$; duration, $F(1, 13) = 35.57$, $p < 0.01$) and texture of the motion component (train or grating) (latency, $F(1, 13) = 6.56$, $p < 0.05$; duration, $F(1, 13) = 5.10$, $p < 0.05$) and the interaction (latency, $F(1, 13) = 5.02$, $p < 0.05$; duration, $F(1, 13) = 8.98$, $p < 0.01$). Adding the platform texture drastically reduced the ambiguity in the train motion, causing subjects to speculate that the train itself was moving, that is, the perception of motion of an object (i.e., the train) was reinforced, which inhibited the perception of self-motion. These findings show that vection can be altered by changing the meaning of the stimulus alone (even when the motion components remain physically identical).

We did an additional experiment in which we used mosaic-like scrambled images of the train, in-train and platform textures as foreground and background (motion component) (see Schulte-Pelkum *et al.*, 2004). These scrambled images were meaningless but contained nearly the same spatial frequency components as the original, unscrambled train, in-train and platform textures (Fig. 7). Ten naïve volunteers participated in this additional experiment. We found that the vection induced by the shuffled image conditions had the same strength as that induced by the grating conditions. While the vection time courses of these shuffled image conditions were similar to those for the grating condition, but not for the train conditions. The image-shuffling destroyed the meaning of the static foreground images and the moving background images, which in turn resulted in the induction of normal vection (rather than train illusion vection).

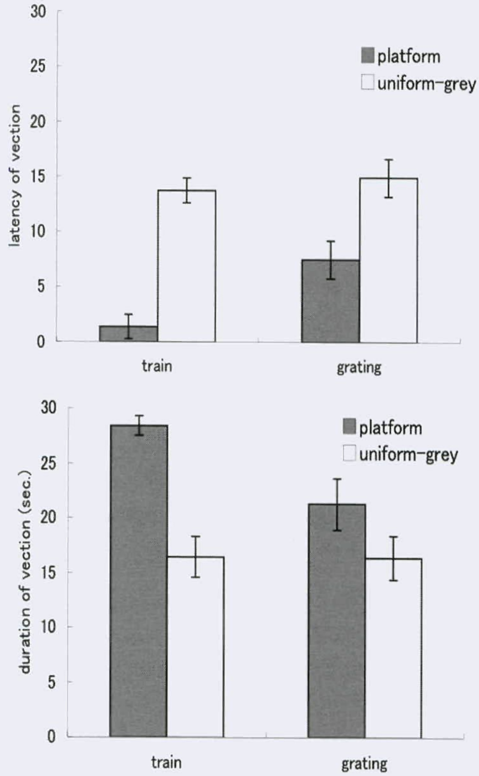

Figure 5. The results of latency and duration of the platform conditions. The horizontal bar indicates the types of motion stimulus. Train indicates a moving train and the grating indicates a moving grating. The foreground texture of the platform highly inhibited vection. The error bars indicate SEs.

7. Discussion

The current results demonstrated that the meaning of stimuli can modulate vection in four ways. First, we observed different vection time courses between the train illusion and the other experimental conditions tests. Second, we found an effect on vection of opening/closing the doors of the simulated train (this could not be explained by physical stimulus properties). Third, we observed that adding a stationary foreground platform texture inhibited vection (relative to a stationary foreground train texture). Finally, when we destroyed the meaning by scrambling the textures of the foreground/background textures, the train illusion also disappeared. The physical attributes of stimuli (size, depth, color, speed, etc., details in Seno *et al.*, 2009) have been extensively examined in previous vection studies. The current study provided novel evidence of the importance of stimulus meaning in vection. Using motion stimuli of the same size, speed and depth, we found that vection latency and duration could be altered by changing the meaning of the stimuli alone. Although this finding is intuitive, it has not been previously reported in a systematic quantitative study.

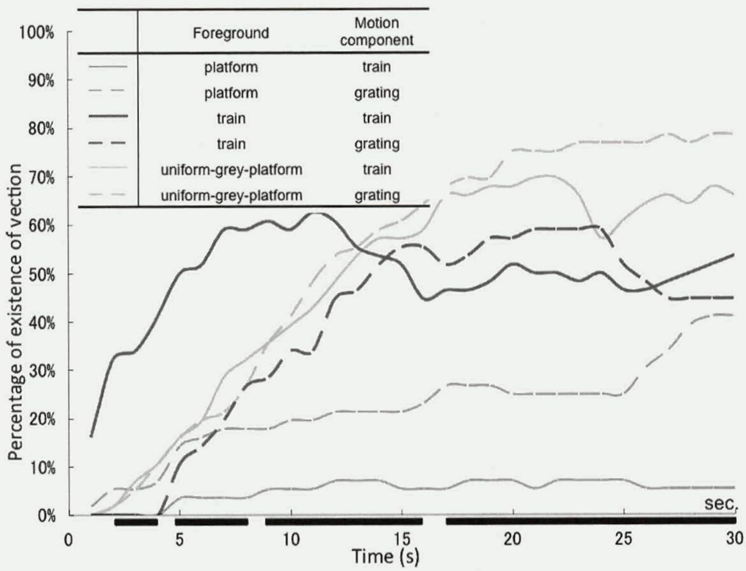

Figure 6. The time courses of vection of the platform conditions. Comparison between train/train condition and platform/train condition was made by paired t-test for two consecutive time bins. Black bar under x-axis depicts the range that the difference between two conditions was significant ($p <$ 0.05). This figure is published in colour in the online version.

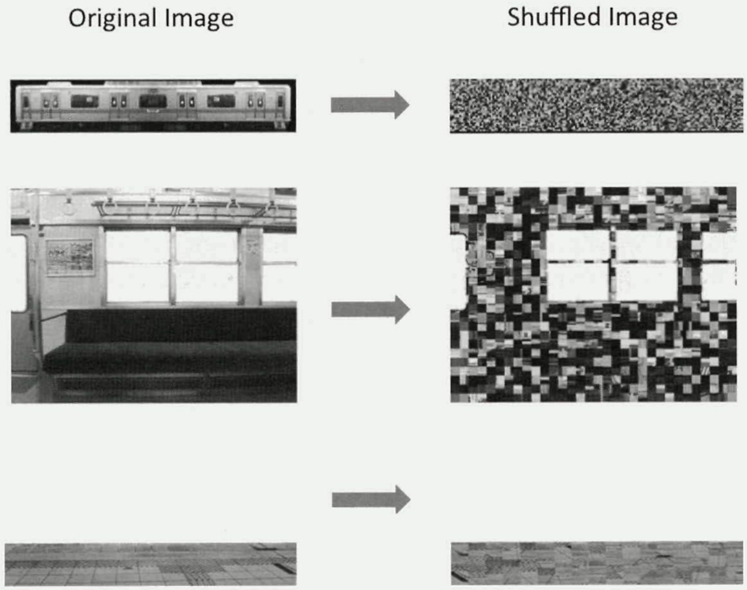

Figure 7. The shuffled image of the train, in-train and platform textures. This figure is published in colour in the online version.

8. Comparison to the Real Train Illusion

The train illusion is anecdotally reported to be stronger in the real world than the version induced in our virtual reality paradigm. This discrepancy is likely to be related to the width of the visual field, binocular stereo-vision and other top-down factors affecting observers' beliefs about being on a moving train. In future, we plan to repeat the experiment under more favorable stimulus conditions and in more realistic settings.

9. Learning/Adaptation Effects in This Study

Since Experiment 3 was conducted after Experiments 1 and 2, learning and adaptation effects may have occurred. However, all subjects had participated in previous vection experiments, and were so accustomed to vection that it is unlikely that their vection criterion would have changed easily. In addition, we calculated vection strength for the former and latter halves of all trials, and found no systematic change, i.e., the increase or decrease of vection between them. Therefore, we believe that substantial adaptation/learning effects were not likely in this study.

10. Perceived Depth Layers and Vection

Ohmi and Howard (1988) reported that perceived depth order is strongly related to vection. The stimuli used in this study also involved multiple layers of depth (e.g., the platform was in front of the moving train). The occluding areas were different in each condition. However, the moving train texture was always the farthest layer from the observer. Thus, the motion component was always placed in the farthest plane, which Ohmi and Howard (1988) reported to be the most important layer. Although facilitation and inhibition of vection were induced by the various foregrounds in a bottom-up fashion, we propose that this bottom-up modulation was weaker than the modulation caused by stimulus meaning. It has been previously reported that a static foreground can enhance vection (e.g., Brandt *et al.*, 1973). However, in the current study, the static foreground station platform texture was found to strongly inhibit the vection induced by the background display motion. This indicates that the inhibition of vection (i.e., top-down modulation by stimulus meaning) was much greater than the facilitation of vection (i.e., bottom-up modulation by the static foreground). Deeper examination of the interactions between the effects of the perceived depth layers and stimulus meaning should be conducted in the future.

11. Top-down and Bottom-up Modulations of Vection

Vection can be modulated by altering a number of bottom-up stimulus properties. For example, larger stimuli can induce stronger vection than smaller stimuli (e.g., Brandt *et al.*, 1973), red stimuli induce vection more weakly than green stimuli, which inhibit vection (Seno *et al.*, 2010), and the farthest stimulus tends to dominate vection (Ohmi and Howard, 1988). These findings suggest that vection is modulated in a bottom-up fashion.

Recently, there are some reports that vection can be modulated in a top-down fashion. Riecke *et al.* (2006) reported that natural 3D scenes can induce stronger vection than the scrambled pattern of them. This is the first report that the stimulus meaning altered vection strength. Palmisano and Chan (2004) showed that vection duration and latency can be modulated by both the delivery of the experimental instructions and their content. Lepecq and colleagues (1995) reported that the instruction 'the chair may move' shortened the latency of vection in children. It has even been reported that imagination can play a role in inducing vection (Mast *et al.*, 2001). In addition, vection could be induced without explicit motion signals by implicit motion signals (Seno and Sato, 2012; Seno *et al.*, 2012a). Furthermore, vection could be induced without global motion awareness (Seno *et al.*, 2012b).

The current results provide clear evidence that vection can be modulated by top-down factors, such as stimulus meaning. These findings indicate that vection and cognition are deeply related. This relationship should be examined in more detail in future studies.

12. Supplemental Material

Additional supporting information may be found at http://prosody.c.u-tokyo.ac.jp/~fukuda/trainillusion.html

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Appendix

Table A.1.
This table shows all stimuli used in this study (foreground and moving component). The percentage shown with the condition name of foreground means the ratio of the area occupied by moving component to the whole display

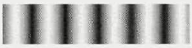
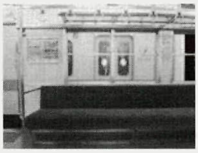
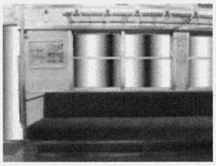
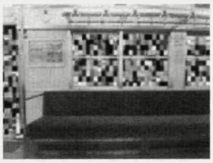
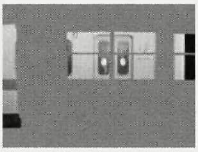
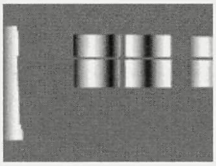
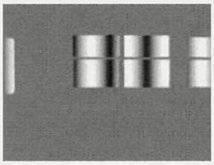
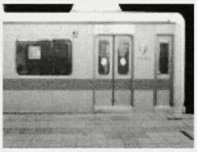
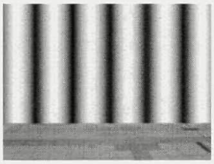
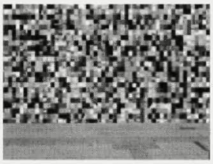
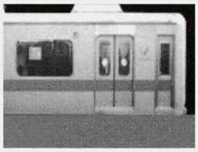
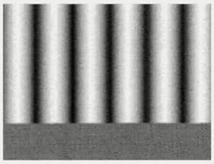
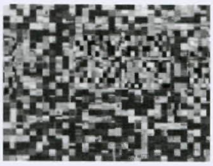
	Train	Grating	Shuffled train
No foreground (100%)			
Train (opened door) (22.8%)			
Uniform-grey-shaped-train (22.8%)			-------
Train (closed door) (23.6%)		-------	-------
Uniform-grey-train (closed door) (23.6%)	-------		-------
Platform (76.4%)			
Uniform-grey-shaped-platform (76.4%)			-------

Table A.1.
(Continued)

	Train	Grating	Shuffled train
Suffled train (23.6%)	-------	-------	
Shaffled platform (76.4%)	-------	-------