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RESEARCH ARTICLE

# Vection can be induced in the absence of explicit motion stimuli

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**Abstract** The present study utilized two separate experiments to demonstrate that illusory self-motion (vection) can be induced/modulated by cognition. In the first experiment, two curved lines, which simulated road edges seen while driving at night, were employed. Although the lines induced adequate strength of forward vection, when one of the lines was horizontally reversed, vection was significantly reduced. In the second experiment, two static converging lines with moving characters, which simulated side edges of a straight road with a traffic sign, were utilized. The road sign moved only during the first 5 s. After the sign disappeared, only static lines or a blank screen were able to induce vection. These results suggested that vection was largely affected by cognitive factors and that vection could be induced by implicit motion stimuli.

**Keywords** Vection · Self-motion · Implicit motion

## Introduction

Self-motion perception as determined by vision alone is termed "vection" (Fischer and Kornmuller 1930). Stimulus attributes for effective vection induction have been extensively studied (Palmisano et al. 2011; Seno et al. 2009; Riecke 2010). In those previous studies, explicit motion signals (e.g., moving luminance-defined dots or gratings) were used as stimuli to induce vection. These stimuli inevitably stimulate low-level motion mechanisms. More recently, Seno and Sato (in press) reported that implicit motion induces vection, even without explicit motion signals. The study used animated movies of human walkers on a homogenous background for vection induction. Although the movies included leg movements in walking, the walker was stationary on the screen, similar to walking on a treadmill. When four individual walkers occupied a large visual field (the four walkers were placed in the upper-right, bottom-right, upper-left, and bottom-left visual fields, respectively), vection was induced with adequate strength. The direction of induced vection was identical to that of the walkers' gait. This is the first report of vection induced purely by high-level motion.

The phenomenon that an impression of motion is experienced in the absence of an explicit motion signal is named "implied motion" (Cutting 2002). Implied motion has been shown to be produced by successive presentations of static images of moving objects (i.e., a running man), which induce a motion aftereffect (Winawer et al. 2008). Another example of implied motion is produced by "motion lines," which are static lines drawn on static image backgrounds of objects in motion, creating a type of implied motion (Ito et al. 2010). In cartoons, this technique is often used to express motion. Motion lines increase the impression of object speed (Carello et al. 1986) and partially negate apparent motion (Kawabe and Miura 2008).

Functional magnetic resonance imaging studies have shown that static images of moving objects activate the middle temporal area (MT) and medial superior temporal area (MST) (Kourtzi and Kanwisher 2000; Krekelberg et al. 2003). In addition, Kim and Blake (2007) showed that viewing images with implied motion activates higher-level brain areas, such as MT. Results from these studies suggested that implied motion is produced by activity in high-level motion processing areas (which correspond to MT, MST, or areas further along the visual-processing pathway) without the involvement of low-level motion processing at V1.

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The present study further analyzed whether implicit motion signals could induce or modulate vection. In Experiment 1, two curved lines, which gave the appearance of side edges of a winding road at night, were presented. In addition, a control condition was presented in which one of the two curved lines was horizontally reversed. The low-level motion components included in the winding road and the control conditions were identical. However, the semantic road information was included only in the winding road condition. Therefore, if a difference in vection strength existed between the two conditions, the results would indicate that cognitive factors contributed to vection modulation. In Experiment 2, two static lines with a moving sign, which simulated forward self-motion on a straight road with a traffic sign at night, were presented. Once the sign vanished, there was no explicit motion in the stimulus. The stimulus did not include bottom-up motion information. If the static stimulus induced vection, the results would strongly indicate that vection could be mediated purely by high-level visual processing. Experiment 2 further examined whether vection was induced without visual stimulus. Experiments 1 and 2 continuously analyzed whether vection was modulated by recognized stimulus meanings and high-level visual processing.

## Experiment 1

Two display conditions were utilized in the present study. The first condition simulated a right–left winding road. In addition, a control condition was imposed in which one of the two curved lines in the winding road condition was reversed, which removed the semantic road information.

### Apparatus

The stimuli subtended 72° (horizontal) × 57° (vertical), when the viewing distance was 90 cm. Stimulus images (1,024 × 768 pixel resolution at 75-Hz refresh rate) were generated and controlled using an Apple computer (MB543J/A). The stimuli were presented on a screen using a rear projector (Electrohome Electronics, DRAPAR). These experiments were conducted in a darkened room.

### Stimulus

Self-motion (3 m/s) was simulated in a three-dimensional space (20 m × 20 m × 120 m). In the winding road condition, the side edges of a winding road were simulated. Two lines, which were about 20 m apart, were wound in a sinusoidal manner within a horizontal dimension to simulate a winding road (see Fig. 1). In the simulated space, a single-wave cycle was 20 m, with a 10-m amplitude. The simulated depth was 120 m, but the actually displayed road was limited to a range of 20 m in depth. The simulated, forward self-motion was a linear translational motion, not a winding forward self-motion, along the road. The simulated eye height was 165 cm. In the control condition, the mirror images of one of the lines in the winding road condition, as well as original images from the other line, were superimposed. Mean luminance of the white line was 36 cd/m$^2$ and luminance of the black background was 0 cd/m$^2$. There was a white fixation point on the screen center, and with exception of the white lines and the fixation point, all other screen areas were completely black, that is, ground texture or side edges of the road were not presented. Duration of the stimulus presentation was fixed at 20 s, and the participants viewed the stimulus binocularly.

### Participants

The participants comprised 11 adult volunteers, who were graduate or undergraduate students (20 and 25 years of age; 6 men and 5 women). All subjects had normal vision and had not experienced any diseases affecting the vestibular system. None of the subjects were aware of the purpose of the experiment. Prior to starting the experimental sessions, they experienced vection by using expanding optic flows (identical stimuli to Seno et al. 2010a, b). The participants previously perceived normal vection by using the same apparatus. Seven participants previously took part in other vection experiments in which explicit expanding/contracting motions were employed. Therefore, the participants recognized what vection was.

### Procedures

Eight trials were conducted for each condition. The two conditions were randomly presented. Participants were instructed to press a button while vection was perceived. This was used to calculate vection latency and duration in each trial. There were vection dropouts even after vection was established. At the end of each trial, the subjects were also instructed to rate the subjective strength of vection via magnitude estimation. The subjects were informed that the estimated values should range from 0 (no vection) to 100 (very strong vection). Although a standard stimulus was not utilized for magnitude estimation, this exact method has been successfully used in the previous studies (Seno et al. 2009, 2010a, b, 2011a, b). The instructions were as follows: “Please press the corresponding button while you are perceiving forward self-motion. If such a decision becomes difficult, or if self-motion perception disappears, please release the button.” Care was taken not to give the subjects any suggestions about the hypotheses, because vection can be influenced by instructions/cogni-

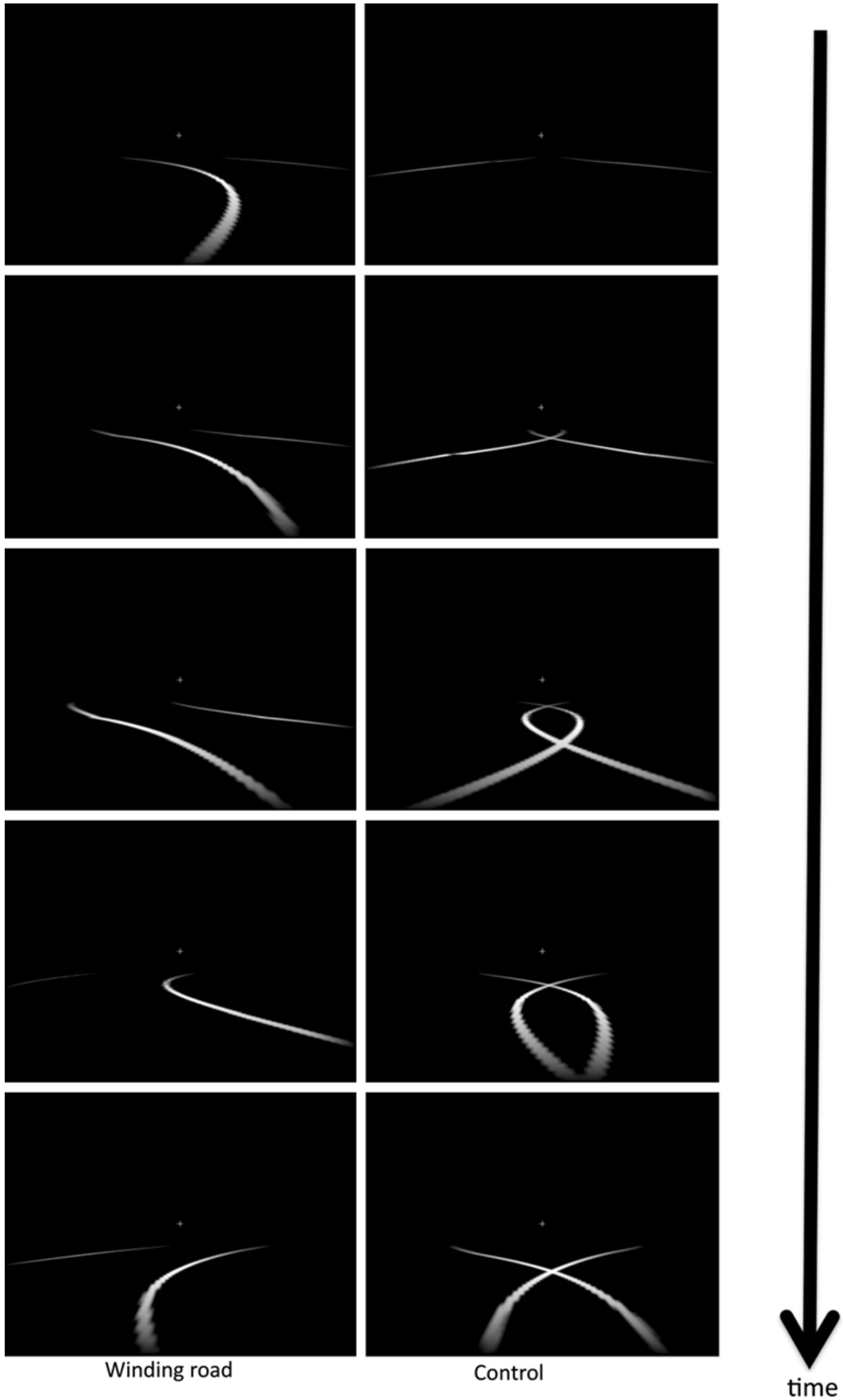


**Fig. 1** Experiment 1 stimuli

tive bias (Lepecq et al. 1995; Palmisano and Chan 2004). Subjects were allowed to practice by pressing the button while viewing a radial optic flow stimulus prior to starting the experiment.

The subjects were allowed to rest between trials. For ethical reasons, the length and timing of the rest periods were freely determined by the subjects (to avoid motion sickness).

### Results and discussion

In the winding road condition, all participants reported the experience of vection in each trial. In the subjective reports, some perceived a winding forward self-motion, and others perceived a translational forward self-motion. Latency and duration were 7 and 11 s, respectively (with an average of 2-s vection dropout). These values were identical to those obtained by normal, explicit, expanding, motion stimuli from our previous studies (Seno et al. 2009, 2010a, b, 2011a, b). The magnitude value in this condition was approximately 50. This was also the plausible value for normal vection. However, in the control condition, weaker vection was obtained, and the strength was weaker than in the winding road condition. There were significant differences between the two conditions with regard to latency, duration, and magnitude (latency, $t(10) = 5.09$, $p < 0.01$; duration, $t(10) = 5.71$, $p < 0.01$; magnitude, $t(10) = 6.08$, $p < 0.01$).

Because stimuli in both conditions included clear contour motion, low-level motion components existed in both displays. However, the amount of low-level motion signals could be identical between conditions. The most important difference was the existence of the meaning of the road. These results suggested that the semantic road information increased vection.

In contrast, it is possible that the winding road condition represented perspective information better than the control condition, because the two contours exhibited the tendency to converge in the upper part of the stimuli. This could be more easily understood as contours that extended on a depth plane. It could be effective to show motion as a perspective to induce forward linear vection, which could induce stronger vection in the winding road condition. However, local motion signals might not be affected by the perspective information because the perspective was global information acquired after integrating local information. Because lowest level motion signals, which were acquired from local regions, might be identical between the two conditions, it is possible that vection was not determined only by the bottom-up motion pathway (Fig. 2).

## Experiment 2

Experiment 2 further examined whether it was possible to induce vection with a static stimulus or without any visual stimulus. If vection were obtained under static-stimulus

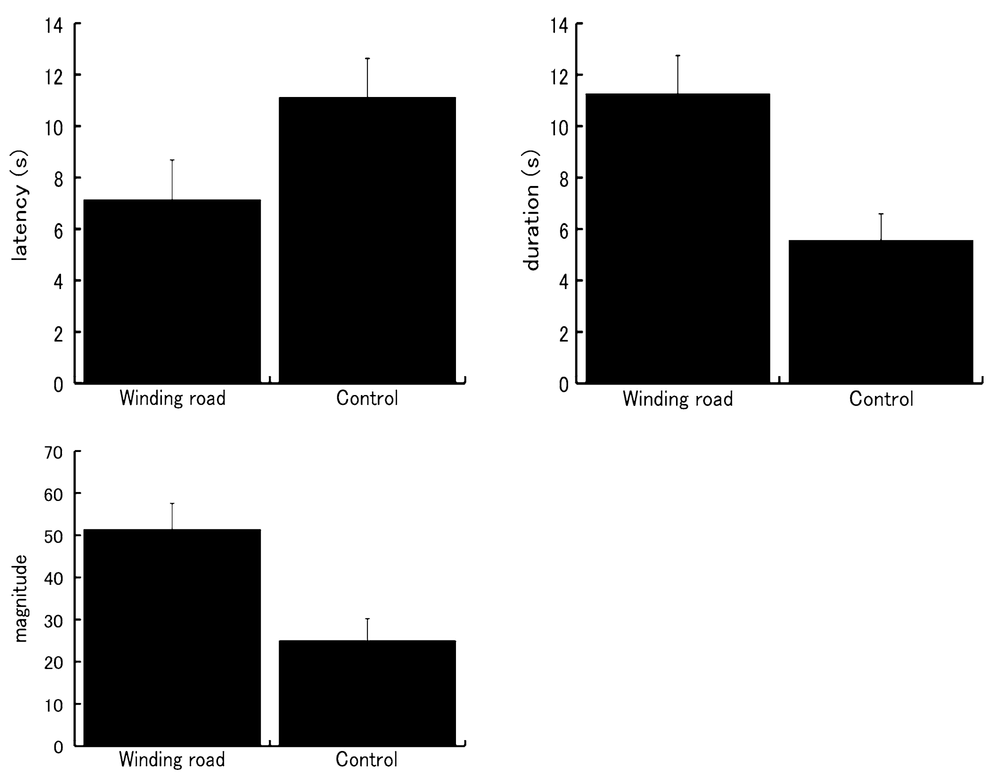


**Fig. 2** Vection latency, duration, and magnitude in both conditions. The *error bars* represent SEMs

conditions, this would strongly indicate that vection was modulated by high-level visual processing and cognition of stimulus meanings.

## Methods

### *Apparatus*

The apparatus was identical to those from Experiment 1.

### *Participants*

Ten naïve volunteers participated in Experiment 2, and six of these individuals also participated in Experiment 1. The subjects had normal vision and were not aware of the purpose of the study.

### *Stimulus*

Three conditions were utilized: (1) lines-only; (2) lines-plus-sign; and (3) sign-only (Fig. 3). In the lines-only condition, two static converging lines were presented, with no explicit motion signals. The lines simulated the side edges of a straight road in a perspective transformation. In the lines-plus-sign condition, an image of a sign (representing "stop" in Japanese) was painted on the road and added to the converging lines. The sign simulated a painted sign on the road and was displayed through the perspective transformation. The image became enlarged over a period of 5 s from the start of stimulus presentation, which simulated forward self-motion on the road. The sign enlargement generated an explicit motion signal and created an impression of forward self-motion on the road as simulated. The sign-only condition was identical to the lines-plus-sign condition, except that no lines were present. This condition included the same explicit motion signal as the lines-plus-sign condition. However, because of the omission of the two lines (road side edges), the strength of implicit motion signaling was expected to substantially decrease under this condition. The duration of stimulus presentation under the three conditions was 20 s. In the sign-only and lines-plus-sign conditions, the moving sign was presented only for the first 5 s. With the exception of the white lines, sign, and fixation point, all screen areas were black.

### *Procedures*

All procedures were identical to those in Experiment 1.

## Results and discussion

In the lines-plus-sign condition, all participants reported a vection experience in each trial. The average latency of vection was 5 s, and the average duration was 10 s. Under this condition, the screen displayed only static lines after the first 5 s. Therefore, for 10 s, vection was elicited by stimuli containing no explicit motion signals. Magnitude and duration included the vection measurements from the first 5 s, and vection during this period was referred to as "standard vection." However, after the standard vection period, the vection experience continued for more than 8 s for all participants. Therefore, at least 8 s of vection arose while viewing entirely static stimuli.

In the sign-only condition, 8 out of 11 participants reported a vection experience. The average duration of all 11 participants was 4 s, with an average magnitude of 19. The average latency of this condition was 8 s (calculated by excluding no vection trials), which suggested that vection was clearly induced during the black, blank screen for 3 s after the sign disappeared. Participants presumably continued to interpret the blank screen as a dark road at night. The average vection duration was not as long as in the lines-plus-sign condition, and the average magnitude of the effect also suggested that the vection experience was weaker than in the previous condition. Therefore, it was speculated that the implicit motion generated within the brain might be weaker than when the two lines functioned as a medium with implicit motion signals.

In the lines-only condition, 5 participants reported a vection experience. Average vection duration and subjective average magnitude values were 2 s and 12, respectively. We think the 2-s vection should not be ignored. The results suggested that there was significant vection in the lines-only condition. The occurrence of some vection experiences in this condition could be explained by the order of experimental conditions. Vection was obtained in lines-only trials only when they were conducted after the lines-plus-sign condition. It is possible that the subjects learned that the two lines were associated with sign movement during the lines-plus-sign condition, which continued to function as implicit motion stimuli. This would serve an example of short-term perceptual learning that induced a vection experience.

One-way analysis of variance revealed significant main effects of the three conditions in latency, duration, and magnitude (latency, $F(2,27) = 5.29$, $p < 0.05$; duration, $F(2,27)$, 17.30, $p < 0.05$; magnitude, $F(2,27) = 14.25$, $p < 0.05$). Multiple comparisons revealed significant differences between the line-plus-sign condition and the other two conditions (Fig. 4).

# General discussion

In Experiment 1, curved lines, which simulated a winding road, induced stronger vection than in the control condition. These results suggested that vection was modulated by high-level components, that is, semantic road information.

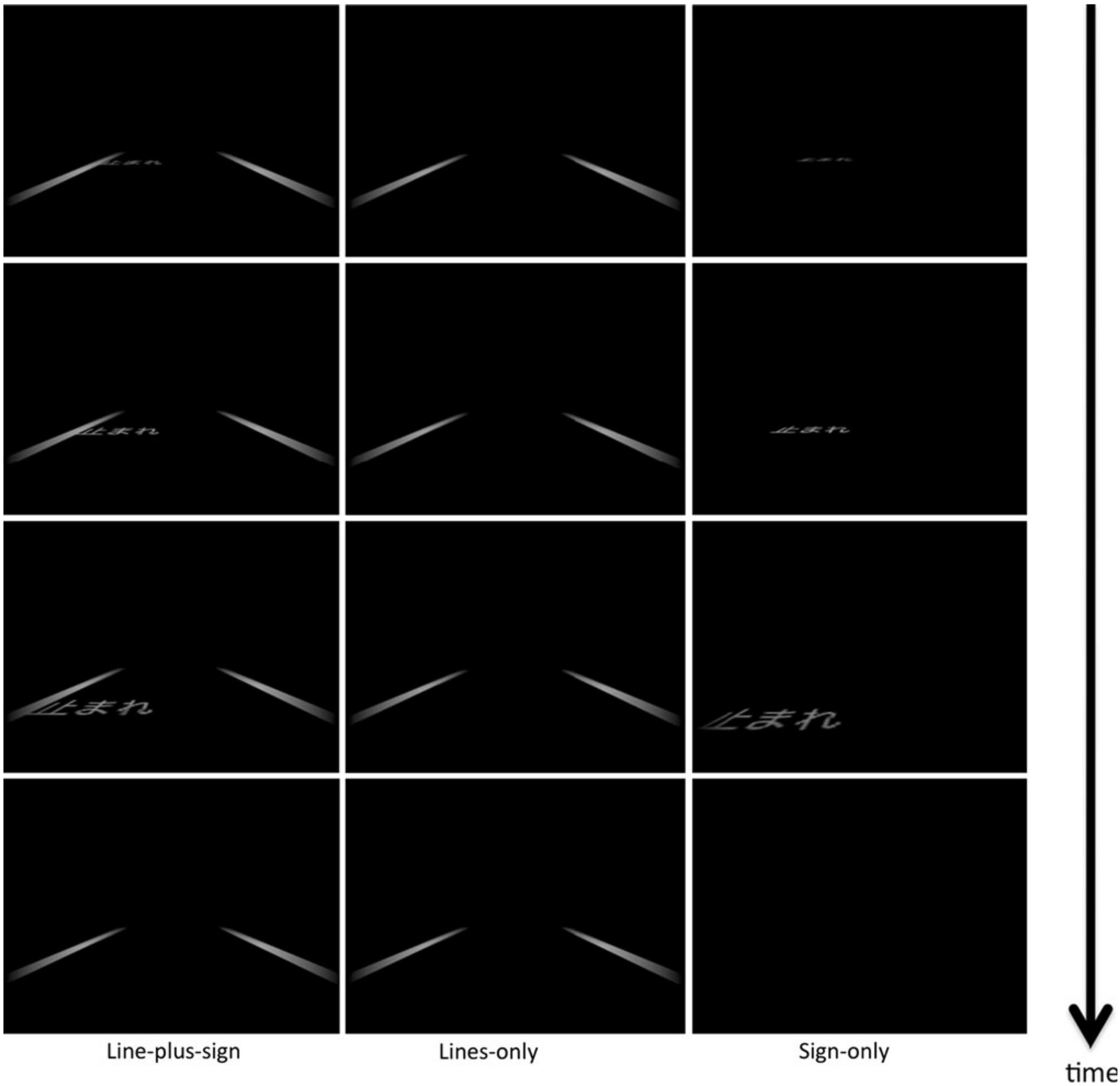


**Fig. 3** Three conditions in Experiment 2

In Experiment 2, the static lines and a moving character, which simulated a road with a traffic sign, induced vection. Importantly, vection was obtained even after the moving sign disappeared. These results demonstrated that participants experienced vection with only static lines and, furthermore, without any visual stimulus.

### Cognition and vection

Previous vection studies revealed that vection is related to attention. Kitazaki and Sato (2003) showed that unattended motion dominates vection. Seno et al. (2011a, b) conducted vection experiments with imposing cognitive tasks, demonstrating that attentional tasks decrease vection strength. These studies confirmed that attention strongly correlates with vection.

Previous studies have also reported cognitive modulation of vection. Lepecq et al. (1995) showed that latency of vection is shortened with knowledge of potential movements of a seated chair in 7- to 11-year-old children. Upward and downward vections are facilitated by the knowledge that upward and downward body movements are possible (Wright et al. 2006). In addition, earlier vection studies used movable platforms to show that the apparatus

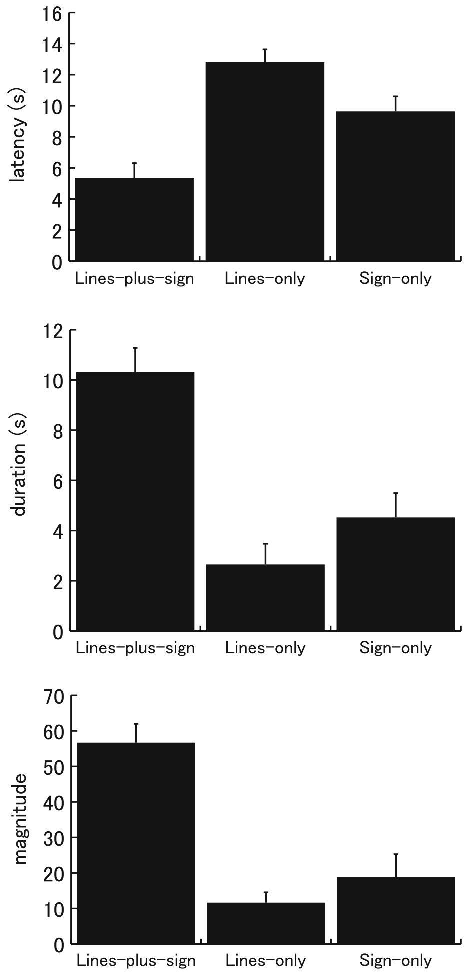


**Fig. 4** Results from Experiment 2. Latency, duration, and subjective-rated magnitude of vection. *Error bars* indicate SEMs

facilitates vection (Andersen and Braunstein 1985; Berthoz et al. 1975), although these effects were not quantified. Palmisano and Chan (2004) showed that instructions to induce an "object-motion bias" in participant cognition and/or expectation significantly increase vection latency.

The interpretation of visual stimuli also affects vection strength. Riecke et al. (2006) showed that natural scenes induce stronger vection than scrambled- or inverted-scene stimuli. In addition, naturalistic stimuli induce stronger vection than non-naturalistic stimuli (Schulte-Pelkum et al. 2004). These studies suggested that cognitive level processing (understanding the meaning of stimuli) affects vection strength.

Similar cognitive effects have been reported for auditory vection. Auditory vection is an illusory self-motion perception induced by auditory stimuli. As demonstrated with visual vection, the movable chairs or knowledge of them can facilitate auditory vection (Väljamäe 2009). Furthermore, auditory vection is modulated by various types of stimulus sounds (Larsson et al. 2004). For example, sound from stationary acoustic landmarks (e.g., fountain) significantly increases vection, compared with moving objects (Riecke et al. 2005), demonstrating that sound recognition affects the strength of auditory vection.

Vection modulation by imagination has been previously reported (Mast et al. 2001). A smaller motion field observed in peripheral vision existed in their stimuli. Their participants could complete an entire motion field through the use of their imagination. In fact, even small physical-existing motion in the area induced vection with the help of their imagination. In Experiment 2, results showed that vection could be induced by imagining motion stimuli without any direct instruction. That is, these results were obtained without training, because knowledge of a driving scene on a road was acquired from daily experiences. This was in contrast to the results from Mast et al. (2001), where training sessions were required for imaging motion fields.

### A possible explanation of vection aftereffect (VAE)

Our previous studies showed that vection was preserved for several seconds even after stimulus presentation was finished. This phenomenon was termed the "vection aftereffect" (VAE) (see details in Seno et al. 2010a, 2011b). Results from Experiment 2 could be partially explained by VAE. However, it is important to keep the following in mind. The VAE direction was opposite to the vection direction that was obtained in adaptation stimuli. Therefore, in the present study, preserved vection in Experiment 2 should be in a reverse direction if that was VAE. However, the directions of preserved vection and standard vection in Experiment 2 were the same. This is a strong support that VAE was not responsible for vection preservation observed in the present study. Vection induction in Experiment 2 might be mediated by high-level motion components involving cognitive modulation. It is also possible that there was a cognitive aftereffect, that is, some kind of cognitive modulation of self-motion perception might have persisted. This is an important question for our future research.

### Comparisons to data from Seno and Sato (in press)

Seno and Sato (in press) also showed that high-level motion induces vection. They used animated movies of humans walking on a homogenous background for vection induction. The movies showed a walking gait, but the entire body did not move forward, similar to an individual walking on a treadmill. This stimulus originated in the back-scroll illusion (Fujimoto and Sato 2006). The original back-scroll illusion stimulus comprised a walking-human animation superimposed on a dynamic counter-phase grating background.

Observers perceived the background gratings moving in a direction opposite to the direction suggested by the gait.

The direction of vection was different between the Seno and Sato (in press) study and the present study. In the former study, vection was induced in the same direction as the walkers' gait. Therefore, the directions of implied motion and vection were identical. In the present study, vection was always induced in the opposite direction of stimulus motion or implied motion. However, there could be a common component between the former study and the present study if it could be assumed that implied background motion induced vection. In the former study, four walkers were situated to occupy a large visual field. We speculate that the four walkers could induce the implicit contrasted background motion. The direction of implied background motion and the suggested direction of the inducers (walkers) were opposite. As a result, the vection direction due to implied background motion could be identical to the motion direction of the inducers. In contrast, in Experiment 2 of the present study, the lines and sign could induce implicit motion in the completed background. The directions of perceptually completed background motion and moving elements (road sign) were identical. As a result, the vection direction caused by implied background motion was opposite to the inducer motion. In both cases, vection was considered to be induced in a direction opposite to the assumed background motion. However, it is important to note that some qualitative differences existed between the former study and the present experiments. Our stimuli included a period that contained no dynamic component (or visual stimulus). Vection was reported even during this period. These results suggested that the present stimuli produced further higher-level motion components and induced a different type of vection. We believe that the possibility of vection induction could be expanded by cognitive factors.

### Brain areas related to vection

The brain areas related to processing vection have been previously revealed by brain-imaging studies. Vection is processed primarily in the ventral pathway, which performs visual motion processing for self-action (Goodale and Milner 1992). In fact, a higher motion-related area (MST) is thought to be related to vection (Brandt et al. 1998; Kleinschmidt et al. 2002). However, implied motion also activates MST (Kourtzi and Kanwisher 2000). Therefore, it is possible that cognitive functions related to the processing of implied motion induced or modulated vection.

### Cognitive biasing according to instructions

A potential limitation of the study is the fact that instructions could have influenced the present results; the participants could have assumed the hypothesis and expected results from these instructions. Even though the subjects did not perceive real vection, they could have produced the mimic vection experiences that the experimenter wanted. To exclude this possibility, an informal observation was conducted with six naïve subjects in which the experimental room light was turned on and the same stimuli, and instructions were used as in Experiment 2. When the room light is bright and the participants can see the entire room image, vection should be significantly weakened. If the experimenter instructions were a critical factor for the results, these same results should be obtained under a bright room condition. However, results showed that vection was not obtained or drastically weakened under a bright room condition. This suggested that the participants actually perceived vection when the room was darkened and that the experimenter instructions and participant expectations had little effect on the results.

## Conclusion

Results from Experiment 1 demonstrated that the stimulus meaning affected vection strength. Results from Experiment 2 showed that after viewing a moving element, even static elements induced vection. These results suggested that vection was modulated by cognitive factors, and high-level motion without bottom-up motion components reliably induced vection.

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## Appendix

Individual data from Experiments 1 and 2 (Fig. 5).

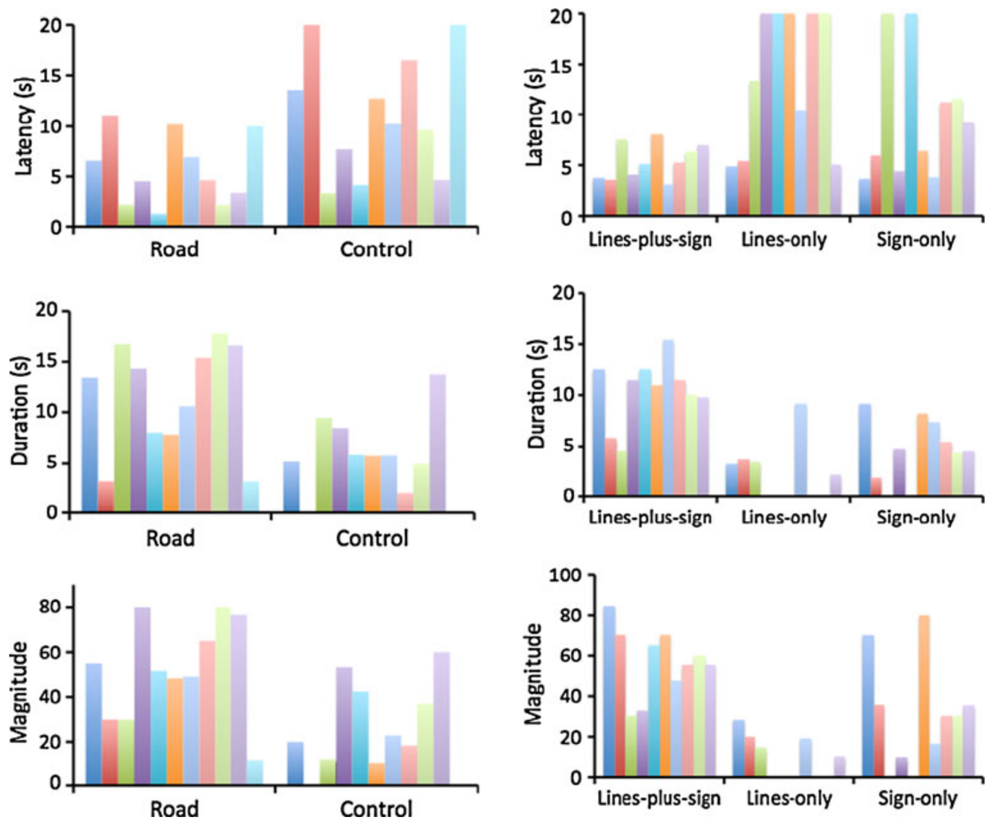


**Fig. 5** Eleven participants' individual data of experiments 1 and 2. Eleven different bars indicate eleven different participants

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