論　　文

VECTION INDUCED BY ILLUSORY MINIATURIZATION OF MOVING PICTURE

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Abstract

The effects of image miniaturization on visually induced self-motion perception (vection) were examined in a psychophysical experiment in which 11 observers participated. The original motion picture stimulus was filmed from a camera mounted on the front of a moving train. This kind of motion stimulus can be considered equivalent to retinal flow that we daily experience under natural visual environment, and termed as "real world stimulus". Saturation enhancement and defocused blur were applied to this original movie, as two types of miniaturization transformations. The results of psychophysical experiment revealed that the miniaturized movies can induce self-motion perception as strong as the original stimulus, although naturalness of the image experienced under the miniaturized conditions were significantly detracted. Impacts of using a real world stimulus as a future vection inducer were discussed base on the results.

1. Introduction

When we move our body under natural circumstances, static external objects apparently move on our retina in a regular manner and form optic flow (Gibson, 1966). For example, forward self-motion creates expanding motion of the external visual scene on the retina, and sideways self-motion results in translational optic flow in the opposite direction to the self-motion (Andersen, 1986). The perceptual mechanism responsible for self-motion perception is able to compute our self-motion (its speed and direction) based on this kind of visual information. Of course, self-motion perception is originally multi-sensory in its nature, involving various sensations arising from sources such as the vestibular or kinesthetic systems. Under conditions of passive self-motion with a constant speed, however, visual cues should be the sole indicator of the self-motion, because vestibular organs can only detect self-acceleration and kinesthesis is irrelevant for passive self-motion (Howard, 1982). Thus, visual information can be considered as a primary determiner of self-motion perception, at least during certain specific conditions of sustained self-motion.

The significant impact of the visual information on self-motion perception is also clearly demonstrated by a perceptual phenomenon called visually induced self-motion perception, also known as vection (Fischer & Kornmüller, 1930). Vection is a kind of perceptual illusion in which a static observer exposed to a visual stimulus, occupying a large part of his/her visual filed and moving uniformly, tends to perceive illusory self-motion in the opposite direction to the visual motion. For example, observing visual expansion results in the illusory perception of forward self-motion, and a rightward moving visual stimulus induces leftward vection. Vection might reflect natural visual processing responsible for self-motion perception, and researchers are convinced that they can approach perceptual mechanism underlying self-motion by investigating vection.

In a history of vection research, investigators have been mainly motivated to examine visual factors which can affect occurrence and strength of vection, using abstract visual motion stimuli such as homogeneous random-dot or striped patterns (see Riecke, 2010 for review). This kind of abstract visual stimulus (i.e. without any specific scenic meaning) has a number of advantages in terms of controlling visual conditions and enabling the experimenter to manipulate the targeted factor while keeping other factors unaffected: it's a traditional and conventional method in psychophysical studies. Using this orthodox methodology, vection studies have succeeded in discovering many important facts about vection, thereby contributing to a better understanding of perceptual mechanisms underlying self-motion perception. These findings include the effect of stimulus size and eccentricity (larger stimulus can induce stronger vection [e.g., Brandt, Dichgans & Koenig, 1973], although stimulus eccentricity is irrelevant to vection strength [e.g., Post, 1988; Nakamura & Shimojo, 1998; Nakamura, 2001]), stimulus depth (motion of the most distant part of the visual scene induces stronger vection than motion of the foreground [e.g., Ohmi, Howard & Landolt, 1987; Ohmi & Howard, 1988; Nakamura & Shimojo, 1999]) or stimulus acceleration (adding simulated viewpoint jitter or oscillation to optic flow facilitates self-motion perception above baseline effects induced by the smooth inducer motion [e.g., Palmisano, Gillam & Blackburn, 2000; Palmisano, Burke & Allison, 2003; Nakamura, 2010; Kim, Palmisano & Bonato, 2012]).

In the natural circumstances, it is quite rare that visual environments are occupied by the abstract patterns without specific meanings just like in the case of random-dot or striped patterns employed in vection experiment. Thus, in this sense, there is no guarantee that vection induced by the abstract visual stimulus under experimental situation does validly reflect visual self-motion perception in our daily living real world. It should be quite important to analyze self-motion perception induced by visual stimuli which are equivalent to our daily experience, although there have been yet only a limited number of psychophysical studies examining the optic flow of natural visual scenes (e.g., Ohmi, 1996; Riecke, Schulte-Pelkum, Avraamides, Heyde & Bulthoff, 2006). Fortunately, the rapid developments in image-processing technologies in recent years now enable us to manipulate specific visual factors in natural visual scenes recorded by moving camera. Here, I would like to term this kind of visual stimulus as "real world stimulus", following Ohmi (1996). Employing real world stimuli as possible vection inducers, we can assess new factors, such as meanings implied in the visual scene or the observer's impressions of the visual pattern, which cannot be examined using conventional abstract visual stimuli. This paper reports a psychophysical experiment which examines the effect of miniaturizing the visual scene on visually induced self-motion perception. This addresses one of the stated frontier challenges of using real world stimuli in vection experiments.

Size and distance perceptions can be modulated by photographing natural visual scenes with a camera that has a tilt-shifting lens - the end result being a photo which appears to be of a scene consisting of small toys or models. These so-called 'miniaturized' images can be easily simulated and made by image-processing techniques from regular photos or movies. Adding defocused blur in peripheral region and enhancing saturation of chromatic colors contained in the image can give a miniaturized impression of visual image to observer, remaining actual image size unchanged (e.g., Held, Cooper, O'Brien & Banks, 2010). The present study investigated self-motion perceptions induced by (quasi-)miniaturized moving images in order to examine possible effects of miniaturization of the visual scene on our spatial orientation. Bubka and Bonato (2010) previously proposed that visual stimuli containing features that are similar to those of natural visual scenes should induce stronger vection than less naturalistic stimuli. In real world situations, we calculate our self-motion based on the retinal flow generated by natural visual environments. If the visual processing underlying self-motion perception is tuned for such natural visual motions, and then, these stimuli might be ideal self-motion inducers. If the miniaturizing transformation examined in this experiment potentially reduces "naturalness" of the visual stimulus, vection experienced with miniaturized visual stimulus may be reduced (as compared with original motion image which is supposed to be considered as fully natural). Again, using an image processing technique called (quasi-)miniaturization, we can assess new visual factor concerning observer's impression towards the visual stimulus ("miniaturization" or "naturalness") under a well-controlled situation; motion information contained in the miniaturized stimulus was identical to the original movie, because the miniaturization was accomplished only by enhancing saturation and blurring image.

2. Materials and Methods

2.1. Participants

Eleven undergraduate students volunteered to participate in this experiment (four males and seven females, ages ranging from 19 to 21). All had normal or corrected-to-normal visual acuity and previous experience participating in vection experiments. However, they were all unaware of the purpose of this experiment.

2.2. Apparatus

Stimulus displays were projected onto a rear projection screen whose size was 140 cm in height and 270 cm in width by a video projector (Viewsonic, PJD6381). Viewing distance was set to 150 cm, and thus visual display subtended 84 degrees (horizontal) by 50 degrees (vertical) in visual angle. Experiments were carried out in a dark room. The participants wore the goggles which limited their visual field so that they could not observe anything other than the visual display (e.g., these blocked the floor and celling of the experimental room, as well as the edges of the projection screen). The participants sat on a comfortable chair in front of the screen without specific head or body constraints. They roughly kept their heads stationary by using the back- and head-rests of the chair (thereby avoiding extra fatigue or reducing the likelihood of severe motion sickness).

2.3. Stimuli

The visual stimuli employed in this experiment were generated from a motion picture shot from a camera mounted on the front of a moving train (this moved at a speed of approximately 60 km/h on a straight path through a Japanese suburban area). The angle of camera recording was adjusted so participants could observe the unmodified version of the movie in (approximately) real/natural scale. The spatial resolution of the visual stimulus was 800 pixels (horizontal) by 600 pixels (vertical), and the refresh rate was set to 30 Hz. The original movie was extracted from advertising movies made by train company.

There were two ways to accomplish this miniaturization, namely by "saturation enhancement" and "defocused blur." In the case of saturation enhancement, the RGB (red-green-blue) of each pixel in each frame in the motion image was converted at first to HSV (hue-saturation-value), and then saturation (S) was increased by 20 %. Saturation was calculated by dividing the difference between maximum and minimum RGB values by sum of these values (If saturation exceeded 1.0, this was clipped and set at 1.0). Then HSV in each pixel was re-converted into RGB, and combined together to form a movie. In the case of defocused blur manipulation, the top and bottom of the visual stimulus (both 30% of the image) was blurred

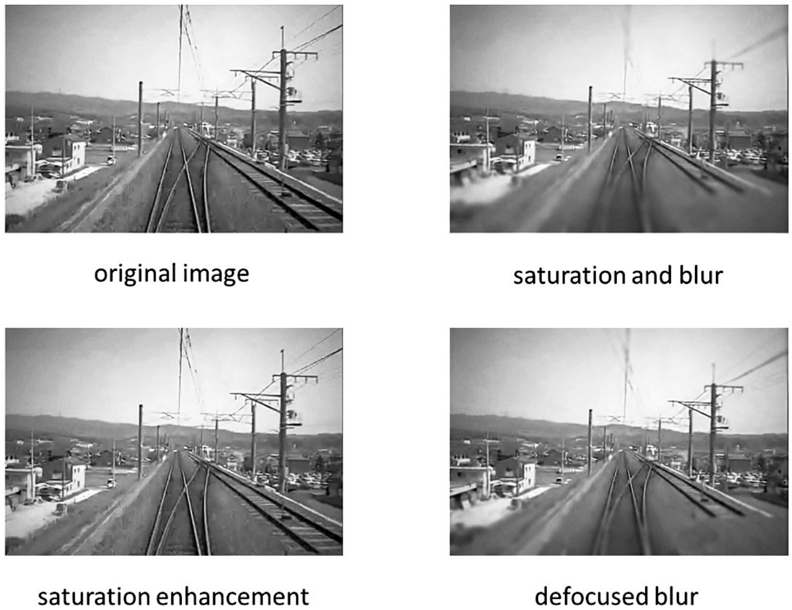

Figure 1 Sample snapshots of visual stimulus employed in each stimulus condition

with a median filter whose kernel size was 20 pixels (Smoothing with a median filter was applied to each RGB channel independently in order to keep color information in the motion image). Previous informal observations confirmed that both of these transformations generate significant miniaturization effects.

There were four experimental conditions. In the "original image" condition, the original motion picture filmed from the train was presented without any miniaturization transformations. In the "saturation enhancement" and the "defocused blur" conditions, visual stimulus modifications were applied as described above. In a further "saturation and blur" condition, both saturation enhancement and defocused blur were applied to miniaturize the motion image. Figure 1 indicates snapshots from the motion images employed as visual stimulus in four different stimulus conditions.

2.4. Procedure

The participants' task in the experiment was to press a mouse button whenever they felt their bodies were moving (as if they were riding on a train). They were instructed to release the mouse button whenever their self-motion perception disappeared, and then press it again if self-motion perception returned. After each stimulus presentation, participants were also asked to estimate strength of self-motion experienced during stimulus observation, using scale from 0 to 100 (or beyond). 0 means that there was no self-motion at all, and 100 means that self-motion perception was as strong as in the original image condition. The participants also estimated the miniaturization and naturalness of the visual stimulus display. For their miniaturization ratings, they were asked: "Did the visual stimulus you observed in this trial appear to be like a movie consisting of miniature models like toys or dolls?", and estimated this with a scale from 0 (not at all) to 100 (completely yes). For their naturalness ratings, they were asked: "Did the visual stimulus you observed in this trial appear to be a recording of a natural visual scene?" using the same scale.

Before all experimental trials, the participants executed four training trials. The purpose of the training trial was to familiarize observers with the experimental procedure, and acquire a standard for evaluation of self-motion strength. The visual stimulus employed in the training trial was the same as in the original image condition, and the observers were instructed to assign an evaluation of 100 to self-motion perception experienced in the training trials. Duration for each stimulus presentation was set to 60 seconds. Four experimental trials were repeated for each of four different stimulus conditions (thus there were 16 experimental trials tested in total) in a pseudo-random order. Before executing each trial of the original image condition, the participants were explicitly informed that the next trial would be the original condition, and were asked to retune the standard for their self-motion evaluation by instructing to assign evaluation of 100 to self-motion perceived in the original image condition.

3. Results

Vection onset latency and accumulated duration were calculated based on the participant's mouse pressing in each individual trial. Hence, we can utilize latency, duration and estimation as indices of vection strength. It has been shown that stronger vection tends to have shorter latencies, longer durations and higher strength estimates. The three vection indices, as well as the estimates of miniaturization and naturalness, were averaged across 11 participants, because we were mainly motivated to examine difference between the stimulus conditions, not between the participants.

Figures 2 and 3 indicate averaged vection indices and estimated values for miniaturization and naturalness obtained in four different stimulus conditions (it should be noted that vection strength estimates were always assigned to 100 in the original image condition). Analyses of variance with repeated measurements (rANOVAs) revealed that there were no significant differences in vection strength between the conditions ($Fs < 1.0$ for all indices). Thus, it can be concluded that vection induced in all of the stimulus conditions examined in this experiment had equivalent strengths, irrespective of any miniaturization transformations.

Another rANOVAs indicated significant differences of miniaturization and naturalness estimates

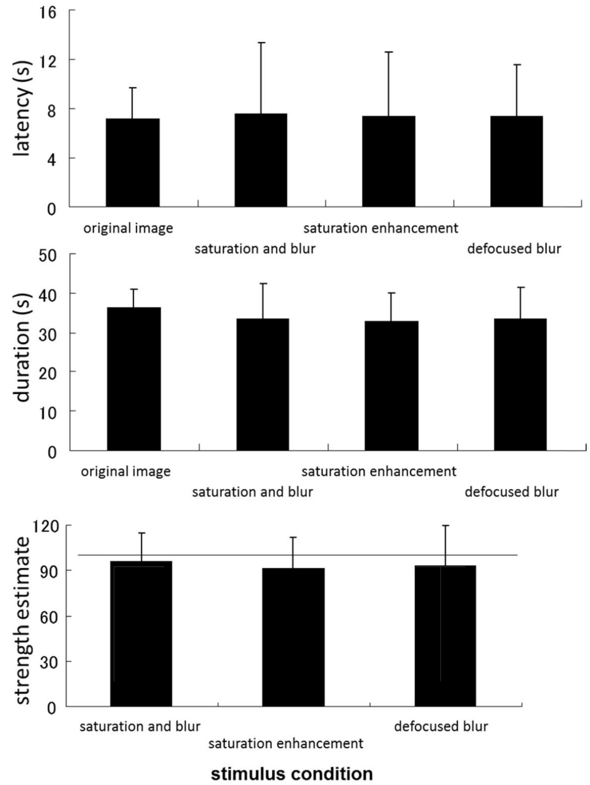

Figure 2 Averaged vection indices under different stimulus conditions. Error bars indicate standard deviations. It should be noted that strength estimate in the original image condition was always assigned to 100 (depicted as horizontal line in the lower panel).

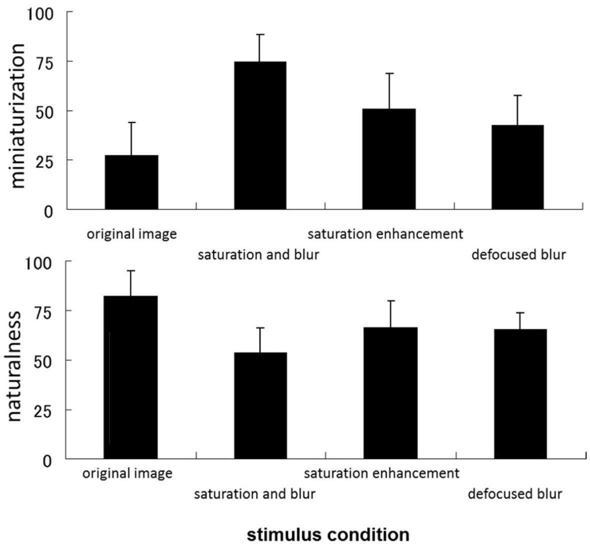

Figure 3 Averaged estimations for naturalness and miniaturization under different stimulus conditions. Error bars indicate standard deviations.

between the stimulus conditions (miniaturization: $F(3, 30)=10.68$, $p<.0001$, $\eta^2=.516$, naturalness: $F(3, 30)=26.88$, $p<.0001$, $\eta^2=.736$). Miniaturization estimates were the highest in the "saturation and blur" condition and the lowest in the original image condition. In the "saturation enhancement" and the "defocused blur" conditions, miniaturization estimates were at intermediate level between the "saturation and blur" condition and the original image condition. By contrast, naturalness estimates were the highest in the original condition and the lowest in the "saturation and blur" condition. Naturalness estimates were almost equivalent in the "saturation enhancement" and "defocused blur" conditions, and falling in between the two extreme conditions. Multiple comparisons using Tukey's HSD test ($\alpha=0.05$ for all comparisons) revealed that, both for miniaturization and naturalness estimates, there were significant differences between the original image condition and the other three conditions. There were also significant differences of miniaturization and naturalness estimations between the saturation and blur conditions and the other conditions, while differences between the saturation enhancement and the defocused blur conditions were not significant.

4. Discussion

Both kinds of miniaturizing transformation employed in this experiment, namely saturation enhancement and defocused blur, successfully evoked impressions of miniaturization when applied to a motion picture filmed in real natural visual scene, although actual image size was not manipulated. Ratings showed that when both transformations were applied (the saturation and blur condition) miniaturization ratings were significantly higher than when only one transformation was applied (either the saturation enhancement condition or the defocused blur condition). This might indicate that the miniaturizing transformations employed here were linearly additive in their effects. Interestingly, the naturalness ratings varied in the opposite direction to miniaturization ratings as a function of the stimulus condition (coefficient of correlation between two estimates was -0.53 [p<.01]), suggesting that the observer's impressions of naturalness and miniaturization have a type of trade-off relationship with each other.

On the other hand, the experiment reported here failed to find significant variations of vection strength as a result of these miniaturizing transformations. While the visual transformations employed in this experiment did not alter the observer's self-motion perception, they did powerfully alter the perceived miniaturization and naturalness of these motion picture stimuli. Thus, the results of this experiment do not support the "naturalness hypothesis" originally proposed by Bubka and Bonato (2010) in which they assumed that more natural visual stimulus can induce stronger vection.

The current investigation aimed to novelly examine the effects of observer's visual impression of moving pictures (miniaturization and naturalness in this experiment) on vection, which cannot be approached using an abstract visual pattern conventionally employed in the previous vection experiments (e.g., a random-dot or alternating stripe pattern). In order to achieve the purpose, a psychophysical experiment using a real world stimulus, i.e., a natural visual scene recorded by moving camera which supposed to be equivalent to retinal flow we experienced in our daily self-motion under natural visual environment were conducted. The results demonstrated that some higher-order visual cognitive manipulations (scene miniaturization and decreasing scene naturalness) do not alter self-motion perception. However, one can still point out that there are some possibilities that lower-order visual features may affect the results. It has been reported that chromatic information can modulate vection experience (e.g, Bonato & Bubka, 2006; Nakamura, Seno, Ito & Sunaga, 2010), specifically real world stimulus with natural color can induce stronger vection than monochromatic version of it (Bubka & Bonato, 2010). One can speculate that visual stimulus with enhanced saturation (or chromaticity) would favor self-motion perception. In addition, Palmisano and Gillam (1998) revealed that there is an interaction between stimulus eccentricity and spatial frequency in efficiency of vection induction; visual stimulus with higher spatial frequency can induce stronger vection in the observer's central visual field, but lower-frequency stimulus is more effective in the peripheral area. In the defocused blurred version of the stimulus used in this experiment, there was no difference in the higher frequency component seen in the periphery and in the lower frequency component seen in the central area, because low-pass filtering was applied only for top and bottom of the stimulus, but it is still possible that the lower frequency component would be more salient in the peripheral visual field by lacking of higher frequency, whereas higher frequency component might be relatively enhanced in the central visual field due to spatial contrast against blurred surrounding. Thus, it can be considered that the visual stimulus with defocusing blur had similar features with the optimal inducers described above (as a result of perceptual processing), and would also have an advantage in inducing vection, just like as saturation enhancement . This experiment failed to find significant image miniaturization effects on self-motion perception. However, it may still be possible to speculate that higher-level (decreasing vection by detracting naturalness) and lower-level visual processes (increasing vection by enhancing chromaticity and by selectively removing higher spatial frequencies from peripheral regions) might have cancelled each other out (resulting no overall effect of these visual transformations). Further efforts are needed in order to properly manipulate observer's impression towards visual inducer with carefully avoiding variations of lower-level effects.

In the present investigation, only strength of the observer's perceived self-motion, not its speed, was measured. Miniaturizing manipulations, of course, varied the observer's perception of spatial layout of the visual stimulus (it was typically reflected to miniaturization evaluation). Thus, we need to further take into account a scaling factor which is necessary in calculating speed of self-motion in external world based on retinal flow (e.g., Palmisano, 2002), because it would be plausible that faster perceived self-motion tends to evaluate more strong (e.g., Brandt et al, 1973). Together with examining other visual transformations which can modulate a higher-order visual cognition (such as observer's impression or evaluation towards a visual stimulation), we must consider impacts of employing a real world stimulus as vection inducer in future studies. This enables us to examine visual factors which could never otherwise be assessed using conventional abstract visual patterns, and therefore has the potential to provide us with new breakthroughs in our understanding of vection.

note

1 It should be noted that defocused blur was applied to the top and bottom bands of the visual stimulus, not based on the stimulus eccentricity from the center of the display. However, there should still be a tendency that eccentric part of the stimulus was largely occupied by the blurred image, whereas the central part was not blurred.

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