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# Self-motion perception from expanding and contracting optical flows overlapped with binocular disparity

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**Abstract**

Expanding and contracting patterns were presented on different disparity planes to investigate the role of stereo depth in vection. Experiment 1 tested the effect of stereo depth on inducing vection with expanding and contracting flows on different disparity planes. Subjects reported whether they felt forward or backward self-motion. The results clearly showed the dominance of the background flow in determining one's self-motion direction. Experiment 2 tested the effect of stereo depth on a vection direction using two expanding flows. The center of each expansion was displaced to either horizontal side. The subjects judged in which direction they were going when they felt vection. The results demonstrated that the subjects felt their heading biased toward the direction of the center of the farther expansion while feeling vection. The heading perception from the expanding flow was determined only by the background flow, not by 2-D integration of the retinal motion. The result demonstrates the importance of background flow produced by stereo depth in determining one's self-motion from an expanding/contracting motion.


## 1. Introduction

Some studies have demonstrated that a background (perceptually farther) optical flow determines vection (Ito & Takano, 2004; Kitazaki & Sato, 2003; Ohmi & Howard, 1988; Ohmi, Howard, & Landolt, 1987). Ohmi and Howard (1988) presented an expanding flow pattern and stationary random dots on different disparity planes to test the depth-order effect on inducing forward linear vection. The results showed that the foreground (perceptually closer) dots did not suppress vection induced by the background expanding flow. On the other hand, the opposite depth combination reduced the vection duration to half, not to zero. They attributed the incomplete vection suppression to a possible natural scene situation, that is, an image of a very far object expands slightly during one's forward movement. That is, a combination of an expanding foreground and a stationary background can be interpreted as representing one's forward self-motion without a contradiction.

As for circular vection, Ohmi et al. (1987) and Howard and Heckmann (1989) showed that background flow determined the vection direction when two opposing rotational flows were presented. However, it is possible that the two opposing flows are a cooperative (not competitive) combination for inducing vection because the foreground flow could also induce an "inverted vection" in the same direction as itself (Ito & Fujimoto, 2003; Nakamura & Shimojo, 1999, 2000, 2003). The "inverted vection" may be caused by misregistration of an eye movement in a direction opposite to the foreground flow (Nakamura & Shimojo, 2000). If expanding and contracting flows are presented instead of rotational flow, the effect of "inverted vection" can be removed as the expanding and contracting flow could not be caused by eye-movements.

The purpose of the present paper is to confirm and generalize the above noted background dominance

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in inducing vection using a purely competitive combination of flows. We presented expanding and contracting flows that could induce forward or backward linear vection. In Experiment 1, we superimposed these flows, varying their phenomenal depth. We used a disparity cue to indicate near–far relationship of the flows because it could determine the depth order without ambiguity and was suitable for quantitative manipulation of the phenomenal depth. We predicted that the perceived self-motion direction would be determined by the background flow although the two flows always suggested an opposing self-motion. Experiment 2 tested the effect of stereo depth when two expanding flows overlapped, varying their disparity. The center of each expansion was positioned to left or right of the fixation. If the background flow dominates vection, the perceived heading should be biased toward the center of the background flow.

## 2. Experiment 1

### 2.1. Method

*Subjects.* The second author and three naïve volunteers participated in the experiment. All of the subjects had normal or corrected-to-normal vision.

*Apparatus and stimuli.* The stimulus patterns were generated by a computer (SHARP X68000) and displayed on a video projector (Electrohome Electronics, DRAPAR). The size of the screen was 138 cm (horizontal) × 104 cm (vertical), subtending 75° (horizontally) and 60° (vertically) from a viewing distance of 90 cm. A black cloth covered the left, right and upper sides of the subjects. The display for each eye was treated as a 256 (vertical) × 512 (horizontal) dot matrix. The resolution was not so high, but the quality of the motion display was enough to compel the subjects to feel self-motion. The dot positions were renewed at 55 Hz, creating an impression of motion, while the images on the screen were refreshed at 110 Hz presenting each eye image alternately. The subjects wore LCD shutter goggles (CrystalEyes2) to achieve stereoscopic viewing. The number of dots in each flow pattern was 400 for all of the conditions, i.e., when expanding and contracting flows were overlapped, there were 800 dots on the screen for each eye. The dot luminance measured through the goggles was 7.0 cd/m$^2$ and background luminance was 0.01 cd/m$^2$. The dot diameters were 8.8′. The dot size on the screen was constant although each flow represented an optical motion arising when an observer moved forward or backward through an endless tunnel. Bright dots were attached to the inner surface (Ito, 1996).

The flows were first simulated on the zero-disparity plane as a 2-D expanding or contracting motion display. Therefore, the dots creating each flow pattern had the same disparity and it did not change over time. When they were presented to the subjects, a disparity was added to one of the two overlapping flows. The section of the simulated tunnel was a square (276 cm × 276 cm). The simulated observer's speed was 1.4 m/s. As the farther surface beyond 4 m along the line of sight was not displayed, there were no dots around the fixation cross at the center of the screen. The dots in an expanding (contracting) flow appeared (disappeared) around the fixation and disappeared (appeared) at the screen edge. The two flows were combined as follows (Fig. 1);

*Expansion-zero-disparity conditions:* the expanding flow was presented on the zero-disparity plane with the fixation cross. The contracting flow was presented with an added disparity of 0′, 8.8′, 26.3′ or 44′ in a crossed or uncrossed direction without other changes in the retinal flow. The zero-disparity plane had a relative disparity of 52.2′ in an uncrossed direction from the real screen surface. Thus, the screen frame func-

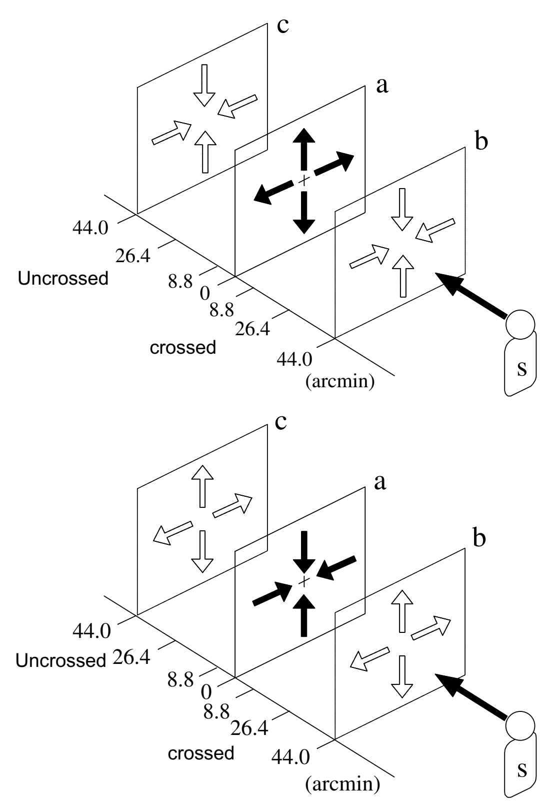


Fig. 1. Schematic illustrations of the stimuli used in Experiment 1. The upper panel shows the stimulus under *expansion-zero-disparity* conditions. An expanding flow pattern was presented on the same disparity plane with that of the fixation cross (a). A superimposed contracting flow pattern varied in seven steps of disparity. (b) or (c) indicates the condition under which a contracting pattern was presented on a plane with 44.0′ uncrossed or crossed disparity, respectively. The lower panel shows the stimulus under *contraction-zero-disparity* conditions. Under this condition, the expansion and contraction were switched.