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Expanding and contracting optic-flow patterns and vection

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Abstract. When stationary observers view an optic-flow pattern, visually induced self-motion perception (vection) and a form of motion sickness known as simulator sickness (SS), can result. Previous results suggest that an expanding flow pattern leads to more SS than a contracting pattern. Sensory conflict, a possible cause of SS, may be more salient when an expanding optic-flow pattern is viewed. An experiment was conducted to test if a more salient sensory conflict accompanying expanding flow patterns might inhibit vection. Participants ($n = 15$) viewed a pattern of blue squares, either steadily expanded or contracted, on a large rear-projection screen. Vection onset and magnitude were measured for 30 s with a computer-interfaced slide device. Vection onset was significantly faster, and vection magnitude stronger, when a contracting pattern was viewed. We propose that our extensive experience with forward self-motion may form a neural expectancy (exposure-history) about the sensory inputs which typically accompany expanding flow. However, since backward self-motion is less common, there may be a weaker exposure-history for contracting flow, and as a result these patterns generate less salient sensory conflict and subsequently less vection.

1 Introduction

Self-motion perception is a common feature of daily life. As we move through the world, our senses provide us with information about where we are going and how fast we are getting there (Howard 1982). Vision often plays an instrumental role. Gibson (1950, 1966) asserted the importance of 'optic flow' for self-motion perception. A large radially expanding optic flow will typically lead to forward self-motion perception (directly towards the focus of expansion—also known as the focus of radial outflow), whereas a contracting optic flow will typically lead to backward self-motion perception.

The non-visual senses also play important roles in self-motion perception. For example, the vestibular organs, responding to gravity and inertia, provide inputs regarding changes in speed and/or heading. During natural forms of self-motion, such as walking, visual and non-visual inputs typically agree, yielding a seamless, unified perceptual experience (Gibson 1966; Howard 1982); inconsistencies are rare. However, inconsistencies (or conflicts) often occur during modern forms of locomotion, both real and virtual.[1]

1.1 *Vehicular and virtual self-motion*

Consider a passenger in a vehicle who is not looking out of a window (eg reading a book). Visual input will indicate that no self-motion perception is occurring, but vestibular

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[1] It should be noted that some theorists (eg Riccio and Stoffregen 1991; Stoffregen and Riccio 1991) argue that there are no situations of inconsistency (ie sensory conflict). Rather, they argue that in terms of sensory inputs, situations can be either redundant or non-redundant. Furthermore, each pattern of multimodal stimulation represents a specific type of self-motion. For example, a non-redundant pattern of stimulation that contains only visual information that the observer is swaying, might specify sway on a non-rigid surface (eg standing on a rocking boat).

input may. In these cases, sensory conflict often occurs. For drivers and pilots, who often see and feel where they are going, there is typically more consistency and thus less conflict.

During virtual travel, sensory conflicts are common. Wide screen films (eg IMAX) often lead to visually induced self-motion perception known as vection (Fischer and Kornmüller 1930; Tschermak 1931) even though non-visual sensory inputs indicate that the observer is stationary. The same is true for vehicle simulators and other virtual-reality platforms. For example, in a fixed-base flight simulator vection may result from the visual display even though the user is stationary relative to Earth. The same is true in an optokinetic drum, a large cylinder that rotates around a stationary (relative to Earth) observer and typically induces circular vection in the opposite direction. In these cases vision indicates self-motion is occurring but non-visual inputs do not.

1.2 *Sensory conflict effects*

Sensory conflict potentially leads to at least two outcomes. In vehicles, kinetosis, commonly known as motion sickness, may result. Although what leads to kinetosis is still debated, a commonly proposed causal factor is sensory conflict (Reason and Brand 1975; Oman 1990). While such conflicts often involve vision, the vestibular system has been strongly implicated in causing kinetosis, since individuals who lack a functioning vestibular system seem to be immune (Cheung et al 1991). In virtual environments, sensory conflict often leads to simulator sickness (SS) (Kennedy et al 1989), a variant of kinetosis.

Sensory conflict may also affect vection, specifically by diminishing it. Often in virtual environments vection does not occur immediately; there is typically a brief onset latency. Zacharias and Young (1981) have suggested that vection onset latency is due to a lack of consistency between vestibular and visual inputs that is the most extreme when a visual stimulus is first viewed. Because the vestibular system responds to changes in speed, this inconsistency dissipates quickly as expected vestibular activity decreases and becomes more similar to what one would expect during steady self-motion.

Other findings suggest that: (i) vection can be 'jump started' with an impulse acceleration that is consistent with optic flow (Brandt et al 1974; Melcher and Henn 1981; Wong and Frost 1981); and (ii) vestibular stimulation that results in a sudden inconsistency can diminish or destroy vection (Young et al 1975; Teixerira and Lackner 1979). Collectively, such reports suggest that consistent sensory inputs typically facilitate vection and inconsistent inputs inhibit vection.[2]

1.3 *Expanding and contracting optic-flow patterns*

Recently, we reported results of an SS experiment in which participants viewed either an expanding or contracting optic-flow pattern on a CRT monitor screen for five min (Bubka et al 2007). In all ways, except flow-pattern direction, conditions were the same. The Simulator Sickness Questionnaire (Kennedy et al 1993) was used to assess symptoms. Results suggest that an expanding optic-flow pattern leads to more overall SS, and higher subscores corresponding to nausea, oculomotor effects, and disorientation. If a sensory conflict explanation is applied to these results, one would logically conclude that less conflict, or a less salient conflict, occurred when the contracting pattern was viewed.

If sensory conflict also suppresses vection, then it logically follows from the results of our SS experiment that an expanding optic-flow pattern will lead to less vection

[2] Not all cases of sensory input inconsistencies inhibit vection. Sometimes increasing the mismatch between visual and non-visual inputs can actually increase vection magnitude. The addition of coherent visual field 'jitter' in an optic-flow pattern enhances vection (Palmisano et al 2000, 2003; Palmisano and Chan 2004). Palmisano's work raises the possibility that because of past experiences of walking and running, visual field jitter is accepted, and perhaps even expected, by the visual system as a normal feature of optic-flow patterns.

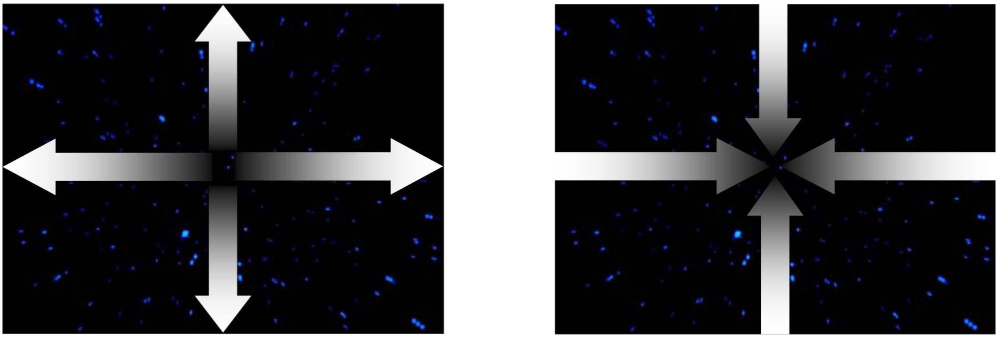
than a contracting pattern. This was the hypothesis for the current study. Few published reports have addressed the effects of optic-flow direction on vection and conclusions are mixed. Reinhardt-Rutland (1982) used a large rotating spiral stimulus to elicit vection and reported that the forward vection induced when the pattern expanded was stronger than the backward vection induced when the pattern contracted (contrary to our hypothesis). Other results suggest that we are more sensitive to contracting optic-flow patterns and that these in turn are more likely to induce vection than expanding optic-flow patterns (Berthoz et al 1975; Edwards and Badcock 1993; Edwards and Ibbotson 2007).

2 Experiment

2.1 *Method*

2.1.1 *Participants.* Fifteen undergraduate volunteers participated in the experiment (eight males), with a mean age of 18.5 years. All had normal or corrected-to-normal vision and no one reported any neurological, vestibular, or gastrointestinal problems. All participants reported general good health at the time of the experiment.

2.1.2 *Stimuli.* The stimulus pattern consisted of an array of light-blue squares against a dark background (see figure 1). The squares either steadily expanded from the centre of the screen (expanding condition), or contracted (contracting condition). Perspective was incorporated into the displays. At maximum size, each element subtended 2.6 deg. As elements expanded, their velocity towards the edge of the screen increased. While simulated speed and distance are relative in this type of display, it is useful to specify these values in real-world units. These expanding/contracting optic-flow displays were consistent with the observer traveling in an aircraft cruising at a speed of 340 km h^{-1} with a visible range of 220 m.[(3)] At any given time, approximately 500 squares were visible on the screen. The resulting display yielded a percept of moving through space. The only difference between the expanding and contracting conditions was the direction of simulated self-motion.



(a) (b)

Figure 1. [In colour online, see http://dx.doi.org/10.1068/p5781] (a) The stimulus patterns used included an expanding optic-flow pattern that led to forward vection, and (b) a contracting optic-flow pattern that led to backward vection.

(3) In virtual environments, speed and distance are relative. The perceived speed of vection depends on how much depth was perceived in the display and this may have varied among individuals. As the perceived depth of the display is reduced, the perceived speed of vection is also reduced. Thus, even though our display was consistent with a speed of 340 km h^{-1} with a visible range of 220 m, other perceived speeds were possible and even likely given that a compression of the depth in the display most likely occurred.

2.1.3 *Apparatus.* The stimulus displays were presented on a flat rear-projection screen 2.3 m tall and 2.8 m wide resulting in a display that subtended 98 deg by 108 deg. The screen was vertically positioned and perpendicular to the participant's line of sight. Displays were generated with an Apple G4 desktop computer and projected with an NEC MT1075 LCD projector (5 m from the screen) at a resolution of 1024×768 pixels and a refresh rate of 48 Hz.

Vection was measured with a Biopac MP100 data-acquisition system (configuration similar to that used by Bonato and Bubka 2006). The participant manipulated the slide control on a Biopac TSD-115 variable transducer using his/her right index finger. The slide was positioned horizontally relative to the participant's line of sight. The system allowed vection onset (in seconds) and magnitude (0%–100%) to be recorded with a Dell desktop computer. The amount of slide distance corresponded to the height of a curve plotted in real time.

2.1.4 *Procedure and design.* The participant was seated 1 m from the projection screen. He/she was told the trial would last 30 s and then provided a detailed description of vection. Instructions were given regarding the slide device and participants were told to explore the entire range of the slide. They were told that not pushing the slide would mean that no vection was being experienced. Pushing the slide completely to the right would mean that vection was saturated, that is the scene on the screen appeared unmoving and the participant perceived himself/herself as moving though a stationary environment. Pushing the slide halfway would mean that the elements on the screen appeared to be moving in one direction and the participant perceived self-motion in the opposite direction (at the same speed).

The participant was instructed to close his/her eyes until the experimenter indicated to open them at which time the trial would begin. The stimulus display was projected and the participant was instructed to open his/her eyes thus indicating the start of the trial. After the 30-s trial concluded, the participant was asked to describe any self-motion perception that he/she may have experienced. The stimulus pattern was changed and after a 5 min rest period elapsed the same procedure was repeated for the subsequent trial.

There were two conditions in this experiment: (i) expanding, and (ii) contracting. Each participant served in both conditions in counterbalanced order.

2.2 *Results*

A composite graph representing all the responses of the participants for the full time course (30 s) of the trials is shown in figure 2a. This graph suggests that the mean slide distance was higher in the contracting condition than in the expanding condition throughout the entire trial. This pattern suggests that the vection perceived in the contracting condition was more salient than the vection perceived in the expanding condition.

Vection onset latency is defined as the time interval between the beginning of a trial and the time at which the slider was first moved to indicate that vection was perceived. Mean vection onset latencies for the expanding and contracting conditions were 7.1 s ($SD = 3.6$, $SE = 0.92$) and 4.3 s ($SD = 2.1$, $SE = 0.54$), respectively (see figure 2b). A t-test for paired samples (two-tailed) indicated that these onset times were significantly different ($t_{14} = 2.8$, $p < 0.013$). Overall vection magnitude was defined as the mean amount of slide distance on the variable assessment transducer that occurred during the entire 30-s trial. This distance was calibrated on a 0–100 scale (0 = no vection, 100 = vection completely saturated). The mean overall vections (figure 2c) obtained in the expanding and contracting conditions as indicated by mean slide distance (0–100) were 13.1 ($SD = 13.2$, $SE = 3.4$) and 23.9 ($SD = 20.1$, $SE = 5.2$), respectively (see figure 1b). The mean slide distance obtained in the expanding condition

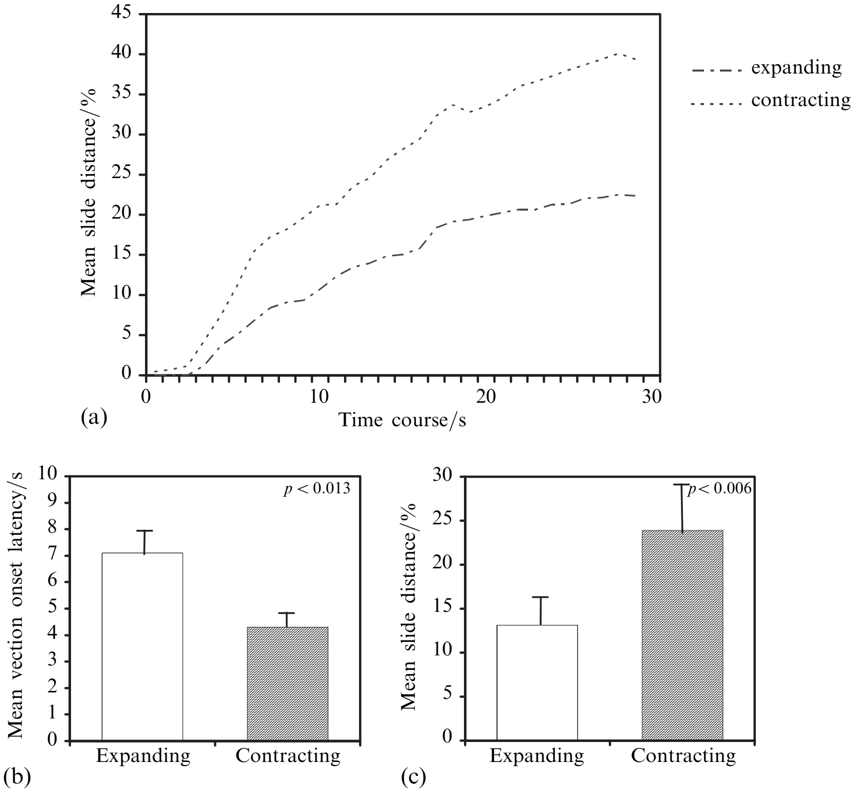


Figure 2. (a) The composite graph representing all the responses of the participants for the full time course (30 s) of the trials, (b) experimental results showing mean vection onset latencies, and (c) mean slide distance percentages (0 – 100) for the 30-s trials. Error bars represent the standard error.

was significantly lower ($t_{14} = 3.2$, $p < 0.006$) than the mean distance obtained in the contracting condition.

Verbal reports pertaining to the participants' perceptions of self-motion were unanimous regarding the direction of vection. When the expanding pattern was viewed, participants reported that forward self-motion was perceived. When the contracting pattern was viewed, participants reported that backward self-motion was perceived.

3 Summary and conclusions

These results suggest that simply changing optic-flow pattern direction can affect vection. Specifically, a contracting pattern leads to a significantly faster onset of vection and an increase in overall vection magnitude. The effect sizes were large; on average, vection onset was 65% faster in the contracting condition than in the expanding condition and overall vection magnitude was 82% higher in the contracting condition. Given participants' unanimous verbal reports regarding the perceived direction of vection, these results collectively suggest that under the current experimental conditions it is easier for participants to perceive backward self-motion than forward self-motion.

One possible explanation for the current results is based on recent findings by Edwards and Ibbotson (2007) that indicate that observers are more sensitive to large-field contracting optic-flow patterns than to large-field expanding optic-flow patterns. They suggest an explanation based on anatomy. Because our feet project forward, it is easier to stop ourselves pitching forward than it is to stop pitching backward, and we can do this over a greater pitch angle. Thus, in order to maintain balance, it is more important for us to detect backward sway (large-field radial contraction) than forward sway (large-field expansion). As a result, they suggest that we are more sensitive to contracting flow and more prone to backwards vection. Such an explanation would predict differences in sensitivity to sideways sway as well. However, we are unaware of any controlled studies that have addressed this issue.

We suggest an explanation based on sensory conflict. In principle, non-visual inputs should have equally indicated that no self-motion was occurring in both conditions; the participant was simply sitting on a stationary stool. However, it is likely that: (i) our greater experience locomoting/moving forwards (as opposed to backwards) strengthened our expectations about the type/nature of non-visual activity that should accompany radially expanding flow patterns, and (ii) the sensory conflict arising from comparisons between visual and non-visual inputs, should be greater for expanding patterns than for contracting patterns.

It has been argued for more than a century (Irwin 1881) that adaptation is the result of sensory rearrangement, a recalibration of what the appropriate sensory inputs should be under a given set of circumstances. The sensory-rearrangement theory (see Reason and Brand 1975) asserts that all situations that lead to kinetosis are characterized by visual sensory input that is inconsistent with one or more non-visual sensory inputs, most notably, the vestibular system (Cheung et al 1991). Establishing that a variance exists requires a comparison of current sensory inputs to those retained from the past. Held (1961) referred to these retained sensory inputs as an 'exposure-history'.

If new sets of visual and non-visual inputs are repeatedly experienced, they come to replace the old exposure-history. An example that helps support this idea is that experienced pilots are more susceptible to SS than less experienced pilots (Braithwaite and Braithwaite 1990; Johnson 2005). Experienced pilots have a well established exposure-history regarding what the visual and non-visual sensory inputs should be during actual flight. When using a flight simulator, experienced pilots are exposed to sensory inputs that do not match their exposure-history, resulting in a higher probability of SS. Less-experienced pilots, having a less-established exposure-history regarding actual-flight, may be more apt to accept the sensory inputs that occur under simulator conditions.

3.1 *Vection and sensory rearrangement*

The same exposure-history that may affect kinetosis may also affect vection. During active forms of self-motion such as walking, sensory inputs will hardly ever deviate from those stored in an individual's exposure-history. However, when vection occurs, sensory inputs will often be inconsistent with an individual's exposure-history, especially if the vection-producing situation is novel. This analysis, if true, may explain why vection occurred faster and with a greater degree of magnitude in the contracting condition of the current study.

It seems reasonable to assume that forward self-motion is more common than backward self-motion. This is true for both natural and vehicular forms of self-motion. It is also a reasonable assumption that forward self-motion was recently experienced by most individuals (they all walked forward when entering the lab). These assumptions suggest that in the expanding condition of the current study, sensory inputs were inconsistent with those stored in the participants' exposure-histories. Specifically, the non-visual inputs that normally accompany expanding optic-flow patterns were absent. This inconsistency may have inhibited vection.

The same sort of inconsistency probably occurred in the contracting condition, but not to the same degree. Given the less common occurrence of backward self-motion, a weaker influence of the exposure-history in the contracting condition may have led to less inhibition of vection. Hence, vection onset was faster and magnitude stronger in the contraction condition.

3.2 *Future research*

Although our assumption that expanding optic-flow patterns are more commonly encountered than contracting patterns is one that we think few would argue with, more research is needed to support the existence of a causal link between experience and vection. One question that should be addressed is how much influence does recent history exert on vection? In other words, how much exposure to a set of sensory inputs does the orienting system need to reconfigure an individual's exposure-history? And furthermore, are there procedures that could be employed that would hasten adaptation processes? Future experiments in our lab will be designed to address some of these questions.

Theoretical predictions can be made about other types of vection (eg yaw, pitch, roll, and horizontal linear). If our hypothesis about exposure-histories effects on vection is correct, we can predict that less commonly experienced types of flow patterns will facilitate vection and more commonly experienced types will inhibit it. Such studies will require careful controls and it is almost certainly the case that other variables besides exposure-histories affect vection. Although studies related to these types of vection have been conducted, comparisons under controlled conditions that hold all other variables constant are lacking.

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