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Independent modulation of motion and vection aftereffects revealed by using coherent oscillation and random jitter in optic flow

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ABSTRACT

We added simulated vertical viewpoint jitter and oscillation to radial optic flow displays designed to induce forward vection. Display jitter and oscillation were both found to increase vection strength during, and reduce motion aftereffects (MAE) following, exposure to the optic flow (compared to no-jitter controls). Display jitter, which induced the strongest vection of all the conditions tested, was also found to increase the duration of vection aftereffects (VAE).

1. Introduction

Almost all perceptual properties change their detection thresholds and are biased towards the opposite quality following adaptation. For example, motion direction (e.g. Nishida & Sato, 1995), size (e.g. Nishida, Motoyoshi, & Takeuchi, 1999), orientation (e.g. Sekuler & Littlejohn, 1974), face (e.g. Moradi, Koch, & Shimojo, 2005) and gender (e.g. Afraz & Cavanagh, 2009) can all generate such aftereffects. In the case of the first example, it has long been known that motion aftereffects (MAE) can occur after prolonged exposure to visual motion. The earliest reports of the MAE date back to ancient Greece, with Aristotle reporting a MAE after viewing the rapidly moving water of a flowing river (Mather, Verstraten, & Anstis, 1998). In this study we also examine aftereffects of visual self-motion perception, i.e. the vection aftereffect (VAE). The first clear report of a VAE – distinct and separate from the MAE – was only made in 1974 (Brandt, Dichgans, & Büchele, 1974). It received little further examination until Seno, Ito, and Sunaga (2010) recently showed that the VAE can persist after both the display motion and the MAE had ceased.

Stationary observers can often experience compelling visual illusions of self-motion, referred to as vection (Fischer & Kornmuller, 1930), when they are exposed to large patterns of optic flow. For example, a vection experience is also likely to occur in Aristotle's above-described scenario – where the observer views a wide, quickly flowing river (e.g. from above on a bridge). This vection will typically occur in the opposite direction to the river's motion during exposure to its optic flow. As stated above, prolonged viewing of this optic flow will generate a MAE when the observer changes his/her view to another, stationary, part of the surrounding scene (e.g. Nishida & Sato, 1995). However, what happens to the observer's vection experience after prolonged viewing of optic flow? Brandt, Dichgans, and Büchele (1974) reported that vection persisted when observers were placed immediately into darkness following 30 s to 15 min exposure to optic flow. This persistence appears to be the first report of an after-effect of vection. The VAEs found by Brandt, Dichgans, and Büchele (1974) were strongly mediated by oculomotor responses. They used a luminance-defined moving grating that moved rightward or leftward and the subjects' eyes were free to track the rotating drum. Brandt et al. found that the directions of their VAEs were determined by the directions of the subject's optokinetic nystagmus (OKN) and optokinetic after nystagmus (OKAN). More recently Seno, Ito, and Sunaga (2010) showed that VAEs can be induced without oculomotor mediation by using an expanding and contracting optic flows. These expanding and contracting optic flows did not generate smooth pursuit eye-movements. Thus they showed that without oculomotor mediation: (i) vection aftereffects (which they named VAEs) occur in the opposite direction to the vection experienced during adaptation; and (ii) these VAEs are distinct from general motion aftereffects (or MAEs). In this study, radially expanding or contracting optic flow patterns were presented during adaptation, and then after this adaptation period, static dots or dynamic random dots were presented. While VAE duration appeared to be independent of MAE duration (measured on separate trials), VAE duration increased with the strength of the vection experienced during adap-

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tation. Longer VAEs were found following exposure to radially contracting displays (which induced stronger backwards vection) compared to radially expanding displays (which induced weaker forward vection). Similarly, when vection during the adaptation period was facilitated or inhibited by the presence of a near or far static dot plane (superimposed onto the optic flow display), the duration of the subsequent VAE was increased or decreased respectively. To our knowledge there has been no VAE research other than the two studies described above.

In the earlier study, we examined the relationship of the VAE to the strength of the vection induced by presenting purely radial flow during the adaptation period. Simulated viewpoint jitter and oscillation have both been shown to facilitate the vection in depth induced by such radial flow patterns – see Palmisano, Gillam, and Blackburn (2000), Palmisano, Burke, and Allison (2003), Palmisano and Chan (2004), Palmisano et al. (2007) and Palmisano and Kim (2009). The exact cause of these jitter and oscillation based vection enhancements is still unknown (see Palmisano et al. (2011) for a review). These enhancements cannot be explained by prevailing sensory conflict accounts of visual self-motion perception, which predict that rather than enhancing vection, this simulated viewpoint jitter/oscillation should impair vection by increasing the visual-vestibular conflict experienced by the stationary observer (as unlike purely radial flow simulating constant velocity self-motion, this jittering/oscillating radial flow should be accompanied by significant and sustained vestibular inputs).

In the present study, we investigated the effects that adding simulated viewpoint jitter and oscillation have on the vection, the MAE and the VAE induced by radial flow. Our radially expanding displays simulated constant velocity forward self-motion in depth, and therefore should induce forward vection during adaptation and contracting MAEs post-adaptation. When visual jitter or oscillation was then added to these radial flow displays, they also simulated continuous random/oscillatory vertical impulse self-accelerations (similar to the effects of 'camera shake' or 'head bobbing' while walking respectively). We expected that this visual jitter and oscillation would decrease the durations of the MAEs generated following exposure to the radial flow (see the reduced motion adaptation hypothesis in the following paragraph).

We were particularly interested in what would happen to the VAE when, by adding jitter/oscillation to the radial flow, vection was made more compelling during adaptation phase and the MAE was reduced during the subsequent test phase. If the VAE is only dependent on the strength of vection experienced during adaptation, then we would expect VAE duration to be increased by both visual jitter and oscillation, even though MAE duration should be reduced by these flow components. However, if the VAE is mediated by the MAE, then we might expect both VAE and MAE durations to be shortened by adding visual jitter and oscillation. Seno, Ito, and Sunaga's (2010) findings suggest that the VAE depends on the strength of the vection experienced during adaptation and is independent of the MAE. Based on these findings, we predict adding simulated vertical viewpoint jitter and oscillation to radially expanding flow will increase the (backwards) VAE.

The reduced motion adaptation hypothesis of the simulated viewpoint jitter and oscillation advantages for vection is as follows. When observers are presented with radial flow simulating constant velocity self-motion in depth, their experience of vection should decrease over time as they adapt to the local 1D motion generated by this flow[2] (Denton, 1980; Salvatore, 1968; Schmidt & Tiffin, 1969). However, this adaptation may be reduced by adding either simulated oscillation or random viewpoint jitter to the radial display, which in turn may reduce the decline in vection in depth over time. Visual jitter/oscillation are both composed of up–down opposite directional motion signals, which should cancel each other out. Thus, there should be little adaptation to the jitter/oscillation itself. While adaptation should still occur to motion arising from the main radial component of the optic flow, it is expected that jitter and oscillation should reduce this adaptation by acting as noise (which would impair the extraction of this global radial motion signal). One aim of the current experiments was to test this reduced motion adaptation explanation of these two vection advantages for the first time.

[2] It should be noted that classical motion adaptation would not actually occur to the radial component of the flow, but rather to the 1D local motion (which in our displays was radial). The simulated viewpoint oscillations should make this 1D motion more variable, thus reducing this adaptation.

2. Experiment 1

In Experiment 1, we presented subjects with radially expanding optic flow, either with or without simulated viewpoint oscillation, and recorded: (i) the vection obtained during the adaptation period; and (ii) the MAE and VAE durations (in separate trials) following adaptation. Since simulated viewpoint oscillation was expected to increase vection (compared to conditions with purely radial flow), it was also expected to increase VAE durations. However, this oscillation was also expected to reduce MAE durations (as it should act as noise and thereby reduce adaptation to the local motion arising from the radial component of the optic flow).

2.1. Method

2.1.1. Apparatus

Stimulus displays (pixel resolution, 1024×768; refresh rate, 75 Hz) were generated and controlled by a computer (Apple MB543J/A). They were rear projected onto a screen by a data projector (DRAPAR; Electrohome Electronics). The experiments were conducted in a darkened room.

2.1.2. Stimuli

Our adaptation and test stimuli were created using OpenGL. They subtended a visual angle of 72° (horizontal) × 57° (vertical) at the viewing distance of (approximately) 90 cm. The mean luminances of the background and the dots were 0.01 cd/m^2 and 36.65 cd/m^2, respectively. The subjects observed the stimulus binocularly.[3]

The adaptation stimuli were (vertically-oscillating and non-oscillating) patterns of radially expanding optic flow, which were presented for either 20 or 60 s. These self-motion displays were created by positioning 16,000 dots at random inside a simulated cube (length 20 m), and moving the observer's viewpoint to simulate forward self-motion of 6 m/s. In oscillating display conditions, in addition to moving forward, the subject's simulated viewpoint was also oscillated vertically. When present, the amplitude of this added vertical viewpoint oscillation was either 1/3 or 1/6 of the simulated forward movement and the oscillation frequency was either 2 or 4 Hz. We used a triangle wave as the basis for this display oscillation[4]).

[3] We chose binocular viewing of the stimuli. Palmisano (1996) has previously shown that there is no difference in the vection strengths, onsets and durations induced by binocularly-viewed-non-stereoscopic and monocularly-viewed radial flow. This has been replicated many times since. He did find a stereoscopic advantage for vection, when binocular disparities were consistent with the available monocular information provided by his relatively sparse radial flow patterns (Palmisano, 1996, 2002). Subsequent studies with real world motion picture optic flow stimuli have failed to find a significant stereoscopic advantage for vection (e.g. Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 1999; Ohmi, 1998).

[4] Palmisano, Allison, and Pekin (2008) have previously used simulated viewpoint oscillation based on a triangle wave stimulus. The effects on vection were very similar to simulated viewpoint oscillation based on a sinusoidal stimulus.