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Global-perspective jitter improves vection in central vision

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Abstract. Previous vection research has tended to minimise visual – vestibular conflict by using optic-flow patterns which simulate self-motions of constant velocity. Here, experiments are reported on the effect of adding 'global-perspective jitter' to these displays—simulating forward motion of the observer on a platform oscillating in horizontal and/or vertical dimensions. Unlike non-jittering displays, jittering displays produced a situation of sustained visual – vestibular conflict. Contrary to the prevailing notion that visual – vestibular conflict impairs vection, jittering optic flow was found to produce shorter vection onsets and longer vection durations than non-jittering optic flow for all of jitter magnitudes and temporal frequencies examined. On the basis of these findings, it would appear that purely radial patterns of optic flow are not the optimal inducing stimuli for vection. Rather, flow patterns which contain both regular and random-oscillating components appear to produce the most compelling subjective experiences of self-motion.

1 Introduction

A number of sensory systems are responsible for the perception and control of self-motion—visual, vestibular, proprioceptive, somatosensory, and auditory systems may all play a role (Benson 1990; Gibson 1966; Howard 1982; Johansson 1977). Of these modalities, the visual and vestibular systems appear to be particularly important. Research has shown that the visual system can register any type of self-motion on the basis of the optic flow(1) presented to the observer (ie active/passive, linear/rotary, constant velocity/accelerating self-motions—Brandt et al 1973; Lishman and Lee 1973). However, vision appears primarily sensitive to optic-flow patterns with low temporal frequencies and/or simulating self-motions of constant velocity (Berthoz et al 1975, 1979; Dichgans and Brandt 1978; van Asten et al 1988). Conversely, the vestibular system registers only accelerating self-motions—on the basis of the inertia of the fluid in the semicircular canals and otolith organs (Benson 1990; Howard 1986a). As a result, this modality is primarily sensitive to brief high-frequency stimulations (> 1 Hz; Diener et al 1982, 1984; Melville-Jones and Young 1978) and is unable to distinguish between traveling at a constant linear velocity and remaining stationary (Lishman and Lee 1973).

Visual and vestibular systems normally provide redundant information about self-motion (Gibson 1966). However, there are situations where they apparently conflict(2) (for example when a stationary observer views an IMAX movie representing

(1) Optic flow is defined here as the temporal change in the pattern of light intensities in different directions at the moving point of observation (Gibson 1966; Warren et al 1988).

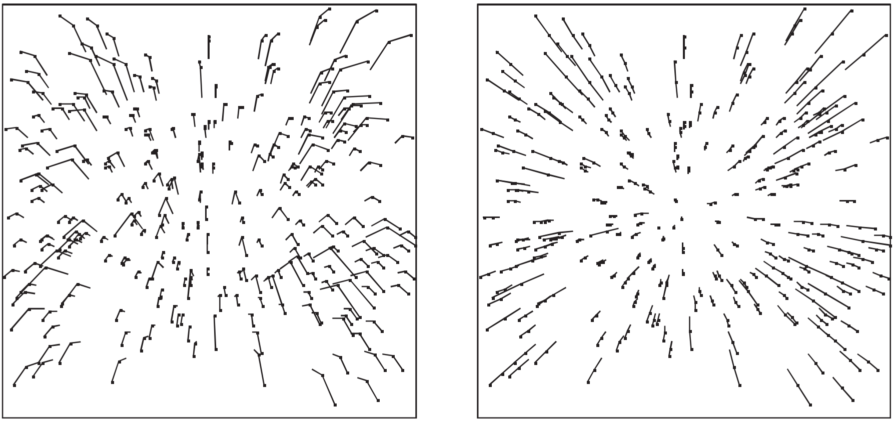
(2) The concept of visual – vestibular conflict is not accepted by all researchers. According to Riccio and Stoffregen (1991) there are no situations of sensory conflict, only situations of 'nonredundancy'. Each pattern of multimodal stimulation, regardless of whether it is redundant or nonredundant, represents a specific type of self-motion (ie a possible state of affairs). For example, a nonredundant pattern of multimodal stimulation, which contains visual information that the observer is swaying without corresponding somatosensory information, might specify sway on a nonrigid (as opposed to a rigid) surface.

accelerating self-motion). The simplest solution to such a conflict would be for vision to dominate self-motion perception (Lishman and Lee 1973). Consistent with this notion, compelling illusions of self-motion can be induced by visual information alone—referred to as vection. For example, Lee and his colleagues have shown that when subjects are placed inside a 'swinging room'—where the walls and ceiling swing back and forth—they quickly experience a visual illusion that they themselves are swaying (Lee and Aronson 1974; Lee and Lishman 1975; Lishman and Lee 1973). They argue that such illusory self-motions occur because visual information (indicating self-motion) overrides input from the vestibular, somatosensory, and proprioceptive systems (indicating that the observer is in fact stationary).

However, other vection research suggests that visual–vestibular conflicts are not so simply resolved. Psychophysical studies with optic-flow patterns which simulated constant velocity (rotary) self-motions showed that: (i) stationary observers initially (for the first 3–4 s) perceive the flow as entirely due to object motion; (ii) they then experience a period of perceived self-acceleration in the opposite direction to the flow; and (iii) finally, after about 8–18 s exposure, observers perceive the flow as entirely due to self-motion (Brandt et al 1973; Held et al 1975; Young et al 1975). Zacharias and Young (1981) explain this time-course in terms of the presence or absence of visual–vestibular conflict—defined as the difference between the current vestibular signal and the expected vestibular signal based on the optic flow. According to their theory, the optic flow initially produces a visual–vestibular conflict in stationary subjects, since the expected vestibular input is absent (real self-motions of constant velocity are preceded by a brief period of acceleration which would be detected by the vestibular system), resulting in perceived object motion. This conflict fades quickly and disappears, as the expected vestibular input decreases below detection threshold (real constant-velocity self-motions generate negligible vestibular input), resulting in exclusive vection.

Additional support for the notion that visual–vestibular conflict impairs vection is provided by observations that: (i) onset latencies for (circular) vection are shorter when visual and vestibular inputs are initially consistent (eg the observer undergoes an impulse acceleration in the simulated direction of self-motion while viewing a display indicating constant velocity self-motion—Brandt et al 1974; Melcher and Henn 1981; Wong and Frost 1981); (ii) conflicting vestibular input can destroy (circular) vection (eg sudden acceleration of the observer in the opposite direction to the simulated self-motion—Teixeira and Lackner 1979; Young et al 1973); (iii) (linear) vection along the vertical spinal axis has shorter onset latencies than (linear) vection along the horizontal sagittal axis—the former being thought to generate less visual–vestibular conflict than the latter (Giannopulu and Lepecq 1998); and (iv) the lack of any vestibular input during visual displays simulating a roller-coaster ride results in rather weak vection (Wann and Rushton 1994).

In the present experiments we further examined the effect of visual–vestibular conflict on vection. Visual displays were of two types: (i) Non-jittering displays simulated forward self-motion of constant velocity through a three-dimensional cloud of objects (see figure 1b). These radially expanding patterns of optic flow were similar to those used in previous linear-vection studies and produced minimal/transient visual–vestibular conflict (eg Andersen and Braunstein 1985; Ohmi and Howard 1988; Palmisano 1996; Telford et al 1992; Telford and Frost 1993). (ii) Jittering displays simulated forward self-motion of constant velocity combined with continuous, random horizontal and/or vertical impulse self-accelerations (similar to the effects of 'camera shake'—see figure 1a). These displays were radially expanding patterns of optic flow superimposed with horizontal and/or vertical 'global perspective jitter' (at particular points in time, the same randomly determined displacement, modified by perspective, was applied to all points in



(a) (b)

Figure 1. A representation of (a) jittering and (b) non-jittering patterns of radially expanding optic flow.

the flow field).[3] Unlike non-jittering displays, jittering displays were designed to produce a situation of sustained visual–vestibular conflict in a stationary observer.

Given the above findings, we expected that the lack of consistent vestibular input would bias observers to perceive jittering patterns of optic flow as due to object motion rather than self-motion. If so, vection should diminish as the magnitude and temporal frequency of the jitter increases (ie as the mismatch between visual and vestibular information increases).

2 Experiment 1: Does global-perspective jitter impair vection?

2.1 *Method*

2.1.1 *Subjects.* Seven male and seven female undergraduate psychology students (aged between 18 and 24 years) participated in this experiment. All had normal or corrected-to-normal vision and had not previously experienced illusions of self-motion in the laboratory.

2.1.2 *Design.* Two independent variables were manipulated in this experiment. (i) *Display type*. Displays were either jittering or non-jittering patterns of radially expanding optic flow. When present, global-perspective jitter occurred along either the horizontal (x) axis, the vertical (y) axis, or both the x- and y-axes. (ii) *Display speed.* Each display simulated one of three speeds of forward self-motion: 2.7 m s^{-1}, 4 m s^{-1}, and 7 m s^{-1}. Regardless of their type or speed, all displays simulated self-motion through a three-dimensional cloud of 150 randomly positioned objects.

2.1.3 *Apparatus.* Displays were generated on an IBM 486-DX (75 MHz) personal computer and presented on a superVGA monitor with 1024 H $\times$ 768 V pixel resolution. The screen of this monitor subtended a visual angle of 40 deg H $\times$ 32 deg V when viewed from a chin-rest 50 cm away. Since vection has been found to be dominated by the motion of the perceived background (Ohmi and Howard 1988; Telford et al 1992), inducing displays were presented 20 cm behind a large black cardboard mask. Kinetic occlusion always indicated that the display was in the background while the mask was in the foreground. This mask was placed in front of the subject, and two large partitions were placed on either side to restrict the subject's vision. Only the monitor could be seen

[3] 'Global-perspective jitter' should not be confused with 'global jitter'. While the former represents forward self-motion on a platform which is oscillating along the horizontal and/or vertical axes, the latter represents forward self-motion through a sandstorm.

through a square window at the far end of this black viewing booth (1 m wide × 2 m deep × 2 m high). As the inducing displays were viewed monocularly, the subject's right eye was always covered by an eye-patch.

2.1.4 *Visual displays.* Non-jittering displays simulated forward self-motion (z-axis) of a constant velocity relative to a three-dimensional cloud of randomly positioned objects. This was achieved by increasing the velocity and total area (0.07 deg – 1.21 deg) of each object as it appeared to approach the observer. Jittering displays were identical to non-jittering displays, with the exception that horizontal (x-axis) and/or vertical (y-axis) jitter was added to the optic flow. They simulated the observer moving forward on a platform which oscillated in horizontal and/or vertical directions. The absolute amount of horizontal and/or vertical jitter for each frame was randomly selected from a range of $0 - \frac{1}{3}$ of the simulated forward displacement. Its direction (left/right for horizontal jitter and up/down for vertical jitter) alternated from frame to frame. This signed jitter was then given the appropriate perspective transformation before it was applied to objects at different simulated locations in depth, ie the jitter component was less for more distant objects; we refer to this as global-perspective jitter.

Both jittering and non-jittering optic flow consisted of moving green filled-in squares (with a luminance of 3 cd m^{-2}) on a black background (0.03 cd m^{-2}). As objects disappeared off the edge of the screen, they were replaced at the opposite end of space (a simulated distance of 20 m along the z-axis) at the same (x, y) coordinates. To reduce the sensation of their sudden appearance, these objects were initially replaced as dots which were slightly darker (1.6 cd m^{-2}) than the nearer objects. All displays had a frame rate of 30 Hz and were symmetrical about both the x-axis and the y-axis.

2.1.5 *Procedure.* Subjects were told that they would be shown displays of moving objects and: "Sometimes the objects may appear to be moving towards you; other times you may feel as if you are moving towards the objects. Your task is to press the mouse button down when you feel as if you are moving and hold it down as long as the experience continues. If you don't feel that you are moving then don't press the mouse button" (instructions modified from Andersen and Braunstein 1985). Subjects were also informed that each display had a fixed duration of 3 min and an intertrial interval of 20 s. After two practice trials, the experimental displays were presented in a random order.

2.2 *Results*

Vection was reported in 166 of the 168 trials (fourteen subjects responding to twelve stimuli). Of the two trials where vection was not induced, one had a non-jittering display and the other had a display which jittered in both the x-axis and the y-axis. Separate repeated-measures ANOVAs were performed on the onset and duration data. The means are shown in figures 2a and 2b. Overall, jittering displays were found to produce significantly shorter vection onsets ($F_{1,13} = 11.39$, $p < 0.002$) and significantly longer vection durations ($F_{1,13} = 15.13$, $p < 0.0001$) than non-jittering displays. However, displays with horizontal jitter did not produce significantly different vection onsets ($F_{1,13} = 0.166$, $p > 0.05$) or durations ($F_{1,13} = 2.055$, $p > 0.05$) from displays with vertical jitter. Similarly, displays which jittered in both directions (horizontal and vertical) did not produce significantly different vection onsets ($F_{1,13} = 0.187$, $p > 0.05$) or durations ($F_{1,13} = 0.857$, $p > 0.05$) from displays which jittered in only one direction.

Increasing the simulated speed of forward self-motion did not significantly affect either vection onsets ($F_{2,26} = 1.034$, $p > 0.05$) or vection durations ($F_{2,26} = 0.240$, $p > 0.05$). No two-way interactions (ie between display type and display speed) reached significance in this experiment.

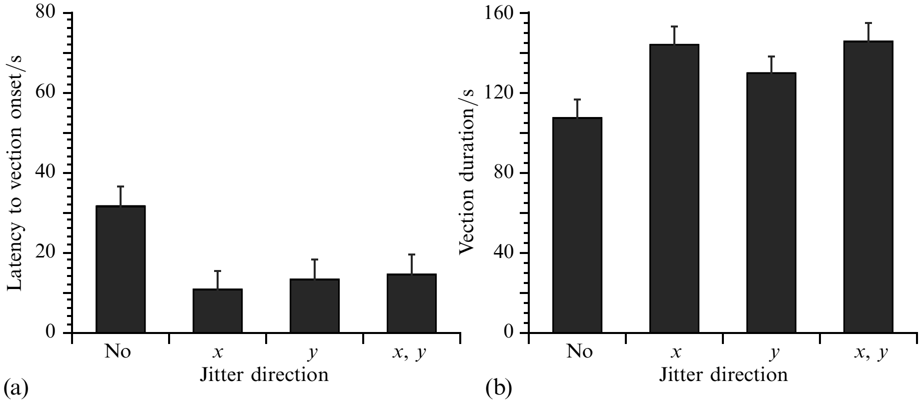


Figure 2. The effect of global-perspective jitter on (a) vection onsets and (b) vection durations (experiment 1). Displays either had no jitter (No), jitter along the *x*-axis (*x*), jitter along the *y*-axis (*y*), or jitter along both the *x*-axis and the *y*-axis (*x*, *y*). Error bars represent standard errors of the means.

2.3 *Discussion*

Contrary to prediction, jittering patterns of optic flow were found to induce the most compelling illusions of self-motion. Optic flow patterns with global-perspective jitter produced shorter vection onsets and longer vection durations than those without. Even when this global-perspective jitter occurred in both horizontal and vertical directions (which would have produced the most salient visual – vestibular conflict according to Zacharias and Young's theory), jittering patterns of optic flow were still found to produce more compelling illusions of self-motion. On the basis of subjects' spontaneous reports,[(4)] it would appear that both radially expanding and jittering components of the flow were interpreted as self-motion, not object motion. Thus, it would appear that global-perspective jitter was playing a role in the visual perception of self-motion, which overcame any potential impairment produced by its visual – vestibular conflict.

One possible explanation for the advantage of jittering optic flow over non-jittering optic flow is that the latter, purely radial (expanding) flow rarely occurs in the real world. Walking, running, and even passive transportation usually produce additional random and oscillatory components in the optic flow (Cutting et al 1992). For example, the optic flow presented to a runner will have the following components: (i) a radially expanding component generated by his/her forward displacement; (ii) a vertical sinusoidal component generated by his/her regular up and down displacements; (iii) a horizontal sinusoidal component generated by his/her regular side-to-side displacements; and (iv) a random component produced by random horizontal, vertical, and depth displacements (these can become quite significant if the terrain is uneven). Hence, it is possible that jittering optic flow with its additional random (jitter magnitude varied from frame to frame) and oscillatory characteristics (jitter direction — up/down or left/right — alternated from frame to frame) tapped into processes used to perceive self-motion from naturally occurring patterns of optic flow. If so, it might be expected that as jittering optic flow becomes more ecological (ie as jitter range and temporal frequency are reduced), this jitter advantage for vection will increase. This prediction is examined in the following experiments.

[(4)] Many subjects spontaneously reported that the experience of self-motion induced by jittering optic flow was similar to walking under the influence of alcohol.

3 Experiment 2: Does jitter magnitude affect vection?

Experiment 1 showed that adding global-perspective jitter to radially expanding optic flow improves the vection induced in central vision. However, in this experiment, all jittering displays had the same range of random jitter ($0-\frac{1}{3}$ of the simulated forward displacement per frame). While jitter of this magnitude could have been produced by real-world situations (eg running over uneven terrain, driving a car over an unsealed road, or flying a plane through a region of high turbulence), it is larger than the random flow components accompanying most common self-motions. The present experiment was designed to examine whether reducing the range of random jitter (to $0-\frac{1}{4}$ or $0-\frac{1}{5}$ of the forward displacement per frame) would increase the 'jitter advantage' for vection.

3.1 *Method*

The apparatus, visual displays, and procedure were identical to those of experiment 1, the sole exception being that two additional jitter ranges were used ($0-\frac{1}{4}$ and $0-\frac{1}{5}$ of the simulated forward displacement per frame).

3.1.1 *Subjects.* Six male and seven female undergraduate psychology students (aged between 21 and 28 years) participated in this experiment. All had normal or corrected-to-normal vision and had not previously experienced illusions of self-motion in the laboratory.

3.1.2 *Design.* Two independent variables were manipulated in this experiment. (i) *Display type*. Displays were either jittering or non-jittering patterns of radially expanding optic flow. When present, global-perspective jitter occurred along either the x-axis, the y-axis, or both the x- and y-axes. (ii) *Jitter range*. The absolute amount of horizontal and/or vertical jitter for each frame was randomly selected from one of three ranges: either $0-\frac{1}{5}$, $0-\frac{1}{4}$, or $0-\frac{1}{3}$ of the simulated forward displacement (all displays simulated a forward self-motion of 4 m s^{-1}). This absolute jitter was then altered according to perspective before it was applied to objects at different simulated locations in depth.

3.2 *Results*

Vection was reported in 155 of the 156 trials (thirteen subjects responding to twelve stimuli). The only trial that failed to induce vection had a non-jittering display. Separate repeated-measures ANOVAs were performed on the onset and duration data. As in experiment 1, jittering displays were found to produce significantly faster vection onsets ($F_{1,12} = 12.225$, $p < 0.001$) and significantly longer vection durations ($F_{1,12} = 24.613$, $p < 0.0001$) than non-jittering displays (see figures 3a and 3b). While displays with the maximum and middle ranges of jitter ($0-\frac{1}{3}$ and $0-\frac{1}{4}$) did not produce

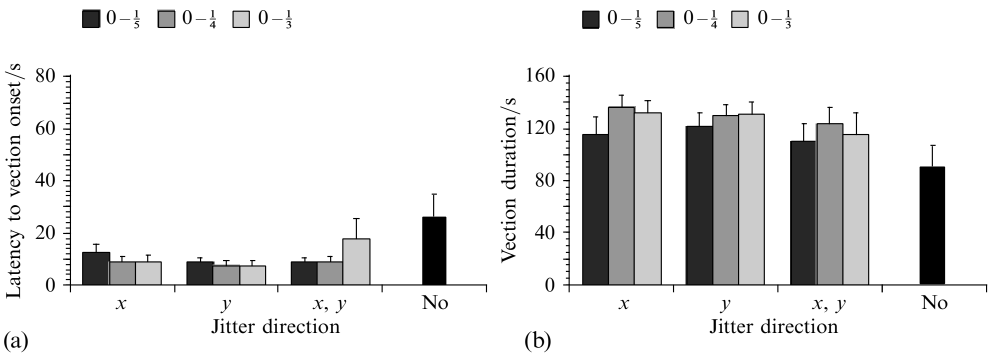


Figure 3. The effect of jitter magnitude on (a) vection onsets and (b) vection durations (experiment 2). Displays either had no jitter (No) or three different jitter ranges ($0-\frac{1}{5}$, $0-\frac{1}{4}$, $0-\frac{1}{3}$ of the forward displacement). The latter jittering displays had jitter along either the x-axis (x), the y-axis (y), or both the x-axis and the y-axis (x, y). Error bars represent the standard errors of the means.

significantly different vection onsets from those with the smallest jitter range ($0-\frac{1}{5}$) ($F_{1,12} = 0.01$, $p > 0.05$), they did produce significantly longer vection durations ($F_{1,12} = 7.754$, $p < 0.02$). Displays with maximum range of jitter ($0-\frac{1}{3}$) did not produce significantly different vection onsets ($F_{1,12} = 0.557$, $p > 0.05$) or durations ($F_{1,12} = 0.588$, $p > 0.05$) from those with the middle jitter range ($0-\frac{1}{4}$). No other main effects or interactions reached significance in this experiment.

3.3 *Discussion*

Contrary to the notion that the processes underlying visual self-motion perception might prefer more ecological patterns of optic flow, decreasing the range of the random jitter was found to reduce the 'jitter advantage' for vection durations (but not the 'jitter advantage' for vection onsets). This finding was also contrary to Zacharias and Young's (1981) visual–vestibular conflict theory of vection, which predicted that flow patterns with larger ranges of random jitter would impair vection more than those with smaller ranges of random jitter (as the former would produce a greater mismatch between current and expected vestibular signals).

4 Experiment 3: Does jitter frequency affect vection?

Research suggests that visual and vestibular systems are specialised for different types of self-motions, the former being primarily sensitive to low-temporal-frequency stimulation and constant-velocity motion, and the latter being primarily sensitive to high-temporal-frequency stimulation and brief acceleration (Howard 1986b). While linear vection prefers visual stimulation below 1–0.5 Hz (Berthoz et al 1975, 1979; Dichgans and Brandt 1978; van Asten et al 1988), vestibular responses to linear acceleration are only elicited at stimulus frequencies above 1 Hz (Diener et al 1982, 1984; Melville-Jones and Young 1978). In the previous experiments, global-perspective jitter always occurred at 30 Hz (ie jitter occurred on each frame of the display). Thus, it is possible that the jitter advantage for vection might be more pronounced for jitter with lower temporal frequencies (closer to the frequencies preferred by visual self-motion perception). The present experiment was designed to examine the effect on vection of reducing jitter frequency from 30 Hz to 1 Hz.

4.1 *Method*

The apparatus, visual displays, and procedure were identical to those of experiment 2, with the exception that six temporal frequencies of jitter were used.

4.1.1 *Subjects.* Four male and six female postgraduate psychology students (aged between 23 and 28 years) participated in this experiment. All had normal or corrected-to-normal vision and had not previously experienced illusions of self-motion in the laboratory.

4.1.2 *Design.* Two independent variables were manipulated in this experiment. (i) *Display type.* Displays were jittering or non-jittering patterns of radially expanding optic flow. (ii) *Jitter frequency.* When present, horizontal and vertical jitter occurred at one of the following temporal frequencies: 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, 15 Hz, or 30 Hz. When required, the absolute amount of jitter was randomly selected from the range $0-\frac{1}{4}$ of the simulated forward displacement (all displays simulated a forward self-motion of $4\ \mathrm{m\ s^{-1}}$). This absolute jitter was then altered according to perspective before it was applied to objects at different simulated locations in depth.

4.2 *Results*

Vection was reported in 139 of the 140 trials (ten subjects responding to fourteen stimuli). The only trial that failed to induce vection had a non-jittering display. Separate repeated-measures ANOVAs were performed on the onset and duration data. Overall, jittering displays were still found to produce significantly shorter vection onsets ($F_{1,9} = 24.137$,

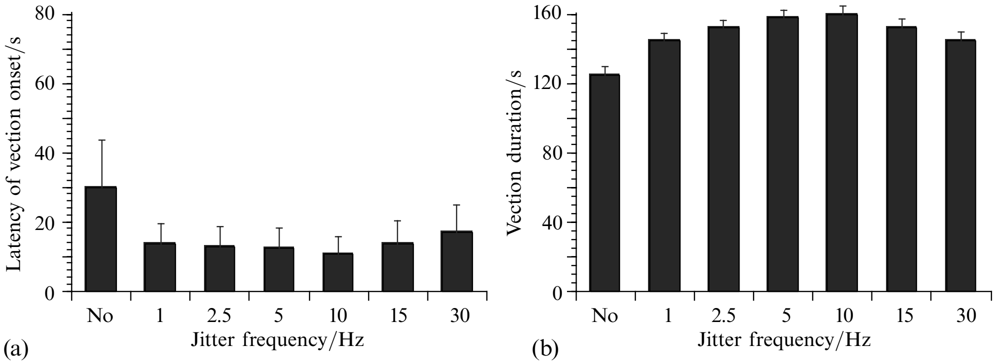


Figure 4. The effect of jitter temporal frequency on (a) vection onsets and (b) vection durations (experiment 3). A display either had no jitter (No) or jitter along both the x- and y-axes occurring at either 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, 15 Hz, or 30 Hz. Error bars represent the standard errors of the means.

$p < 0.0001$) and longer vection durations ($F_{1,9} = 56.326$, $p < 0.0001$) than non-jittering displays (see figures 4a and 4b). Displays with jitter frequencies of 5 and 10 Hz produced significantly longer vection durations than displays with other jitter frequencies ($F_{1,9} = 13.020$, $p < 0.0001$). However, displays with 5 Hz and 10 Hz jitter frequencies did not produce significantly different vection onsets from displays with other jitter frequencies ($F_{1,9} = 1.079$, $p > 0.3$).

4.3 *Discussion*

While vection onsets were relatively unaffected by the temporal frequency of the global-perspective jitter, jitter frequency did appear to play an important role in vection duration. Specifically, 5 – 10 Hz jitter frequencies were found to produce significantly longer vection durations than higher or lower jitter frequencies. This result would appear to be in stark contrast with the findings of previous studies that linear vection is optimal at low temporal frequencies (ie below 1 – 0.5 Hz—Berthoz et al 1975, 1979). Since reducing the jitter frequency below 5 Hz (experiment 3) and decreasing the range of the random jitter (experiment 2) both resulted in a diminished jitter advantage, it would appear that jittering displays were not improving vection by mimicking the optic-flow patterns produced by naturally occurring self-motions.

5 Conclusions

Contrary to the notion that visual – vestibular conflict impairs vection, the current experiments have demonstrated that jittering patterns of optic flow induce more compelling illusions of self-motion than non-jittering patterns of optic flow (regardless of the direction, range, or temporal frequency of the random jitter). It is possible to interpret these findings as support for the notion that visual information dominates the perception of self-motion (ie vestibular information plays a subordinate role in this process—Lee andLishman 1975; Lishman and Lee 1973). However, it is also possible that any potential impairment produced by visual – vestibular conflict was obscured by a larger 'jitter advantage'. The latter possibility suggests that the specific characteristics of the visual and vestibular input might determine which source of information dominates the perception of self-motion.

What features of global-perspective jitter were responsible for the vection improvements found in the present experiments? One possibility was that global-perspective jitter improved vection by obscuring certain artifacts in the computer-generated displays. For example, if the visual system was able to resolve the slight relative motions between individual objects in non-jittering displays (produced by their serial—not parallel—production and deletion), this would have reduced/impaired the perception of self-motion (as this would have biased the observer to perceive object-motion, as opposed to self-motion). However, the addition of horizontal and/or vertical jitter could have obscured these artifactual motions and hence might have biased the observers—perceiving only the global motion of the objects—towards the perception of self-motion. This possibility appears remote as jittering and non-jittering displays were designed to avoid 'pixel creep'—both having frame rates of 30 Hz.

Global-perspective jitter could also have improved vection by reducing adaptation to the optic flow. Consider the time course of the vection induced by a non-jittering pattern of radially expanding optic flow, representing linear self-motion of constant velocity. As the observer adapts to this repetitive and unchanging optic flow, his/her impression of self-motion should continually diminish in magnitude (Denton 1980; Salvatore 1968; Schmidt and Tiffin 1969). However, if a reasonable amount of global-perspective jitter is added to the radial flow, it should become more difficult to adapt to this combined flow and hence result in little or no decline in vection over time. Consistent with this account, patterns of optic flow with global-perspective jitter were found to produce longer vection durations than those without (experiments 1 – 3). It should be noted, however, that reduced adaptation alone could not account for the finding that jittering optic flow produced faster vection onsets than non-jittering optic flow, since substantial adaptation to the latter would only occur after vection had been first perceived (eg 30 – 60 s after stimulus onset—Dichgans and Brandt 1978).

A further way that global-perspective jitter might have improved vection is by enabling changing-size detectors to extract accurate information about motion in depth from self-motion displays (these contained both motion perspective and changing-size cues to motion in depth). At first, Regan and Beverley (1978) found evidence for neural mechanisms (changing-size detectors) which are specifically sensitive to changes in retinal image size. However, a later study suggested that these changing-size detectors provide precise information about motion in depth only when the changing-size stimulus contains frontal plane jitter. Regan and Beverley (1980) noted that during certain trajectories of motion in depth one or other edge of the object remains stationary (or nearly so) as it expands or contracts. They hypothesised that under these circumstances frontal-plane jitter might facilitate the extraction of motion in depth (by removing the restriction of a stationary edge). In different trials, they adapted subjects to stimulus squares which simulated motion along different three-dimensional trajectories: while changing-size cues always simulated the same amount of motion in depth, changing-position cues simulated different amounts of frontal-plane motion in different trials. After this adaptation period, subjects set the stimulus square so that its motion in depth was barely visible. Regan and Beverley found that subjects' final settings were unbiased by the frontal-plane component of adaptation displays only when these contained additional (8 Hz) frontal-plane jitter—suggesting that changing-size detectors require frontal-plane jitter if they are to provide accurate estimates of motion in depth. Thus, in the current experiment, jittering patterns of optic flow might have provided additional changing-size-based information about the three-dimensional trajectory of the (simulated) self-motion that was not available in non-jittering optic flow, which in turn resulted in more compelling subjective experiences of self-motion.

In conclusion, the current experiments demonstrate that global-perspective jitter can play a significant role in the visual perception of self-motion. Global-perspective jitter was found to improve vection induced by optic-flow displays, even when corresponding vestibular stimulation was absent. On the basis of these findings, it would appear that purely radial patterns of optic flow are not the optimal inducing stimuli for vection. Rather, it would appear that flow patterns which contain both regular and random/oscillating components produce the most compelling subjective experiences of self-motion.

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