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Stephen A. Palmisano

University of Wollongong, stephenp@uow.edu.au

Amy Y. Chan

University of Wollongong, amychan@uow.edu.au

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Jitter and size effects on vection are immune to experimental instructions and demands

Abstract

Both coherent perspective jitter and explicit changing-size cues have been shown to improve the vection induced by radially expanding optic flow. The current study examined whether these stimulus-based vection advantages could be modified by altering cognitions/expectations about both the likelihood of self-motion perception and the purpose of the experiment. In the main experiment, participants were randomly assigned into two groups – one where the cognitive conditions biased participants towards self-motion perception and another where the cognitive conditions biased them towards object motion perception. Contrary to earlier findings by Lepecq et al (1995), we found that identical visual displays were less likely to induce vection in 'object motion bias' conditions than in 'self-motion bias' conditions. However, significant jitter and size advantages for vection were still found in both cognitive conditions (cognitive bias effects were greatest for non-jittering-same-size control displays). The current results suggest that if a sufficiently large vection advantage can be produced when participants are expecting to experience self-motion, it is likely to persist in object motion bias conditions.

Keywords

instructions, experimental, demands, immune, jitter, vection, effects, size

Disciplines

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**JITTER AND SIZE EFFECTS ON VECTION ARE IMMUNE TO
EXPERIMENTAL INSTRUCTIONS AND DEMANDS**

Stephen Palmisano and Amy Y.C. Chan

**Department of Psychology
University of Wollongong, Wollongong
NSW, 2522, AUSTRALIA**

Other Contact Information:

Tel: (612) 4221-3640

Fax: (612) 4221-4163

Email: Stephenp@uow.edu.au

Keywords: self-motion, vection, cognition, jitter, changing-size

ABSTRACT: Both coherent perspective jitter and explicit changing-size cues have been shown to improve the vection induced by radially expanding optic flow. The current study examined whether these stimulus-based vection advantages could be modified by altering cognitions/expectations about both the likelihood of self-motion perception and the purpose of the experiment. In the main experiment, participants were randomly assigned into two groups – one where the cognitive conditions biased participants towards self-motion perception and another where the cognitive conditions biased them towards object motion perception. Contrary to earlier findings by Lepecq et al (1995), we found that identical visual displays were less likely to induce vection in ‘object motion bias’ conditions than in ‘self-motion bias’ conditions. However, significant jitter and size advantages for vection were still found in both cognitive conditions (cognitive bias effects were greatest for non-jittering-same-size control displays). The current results suggest that if a sufficiently large vection advantage can be produced when participants are expecting to experience self-motion, it is likely to persist in object motion bias conditions.

While a number of sensory systems appear to be involved in self-motion perception (Howard 1986), research has shown that compelling illusions of self-motion can often be induced in stationary observers using visual information alone (e.g. Dichgans and Brandt 1978; Lishman and Lee 1973). These visually induced illusions of self-motion (known as *vection*) have traditionally been regarded as automatic experiences determined by low-level perceptual processes. However, during the last two decades, questions have been raised about the roles that cognitive factors might play in *vection* (Andersen and Braunstein 1985; Henn et al 1980; Lepecq et al 1995; Mergner and Becker, 1990). For example, based on pilot studies, Andersen and Braunstein (1985) suggested that *vection* might be inhibited if experimental participants thought that they were in an environment where they could not be physically moved. To compensate for this proposed problem, prior to the actual experiment, they physically moved their participants (who were standing inside a large movable booth) in the same direction as the self-motion later simulated by their visual displays.

Consistent with Andersen and Braunstein's proposal, more recent research has demonstrated that knowledge about the plausibility/likelihood of self-motion can alter the time course of *vection*. In an experiment by Lepecq and colleagues (1995), stationary participants (7- and 11-year-old children) were repeatedly exposed to the same visual display, which simulated constant velocity forwards self-motion along their depth axis. For half of the participants, the simulated self-motion was represented as possible (they were seated on a chair equipped with rollers and shown that this chair could be moved back and forth). For the remaining participants, the simulated self-motion was represented as impossible (they were seated on a chair which was attached to the

experimental room and shown that chair motion was impossible). Lepecq and colleagues found that while the probability of inducing vection was not significantly affected by this cognitive manipulation, vection onset latencies were significantly shorter when the self-motion was represented as being possible (as opposed to impossible).

While such cognitive manipulations have been shown to significantly alter the time course of vection induced by identical displays, it is also possible that they might interact with stimulus/display differences in the generation of vection. One often raised concern is that participants might be more likely to report self-motion during more ecological conditions (such as optic flow displays with more moving objects, additional depth cues, etc), not because these additional stimulus features increase vection magnitudes per se, but rather because they increase the plausibility of the simulated self-motion. Since participants' cognitions have often been less tightly controlled than stimulus manipulations, such interactions could potentially account for many of the inconsistencies and conflicting results in the vection literature. However, this possibility remains largely unexplored to date. Thus, the primary goal of the current experiment was to examine the effects of experimental instructions and demands on two previously reported stimulus-based vection improvements. The first of these, the *jitter advantage*, refers to the finding that adding horizontal/vertical coherent perspective jitter (simulating random impulse self-accelerations) to radial flow (simulating constant velocity forwards self-motion in depth) consistently decreases vection onsets and increases vection durations (Palmisano et al 2000; 2003 - Figures 1b and 1c represent pure radial flow and jittering radial flow respectively). The second, *changing-size advantage* refers to the finding that adding explicit changing-size cues to the same radial flow pattern *sometimes*

decreases vection onsets and increases vection durations (Palmisano 1996 - Figures 1a and 1b represent same-size and changing-size patterns of pure radial flow respectively).

<INSERT FIGURE 1 ABOUT HERE>

On the one hand, the very robust jitter advantage for vection seems paradoxical because: (i) unlike non-jittering radial flow, significant and sustained vestibular input would be expected during jittering radial flow and its absence should produce visual-vestibular conflicts in stationary participants; and (ii) the horizontal/vertical self-displacements simulated by jittering radial flow should appear implausible based on the participant's knowledge of the experimental setup (e.g. sitting on a wheeled chair)¹. On the other hand, reports that the changing-size advantage is less robust than the jitter advantage also appear paradoxical, since the presence of changing-size cues should increase the plausibility of the self-motion simulated by inducing displays. While real self-motions in depth produce flow patterns with local changes in optical size, as opposed to patterns where the objects remain the same size as their position in depth changes, studies have found that adding changing-size cues to displays sometimes has no effect on vection (Telford and Frost 1993) and even if they do improve vection, such improvements generally disappear as display density increases (Palmisano 1996).

The current study examined whether experimental instructions and demands can alter the effects of coherent perspective jitter and explicit changing-size cues on vection². Prior to the main experiment, two preliminary experiments measured the effects of jitter and size cues on both the perceived 3-D layout of the display (Experiment 1a) and

vection strength ratings (Experiment 1b). The purpose of these experiments was: (i) to determine whether the visual displays would reliably induce vection when participants were unbiased; and (ii) to observe jitter and size effects using a vection measure thought to bias participants towards self-motion perception (magnitude estimation). Then the main experiment examined whether jitter and size effects on vection would persist when cognitive factors biased participants towards object motion perception. While jitter and size advantages for vection were expected to persist when participants were unbiased or biased towards self-motion perception, there were several possible patterns of results for the object motion bias conditions. First, the object motion bias might reduce both the jitter and size advantages for vection - by exaggerating the implausibility of the self-motion induced by jittering displays and by weakening the typically transient advantage provided by changing-size cues. Second, the object motion bias might have different effects on the two vection advantages (e.g. the robust jitter advantage might persist, while the transient changing-size advantage might be reduced/destroyed). Finally, both the jitter and changing-size advantages might be robust to the object motion bias (e.g. the sole result being a general increase in the latencies for vection reporting - as was found in the study by Lepecq et al 1995).

General Method

Participants. Fifty-one undergraduate students, enrolled in an introductory psychology course, received course credit for their participation in these experiments. All had normal or corrected-to-normal vision and had not previously experienced

illusions of self-motion in the laboratory. Different participants were used in Experiments 1 and 2.

Apparatus. Displays were generated on a Macintosh G4 computer and projected onto a large Mylar screen by a Sanyo XGA 2200 data projector [resolution was 1024 pixels (horizontal) x 768 pixels (vertical)]. This screen subtended a visual angle of 64° H x 64° V when viewed binocularly through a large, cylindrical viewing tube 1.75m distant. In addition to providing a frame of reference for both relative motion and depth, this viewing tube blocked the participant's view of his/her stationary surroundings - both stimulus factors have been shown to improve thevection induced by optic flow (e.g. Howard and Howard 1994; Ohmi and Howard 1988). In setups where physical displacement was represented as possible, this viewing tube was attached to the participant's wheeled chair (Experiment 1a, 1b and Experiment 2's self-motion bias condition). However, in setups where physical displacement was represented as impossible, this viewing tube was attached to a large, heavy table lying between the participant and the screen (Experiment 2's object motion bias condition).

Visual Displays. Displays were jittering and non-jittering patterns of radially expanding optic flow - consisting of 400 blue moving objects/dots (with a mean luminance of 3 cd/m^2) on a black background (0.03 cd/m^2). These simulated constant velocity forwards self-motion in depth either with or without horizontal/vertical impulse self-accelerations. In changing-size displays, self-motion in depth was simulated by increasing each object's velocity and total area (0.16° - 2.42°) as the observer appeared to approach it. However, in same-size displays, only object velocity varied with the simulated position in depth (object size remained constant at 0.16°). As objects

disappeared off the edge of the screen, they were replaced at the opposite end of space (a simulated distance of 20m along the depth axis from the observer) at the same horizontal and vertical 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 nearer objects.

When present, coherent perspective jitter was created as follows. First, the magnitude of the horizontal/vertical jitter was randomly selected from a uniform distribution ranging between $-1/3$ to $1/3$ of the simulated forwards displacement for the frame. This signed jitter was then given a perspective transformation before it was applied to objects at different simulated locations in depth (i.e. jitter was less for more distant objects). Coherent perspective jitter was updated 30 times per second (the radial flow component was updated 95 times per second). Since the sign and magnitude of the coherent perspective jitter varied randomly from one jitter frame to the next, it is best represented by a range of frequencies (both high and low) limited by the 30Hz update rate.

Experiment 1a: Effects of jitter and changing-size on perceived 3-D layout

The main purpose of this pilot study was as follows: since naive subjects were presented with our self-motion displays during an unrelated depth perception task, we were able to determine whether these displays would reliably produce vection spontaneously (ie independently of experimental instructions/demands). However, it was also possible that inducing displays that appeared more three-dimensional might be regarded as more plausible self-motion stimuli. Thus, this experiment also allowed us to

examine whether coherent perspective jitter and explicit changing-size cues could improve vection indirectly by making inducing displays appear more three-dimensional/plausible³.

Method

Participants. Six males and eleven females (aged between 21 and 44 years) participated in this experiment. Two additional participants discontinued the experiment after experiencing discomfort/disorientation during testing.

Design. Three independent variables were manipulated in this experiment. (1) *Jitter Type*. Displays were either jittering or non-jittering patterns of radially expanding optic flow. When present, coherent perspective jitter occurred along either the horizontal axis (X), the vertical axis (Y), or both the horizontal and vertical axes (XY). (2) *Size type*. Objects either changed in size as they appeared to approach the observer or remained the same size throughout the display. (3) *Display speed*. Each display simulated one of two speeds of self-motion: 2.5m/s or 5m/s (jitter magnitudes ranged from -1/3 to 1/3 of this forwards speed). The dependent variable measured was the observer's rating of the perceived 'three-dimensionality' of the scene represented by each of these displays.

Procedure. Since the method of magnitude estimation was used, the first display in each testing session set the modulus for participants' depth ratings (Stevens, 1957). This standard stimulus was a non-jittering pattern of same-size optic flow, which simulated the slowest speed of self-motion (2.5m/s). After a period of 50s had elapsed, participants were told that: "You are to rate the perceived three-dimensionality of this scene as '50'. This rating indicates how far apart the objects in this scene are separated from each other

in depth. So a rating of ‘0’ would indicate that all the objects appeared to be the same distance from you – like spots on a wall”. Four practice trials then followed. Prior to the first of these, participants were told to rate the perceived ‘three-dimensionality’ of each display on a bar chart presented at the end of the trial (this had a scale of 0-100 with 5-point intervals). The experimental trials were then presented in a random order (each had a duration of 60s and an inter-trial interval of 20s). The experiment consisted of two blocks of 16 trials – each preceded by a modulus trial. After each block was presented, there was a 2-minute break before the next block of trials was run.

Results

A repeated measures ANOVA was performed on the participants’ ratings of scene depth (see Figure 2 for the means). The main effect for display speed did not reach significance [$F_{1,16} = .319, p > .05$] – that is, displays with faster (5 m/s) simulated speeds of self-motion were not rated as being more three-dimensional than slower (2.5 m/s) displays. The main effect for jitter type also did not reach significance for these depth ratings [$F_{1,48} = 1.37, p > .05$] - demonstrating that horizontal/vertical coherent perspective jitter has little effect on the perceived spatial layout induced by radial flow. The main effect of size type was, however, found to be significant for depth ratings [$F_{1,16} = 28.51, p < .01$]. As expected, changing-size displays were rated as being significantly more three-dimensional than same-size displays. No two-way or three-way interactions reached significance in this experiment.

<INSERT FIGURE 2 ABOUT HERE>

In debriefing after the experiment, fifteen of the seventeen participants spontaneously reported experiencing compelling illusions of self-motion during the experimental sessions (the remaining participants did report experiences of illusory self-motion when prompted). This finding was an important control for potential confounds and experimenter demands in the later vection experiments, since none of these participants had been informed of the possibility of experiencing illusory self-motion at any stage during the experiment.

Experiment 1b: Effects of jitter and changing-size on vection strength ratings

This experiment reexamined the effects of jitter and size on vection strength using the method of magnitude estimation. If experimental instructions and demands contribute to the jitter and size advantages for vection, then these effects might be augmented in this experiment because: (i) participants had just been told that the true purpose of Experiment 1a was to ascertain whether the different displays spontaneously induced compelling illusions of self-motion; (ii) the experimental setup indicated that physical displacement was possible; and (iii) the instructions for this strength rating task would be expected to bias observers towards self-motion perception. However, if the perceived differences in spatial layout found for displays in Experiment 1a reflect differences in their plausibility as self-motion stimuli then only changing-size cues would be expected significantly increase vection strength ratings.

Method

Design. The three independent variables examined were identical to those in Experiment 1a. The dependent variable measured was the observer's rating of the strength of their feeling of self-motion for each display.

Participants. Five males and ten females (aged between 21 and 36 years) agreed to participate in this experiment after completing Experiment 1a.

Procedure. Participants were seated on a movable chair with their feet resting on a footrest attached to the chair. Prior to the experiment, participants were physically moved forwards and backwards on the chair to demonstrate that self-motion was possible. As in Experiment 1a, the first display (a slow, non-jittering pattern of same-size optic flow) was used to set the modulus for participants' vection strength ratings. After 50s had elapsed, participants were asked whether they felt as if they were moving or stationary. If they responded that they were moving, they were told that the strength of their feeling of self-motion corresponded to a value of '50' (with zero representing stationary). Four practice trials then followed. Prior to the first of these, participants were told to rate the strength of their feeling of self-motion for each display on a bar chart presented at the end of the trial (this had a scale of 0-100 with 5-point intervals). The 16 experimental conditions were then presented twice in a random order (each had a duration of 60s and an inter-trial interval of 20s).

Results

Vection was reported on all 480 trials (15 participants responding twice to 16 stimuli). A repeated measures ANOVA was performed on the participants' vection strength

ratings (see Figure 3 for the means). The main effect of display speed was found to be significant for vection strength ratings [$F_{1,14} = 38.94$, $p < .0001$] – 5m/s displays produced stronger ratings than 2.5m/s displays. The main effect of jitter type was also found to be significant for vection strength ratings [$F_{3,42} = 8.33$, $p < .0002$]. Bonferroni-adjusted post-hoc comparisons revealed that: (i) all jittering displays induced significantly stronger vection ratings than non-jittering displays ($p < .0001$); (ii) displays with horizontal jitter did not produce significantly different vection ratings to displays with vertical jitter ($p > .05$); and (iii) displays which jittered in both directions did not produce significantly different vection ratings to displays which jittered in only one direction ($p > .05$). In addition, a significant main effect of size was found for vection strength ratings [$F_{1,14} = 69.00$, $p < .0001$] - changing-size displays produced stronger vection ratings than same-size displays. Two interactions also reached significance, one between size type and speed [$F_{1,14} = 10.99$, $p < .005$] and another between size type and jitter type [$F_{3,42} = 3.40$, $p < .03$] - changing-size cues appeared to increase the effects of jitter and speed on vection strength ratings. No other two-way or three-way interactions reached significance in this experiment.

<INSERT FIGURE 3 ABOUT HERE>

Discussion

Earlier research by Palmisano (1996) suggested that the changing-size advantage for vection could be eliminated by increasing the density of their (30° x 24°) displays (adding changing-size cues to displays of 20/30 moving objects was found to reduce

vection onsets and increased vection durations, but these cues had little effect on displays of 50/100 moving objects). However, this experiment found that the vection ratings induced by larger ($64^\circ \times 64^\circ$) and denser (400 object) same-size displays could still be improved by changing-size cues.

It is possible that the self-motion bias inherent in this magnitude estimation experiment contributed to the unexpected persistence of the changing-size advantage for vection. It is also possible that these changing-size cues only improved vection in depth in this experiment because they significantly increased the perceived depths represented by same-size displays (as demonstrated in Experiment 1b). However, in general, little support was found for the notion that displays which appear more three-dimensional induce more compelling vection. While simulated speed had little effect on perceived layout in Experiment 1a, faster 5m/s displays were found to produce more compelling vection than slower 2.5m/s displays. Similarly, while jitter had little effect on perceived layout in Experiment 1a, all jittering displays were found to induce significantly stronger vection ratings than non-jittering displays. Thus, it appears unlikely that previously reported advantages for vection were produced by coherent perspective jitter or faster speeds increasing the perceived depth represented by the inducing displays.

As predicted, the above results confirm that the strength of the vection induced by our different stimulus conditions ranged from being modest (e.g. $M = 48$, $S.D. = 9$ for slow, same-size, non-jittering displays) to compelling (e.g. $M = 79$, $S.D. = 12$ for fast, changing-size, XY jittering displays). The following main vection experiment used identical inducing displays to those examined in Experiments 1a and 1b (although only the faster, 5m/s simulated speed was used).

Experiment 2: Can cognitions alter the jitter and size effects on vection time course?

This experiment examined whether the previously measured jitter and size effects on vection would persist when cognitive factors explicitly biased participants towards object motion perception. Participants were divided into two groups. In one group, experimental instructions/demands and participant observations indicated that physical self-motion was impossible in the experimental setup and that the purpose of the experiment was to examine object motion perception (not self-motion perception). To avoid task-related instructions biasing participants in this group towards self-motion perception, we examined the vection time course in this experiment (as opposed to directly asking participants about the strength of their vection as in Experiment 1b). In a novel modification of a pre-existing method (e.g. Palmisano et al 2000), we measured the onset and duration of object motion perception and indirectly determined the vection time course from this data. Vection onsets and durations for this object motion bias group were later compared to those obtained for a control group (where self-motion was represented as possible and instructions indicated that the purpose of the experiment was to examine self-motion perception).

Method

Participants. Thirty-four naïve participants (17 males and 17 females aged between 17 and 38) were recruited for this experiment. Two additional participants assigned to

the self-motion bias group, discontinued the experiment after experiencing discomfort/disorientation during testing.

Design. Three independent variables were manipulated in this experiment. (1) *Cognitive Bias Type*. Participants were randomly assigned to either a self-motion or an object motion bias group. (2) *Jitter Type*. As in Experiment 1a and 1b, when present, coherent perspective jitter occurred along either the horizontal axis (X), the vertical axis (Y), or both the horizontal and vertical axes (XY). (3) *Size Type*. Objects either changed in size as they appeared to approach the observer or remained the same size throughout the display. Cognitive bias type was manipulated between participants, whereas jitter type and size type were within-participant factors. Each display simulated a 5m/s forwards speed of self-motion. Two dependent variables were measured for each trial: (i) the latency to vection onset; and (ii) the total vection duration.

Procedure. Different background information was provided to the two experimental groups about the present study. For the self-motion bias group, the experiment was advertised as a virtual reality self-motion ride, while for the object motion bias group it was advertised as a study on object motion perception.

Participants in the two groups also received different sets of standardized instructions at the outset of the experiment. In the self-motion bias condition, participants were seated on a movable chair with their feet resting on a footrest attached to the chair. The viewing tube was also attached to this chair. Prior to the experiment, participants were physically moved forwards and backwards on the chair to demonstrate that self-motion was possible. They were then instructed as follows, "This is an experiment examining visually induced illusions of self-motion. You will be shown a variety of displays

simulating forwards self-motion in depth. Sometimes the objects may appear to be moving towards you; at 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 Palmisano et al 2000). In this condition, the vection onset latency was recorded as the time between the start of the trial and the first mouse button press. The times of later changes in mouse button status were also recorded and used to calculate the total vection duration.

In the object motion bias condition, participants were seated on the same chair. However, physical self-motion was clearly impossible in this instance because: (i) a large, heavy table was placed between the participant and the screen (this table also supported their head-chin rest and the viewing tube); and (ii) participants were instructed to keep their feet firmly on the ground throughout the experiment. Participants in this condition were told: "This is an experiment on object motion perception. You will be shown displays of moving objects. Sometimes the objects may appear to be moving towards you; at other times you may feel that you are moving towards the objects. If you feel that the objects are moving, press the mouse button down and hold it down as long as this experience continues. However, if you feel that you are moving at any time then release the mouse button." Thus, vection onset latency in this condition was recorded as the time of the first mouse button release (since the first mouse button press in this condition indicated object, not self-, motion perception). The times of later changes in mouse button status were also recorded and used to calculate the total vection duration.

In both self-motion and object-motion bias groups, participants were informed that each display had a fixed duration of 1 minute and an inter-trial interval of 20 seconds. After two practice trials, the experimental displays were presented in a random order. Each stimulus condition was presented twice - once in the first testing session and then again in the second testing session. There was a 10 minute break between sessions to prevent fatigue.

Results

Occurrence of Non-vection trials. An independent samples t-test revealed that the self-motion ($M = 0.04$, $S.D. = 0.007$) and object-motion bias groups ($M = 0.206$, $S.D. = 0.162$) produced significantly different proportions of non-vection trials [$t(32) = -3.757$, $p < .001$]. Specifically, of the 272 trials run by each group (17 subjects tested twice on 8 experimental conditions), the self-motion bias group produced 12 non-vection trials whereas the object-motion bias group produced 56 non-vection trials. While these non-vection trials were always restricted to same-size conditions in the self-motion bias group (6 jittering and 6 non-jittering), non-vection trials were produced by both changing-size and same-size conditions in the object motion bias group {20 for changing-size conditions (7 jittering and 13 non-jittering) and 36 for same-size conditions (20 jittering and 16 non-jittering)}.

Onset and Duration Analyses (Non-vection trials included). Separate split-plot analyses of variance (SPANOVAs) were performed on the onset and duration data. As in previous vection studies (e.g. Palmisano et al, 2000; 2003), trials which did not induce vection were assigned a vection latency equal to the trial length and a vection duration of

zero. Although the inclusion of these non-vection trials would have inflated the latencies and deflated the durations obtained with weaker vection stimuli, they were necessary to determine the effectiveness of the different cognitive and stimulus conditions for inducing vection. Consistent with the study by Lepecq and colleagues (1995), a significant main effect of cognitive bias was found for the latency of reported vection ($F_{1,32} = 5.74, p < .02$). On average, participants in the object motion bias group were found to report vection onsets 7.5s later than participants in the self-motion bias group. However, cognitive bias was not found to have a significant effect on vection duration ($F_{1,32} = 1.55, ns$). In addition, significant main effects of size were found for both vection onsets ($F_{1,32} = 33.50, p < .0001$) and vection durations ($F_{1,32} = 36.47, p < .0001$) – indicating that changing-size displays produced faster and longer reported vection experiences than same-size displays (see Figure 4). Significant main effects of jitter were also found for both vection onsets ($F_{3,96} = 7.58, p < .0001$) and vection durations ($F_{3,96} = 13.55, p < .0001$ – see Figure 5). Consistent with previous research, Bonferroni-adjusted post-hoc comparisons revealed that: (i) all jittering displays induced significantly faster vection onsets ($p < .05$) and significantly longer vection durations ($p < .01$) than non-jittering displays; (ii) displays with horizontal (X) jitter did not produce significantly different vection onsets or durations to displays with vertical (Y) jitter ($p > .05$ in both cases); and (iii) displays which jittered in both directions (XY) did not produce significantly different vection onsets or durations to displays which jittered in only one direction (X or Y) ($p > .05$ in each case). Importantly, there were no significant interactions between cognitive bias and either of the stimulus manipulations examined (size and jitter). Specifically, cognitive bias by jitter interactions failed to reach

significance for both vection onsets ($F_{3,96} = .45$, ns) and durations ($F_{3,96} = 1.85$, ns). Similarly, cognitive bias by size interactions failed to reach significance for both vection onsets and durations ($F < 1$ in both cases).

<INSERT FIGURE 4 ABOUT HERE>

<INSERT FIGURE 5 ABOUT HERE>

Onset and duration analyses (Non-vection trials excluded). To test whether the cognitive bias effect found above was due to the greater proportion of non-vection trials in object motion bias conditions, we reanalyzed the data with the non-vection trials excluded, by performing additional SPANOVAs on the onset and duration data. Interestingly, the main effect of cognitive bias for vection onsets failed to reach significance in this case ($F < 1$). As in the analyses including non-vection data, the main effect of cognitive bias for vection duration remained non-significant when the data were reanalyzed ($F_{1,32} = 2.28$, $p > .05$). Similarly, the main effects of jitter remained significant for both vection onsets ($F_{3,96} = 2.75$, $p = .047$) and durations ($F_{3,96} = 6.95$, $p < .0003$). The main effects of size also remained significant for both vection onsets ($F_{1,32} = 34.24$, $p < .0001$) and durations ($F_{1,32} = 23.45$, $p < .0001$). Again, no two or three way interactions were found to be significant for vection onsets or vection durations.

Discussion

Consistent with previous research, the jitter advantage for vection was found to persist – despite the implausibility of the self-motion simulated by the coherent perspective jitter and the presumed increase in visual-vestibular conflict – when experimental instructions and demands strongly biased participants towards object motion. The changing-size advantage for vection was also found to persist in object motion bias conditions. Thus, the proposal that previous failures to replicate the changing-size advantage for vection were due to cognitive artifacts received little support.

Overall, object motion bias conditions were found to produce more non-vection trials and longer latencies for reported vection than self-motion bias conditions. However, object motion bias conditions did not result in significantly shorter vection durations than self-motion bias conditions. This finding suggests that the processes involved in vection induction and deciding whether one is experiencing vection, might be more susceptible to cognitive factors than the processes involved in maintaining the vection experience. Importantly, when the influence of non-vection trials on time course data was taken into account, the effects of our cognitive manipulation on vection latency disappeared. Thus, the major finding of this experiment is that cognitive factors can alter the probability of vection reporting.

While object motion bias conditions could have delayed/prevented vection onsets, this notion appears unlikely. Object motion bias conditions would need to have delayed vection onsets by almost 50s (since the total trial duration was 60s and vection onsets have been previously been reported to range from 3-12s – e.g. Dichgans and Brandt 1978). Rather it appears that object motion bias conditions delayed/prevented vection reporting (as opposed to delaying/preventing the experience). It seems likely that the

different cognitive bias conditions caused systematic shifts in the participant's criterion of what he/she thought qualified as vection. In self-motion bias conditions, participants might have adopted a more liberal criterion for vection – where they were prepared to report vection when they only had a weak perception of self-motion or a perception of combined object and self-motion. However, in object motion bias conditions, participants might have adopted a stricter criterion for vection – where they were only prepared to report full/saturated vection (this occurs when all of the visual motion in the display is perceived to be due to self-motion and hence there is no independent object motion perception).

GENERAL DISCUSSION

The current study examined whether jitter and size effects on vection could be modified by altering the participant's expectations about both the likelihood of vection and the purpose of the experiment. While cognitive manipulations were found to have significant overall effects on vection reporting, both of these stimulus-based vection advantages were found to be very robust to experimenter instructions and demands. The persistence of these jitter-based and size-based vection improvements in object motion bias conditions, clearly demonstrates that they are perceptual rather than cognitive in origin. These results further suggest that if a stimulus manipulation can produce sufficiently large vection advantage when participants are expecting to experience self-motion, it is likely to persist in object motion bias conditions as well. However, the displays used in this study were shown to induce vection: (i) in participants who were

unaware of the true purpose of the study (Experiment 1a); and (ii) that ranged in strength from reasonably compelling to highly compelling (Experiment 1b). So it is still possible that more modest stimulus-based effects might be susceptible to cognitive manipulations when the experimental conditions are less favorable for vection induction (e.g. smaller area of motion stimulation, sparser inducing displays, etc).

Contrary to the findings of an earlier study by Lepecq and colleagues, we found that cognitive factors can alter the likelihood of vection reporting. In Experiment 1b, where physical displacement was represented as possible and instructions for the vection strength rating task indicated that the aim was to examine self-motion perception, vection was reported on every trial. However, non-vection trials were quite common using the self- or object motion perception timing task in Experiment 2 - 20% of trials failed to induce vection in object motion bias conditions compared to 4% of trials in self-motion bias conditions.

Why did the object motion bias conditions reduce the probability of vection reporting, rather than simply increasing the latency of vection reporting as in the Lepecq et al study? One explanation for this finding was that we used a stronger cognitive manipulation than the previous study. In the Lepecq et al (1995) study, even when the experimental setup indicated the self-motion was impossible, the instructions still suggested that the main purpose of the experiment was to measure self-motion perception (participants were instructed to “click a mouse as soon as vection started or not click if vection did not occur” pp. 440). Conversely, in the object motion bias conditions used in our second experiment, the experimental setup not only indicated that self-motion was impossible, but the instructions also suggested that the purpose of the experiment was to

measure object motion perception (“If you feel that the objects are moving, press the mouse down and hold it down as long as this experience continues”). Thus, instead of simply delaying vection reporting, as might be the case with weaker cognitive manipulations, the object motion bias conditions in Experiment 2 actually prevented vection reporting.

Another explanation was based on the fact that while the current study examined the vection induced by a number of different optic flow displays, Lepecq and colleagues only investigated the vection induced by repeated presentations of a single display. While the vection induced by our different displays ranged from being modest to compelling (as demonstrated in Experiment 1b), the strength of the vection in the original study should not have varied greatly from trial to trial. Assuming that a subset of the displays in the current study produced less compelling vection than the Lepecq et al display, then they might have reached the more liberal criterion for vection in self-motion bias conditions, but failed to reach the stricter criterion for vection in object motion bias conditions.

In conclusion, the current research further highlights the importance of cognitive factors in vection research. While jitter and size based vection improvements were found in both self-motion and object motion bias conditions, our cognitive manipulations were found to have significant overall effects on vection reporting. Our findings extend those of previous studies, demonstrating that cognitions which favor object motion perception can not only delay vection reporting, but actually prevent this behavior. The current results illustrate the importance of both controlling experimental demands⁴ and using compelling (as opposed to transient/ambiguous) vection displays in self-motion research,

so as to ensure that experimental manipulations are acting via perceptual rather than cognitive mechanisms.

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Footnotes

¹It was originally suggested that jitter might have improved vection by obscuring ‘jaggies’ in self-motion displays (i.e. artefactual object motions caused by limitations in spatiotemporal resolution). This possibility was, however, discounted when different types of coherent jitter, which should have reduced the salience of ‘jaggies’ by similar extents, were found to produce very different effects on vection (Palmisano et al 2003). While coherent *perspective* jitter (all objects jitter, but further away objects jitter less) always improved vection, coherent *non-perspective* jitter (all objects jitter by identical amounts) had little effect on the vection induced by radial flow.

²Extrapolating from other cognitive research, it is possible that these jitter and size vection advantages have a cognitive origin. Mergner and Becker (1990) found that they could improve/impair the vection induced by accelerating patterns of optic flow, by instructing their participants to attend to either their visual cues (which were consistent with accelerating self-motion) or their vestibular cues (which were consistent with the participant being stationary). Thus, adding jitter and local changes in optical size to inducing displays may improve vection by forcing participants to pay greater attention to their optic flow (as opposed to the input from their non-visual senses – which indicates that they are stationary) – since the changes in 3-D trajectory represented by the former and the looming represented by the latter should emphasize potential collisions with objects in the simulated environment.

³Jitter might have provided more optimal motion parallax information about relative distance. Similarly, changing-size cues should provide extra relative size, kinetic

occlusion and spatial derivative information about the 3-D layout (Andersen 1996; Brenner et al 1996; Epstein and Franklin 1965; Simpson 1988; 1993).

⁴One possible solution to this problem (suggested by an anonymous reviewer) would be to adopt a signal detection approach in futurevection research. Using such an approach, one would be able to differentiate the observer's sensitivity to visual self-motion information from his/her response bias during the experiment (based on extraneous factors, such as his/her expectations of self-motion, motivation for performing the task, etc).

Figure Captions

Figure 1. Velocity field representations of the optic flow used in experiments 1 and 2. Each line segment represents the optical velocity of a texture element. Since all three optic flow patterns share the same radial component, they all simulate the same constant velocity forwards self-motion in depth. (a) Same-size radial flow – in these displays, the global velocity field indicates that the observer is traveling at constant linear velocity along the depth axis. (b) Changing-size radial flow – in these displays, both the global velocity field and local image expansion provide consistent (and potentially redundant) information about the observer’s self-motion in depth. (c) Jittering pattern of changing-size radial flow – in these displays, the global velocity field and local image expansion information indicate that the observer is traveling along the depth axis at a constant linear velocity while undergoing random vertical impulse self-accelerations.

Figure 2. The effects of size type (changing-size or same-size), jitter direction (no, x, y, xy) and simulated speed (2.5m/s and 5m/s) on ratings of the perceived depth represented by inducing displays (Experiment 1a). Error bars represent standard errors of the means.

Figure 3. The effects of size type (changing-size or same-size), jitter direction (no, x, y, xy) and simulated speed (2.5m/s and 5m/s) on vection strength ratings (Experiment 1b). Error bars represent the standard errors of the means.

Figure 4. The effect of cognitive bias type (object motion or self-motion) and size type (changing-size or same-size) on (a) the latency of reported vection and (b) the total

duration of reported vection (Experiment 2, non-vection trials included). Error bars represent the standard errors of the means.

Figure 5. The effect of cognitive bias type (object motion or self-motion) and jitter type (no jitter, horizontal jitter, vertical jitter or combined jitter) on (a) the latency of reported vection and (b) the total duration of reported vection (Experiment 2, non-vection trials included). Error bars represent the standard errors of the means.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.