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## Stimulus eccentricity and spatial frequency interact to determine circular vection

### Abstract

While early research suggested that peripheral vision dominates the perception of selfmotion, subsequent studies found little or no effect of stimulus eccentricity. In contradiction to these broad notions of 'peripheral dominance' and 'eccentricity independence', the present experiments showed that the spatial frequency of optic flow interacts with its eccentricity to determine circular vection magnitude—central stimulation producing the most compelling vection for high-spatial-frequency stimuli and peripheral stimulation producing the most compelling vection for lower-spatial-frequency stimuli. This interaction appeared to be due, in part at least, to the effect that the higher-spatial-frequency moving pattern had on subjects' ability to organise optic flow into related motion about a single axis. For example, far-peripheral exposure to this highspatial- frequency pattern caused many subjects to organise the optic flow into independent local regions of motion (a situation which clearly favoured the perception of object motion not selfmotion). It is concluded that both high-spatial-frequency and low-spatial-frequency mechanisms are involved in the visual perception of self-motion—with their activities depending on the nature and eccentricity of the motion stimulation.

### Keywords

spatial, eccentricity, frequency, interact, determine, circular, vection, stimulus

### Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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**STIMULUS ECCENTRICITY AND SPATIAL FREQUENCY INTERACT  
TO DETERMINE CIRCULAR VECTION**

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**Abstract.** While early research suggested that peripheral vision dominates the perception of self-motion, subsequent studies found little or no effect of stimulus eccentricity. In contradiction to these broad notions of ‘peripheral dominance’ and ‘eccentricity independence’, the present experiments found that the spatial frequency of optic flow interacts with its eccentricity to determine circular vection magnitude - central stimulation producing the most compelling vection for high spatial frequency stimuli and peripheral stimulation producing the most compelling vection for lower spatial frequency stimuli. This interaction appeared to be due, in part at least, to the effect that the higher spatial frequency moving pattern had on subjects’ ability to organise optic flow into related motion about a single axis. For example, far-peripheral exposure to this high spatial frequency pattern caused many subjects to organise the optic flow into independent local regions of motion (a situation which clearly favoured the perception of object-, not self-, motion). It was concluded that both high and low spatial frequency mechanisms are involved in the visual perception of self-motion - with their activities depending on the nature and eccentricity of the motion stimulation.

## 1 Introduction

Visually induced illusions of self-motion are frequent occurrences in the real world. For example, it is not uncommon for observers seated on a stationary train to experience illusory self-motion when a train on the next track pulls out of the station. Mach (1875) was the first to investigate such illusions in the laboratory. In one experiment, he placed subjects inside a large rotating drum with an alternating pattern of black and white stripes on its inner wall. Mach found that when this drum was rotated about the vertical axis of a stationary subject, he/she eventually experienced an illusion of self-rotation in the opposite direction to the drum's motion. In a later study, Mach (1922) presented subjects with a large endless belt (covered with an alternating stripe pattern) moving horizontally across two rollers. He found that this apparatus induced an illusion of self-translation in the opposite direction to the belt's motion. Fischer and Kornmüller (1930) later gave these illusory self-motions the general name 'vection' - with *circular* and *linear vection* referring to illusions of self-rotation and self-translation respectively.

More recent research has shown that vection can be subjectively indistinguishable from real self-motion (Brandt et al 1971; Dichgans and Brandt 1972; 1973; Lishman and Lee 1973). Studies have reported vection to be more compelling when the optic flow<sup>1</sup>: (1) had faster speeds of rotation/translation (Brandt et al 1973); (2) had more and/or larger elements (Brandt et al 1975; Reason et al 1982); (3) stimulated larger retinal areas (Brandt et al 1973); and (4) was perceived to be from the background relative to other parts of the visual environment (Ohmi et al 1987; Ohmi and Howard 1988; Telford et al 1992).

A more controversial claim is that vection is dominated by optic flow presented to the visual periphery (Brandt et al 1973). These investigators restricted stimulus area and eccentricity by mounting masks just inside the inner wall of their rotating drum and found that vection induced by stimulating 30° diameter areas of the mid- or far- periphery (45° or 75° out from the fovea) was almost as compelling as that induced by full-field stimulation. Conversely, they found that stimulating a 30° (or even 60°) diameter area of the central visual field produced little or no vection. Subsequent research by Post (1988), however, suggested that circular vection is independent of stimulus eccentricity. Despite replicating most of the stimulus conditions used in the original Brandt et al study (eccentricity, velocity and stripe width), Post found that stimulating 30° diameter areas in central, mid-peripheral or far-peripheral visual fields all induced circular vection that was approximately 60% of that obtained by full-field stimulation.

Howard and Heckmann (1989) have provided a potential explanation for the discrepant findings of these two studies. They argued that subjects in the Brandt et al study may have misperceived centrally (as opposed to peripherally) placed motion stimuli as being foreground displays. Their argument is based on the facts that: (1) a central display would have been predisposed to be seen as a figure against a more distant ground; and (2) its stationary mask was always placed adjacent to the inner wall of the rotating drum (ie there was very little depth separation between stationary and moving displays). Since earlier research had shown that circular vection is driven by the motion of the perceived background (Ohmi et al 1987), Howard and Heckmann argued that this misperception should have resulted in little or no vection during central stimulation (since the stationary mask would have been the perceived background surface). They examined this notion using a modified rotating drum apparatus - designed so that a  $54^\circ \times 44^\circ$  central motion display could be placed either 15cm in front or 15cm beyond the wall of the rotating drum. The prominent binocular disparities along the vertical edges of the central motion display ensured that its foreground-background status was correctly perceived. Consistent with their theory, they found that while a “far” central motion display produced equivalent vection to an equal area peripheral motion display, the vection produced by a “near” central motion display was less than half this magnitude.

While the above explanation has empirical support, there are a number of unresolved issues. First, it has not been demonstrated that subjects in the Brandt et al study actually misperceived the foreground-background status of central displays. These subjects were exposed binocularly as well as monocularly to each of the stimulus eccentricities. While Howard and Heckmann’s account seems plausible for monocular viewing, it appears less likely for binocular viewing, where disparity-based information about the true depth order would have been available. Second, the above explanation assumes that subjects in Post’s study correctly perceived central motion displays as being beyond their stationary masks. However, since Post’s subjects were only exposed monocularly to the rotating drum, they should have been at least as likely to misperceive the central display’s foreground-background status as those in the Brandt et al study.

The experiments reported here re-examined the role of stimulus eccentricity in circular vection while controlling the perceived depth of the inducing display. Unlike the Brandt et al and Post studies, the stationary mask (when present) was always mounted halfway between the subject and the inner wall of the rotating drum. Binocular and monocular depth cues (eg

binocular disparity, convergence, accommodation, dynamic occlusion, etc) ensured that the moving stripe pattern was perceived to be the background surface at all eccentricities.

## 2 Experiment 1

### 2.1 Method

2.1.1 *Subjects.* Thirty university students (14 males and 16 females, with a mean age of 19.5 years) participated in this experiment for course credit. These subjects had a visual acuity of at least 6/9 in each eye and a stereoacuity of 20 seconds of arc or better at a distance of 40cm. In addition, they were all naive as to the purpose of the experiment and had not previously experienced illusions of self-motion in the laboratory.

2.1.2 *Apparatus.* A rotating-drum-and-chair apparatus (1.3m in diameter and 65cm high) was used. Both drum and chair could be rotated about a subject's vertical axis separately or simultaneously in clockwise or anti-clockwise directions. Sounds generated by these rotations were masked by white noise played through head-phones worn by the subject. The inner wall of the rotating drum was covered with an alternating pattern of black and white vertical stripes - each subtending a visual angle of  $12^\circ$  at the viewing distance of 65cm. The drum's interior was lit from without by eight fluorescent tubes. Light diffused evenly through the drum's translucent plastic wall and roof, producing average luminances of 2 and 35 cd/m<sup>2</sup> for black and white stripes respectively, and a Michelson contrast ratio of 0.88. The rotating chair was an upholstered swivel chair with padded foot- and arm-rests to reduce vibration cues. Its rate of rotation could be adjusted by turning a knob at the end of the right arm-rest. Experimenters monitored this chair speed on a tachometer connected to a scanner on the base of the chair. Attached to the back of the rotating chair was a metal framework which supported a head-rest to restrict head movements. This framework was also used to attach a large black mask during restricted viewing trials. The mask contained five 25 diameter holes - a central hole, two mid-peripheral holes and two far-peripheral holes - which could be opened or closed independently. Around the central hole were two incomplete white diagonal lines (each incomplete line segment was 7.5cm in length) which served as a fixation guide (see Figure 2). The mid- and far-peripheral holes were placed symmetrically  $45^\circ$  and  $75^\circ$  respectively from the central point of the mask<sup>2</sup>.

2.1.3 *Design and Data Collection.* Four independent variables were manipulated. (1) Stimulus area: motion stimulation was either full-field or restricted to 25° diameter areas. (2) Stimulus eccentricity: the 25° diameter areas of motion stimulation were presented either to central, mid-peripheral or far-peripheral vision. (3) Viewing type: exposure to the moving stripe pattern was either binocular or monocular. (4) Direction of drum rotation: the stripes moved in either a clockwise or an anti-clockwise direction.

Two indices of circular vection strength were measured in this experiment: (1) subjects' verbal ratings of their perceived speed of self-rotation; and (2) their nulling chair speeds. The verbal speed ratings were identical to the magnitude estimation measures used in the Post and Brandt et al studies, with the following exceptions. First, the standard stimulus for the speed ratings was a full-field chair rotation (not a full-field drum rotation). Second, subjects were free to choose a numerical value to represent the perceived speed of this real chair rotation (Stevens 1957). In the following drum rotation trials, subjects assigned numbers to represent their perceived speeds of illusory self-rotation relative to this 'free modulus'. It was hypothesised that these modifications would make subjects' speed ratings more accurate/reliable as it should be easier for them to assign numbers to their sensations using such a modulus.

Nulling chair speed, on the other hand, was a novel measure of circular vection strength. It was defined as the speed of chair rotation (in the same direction as the drum rotation) required to cancel circular vection<sup>3</sup>. As subjects actively increased the speed of their chair rotation (ie above the initial speed of 0s), not only would this reduce the relative motion of the stripes, but it would also introduce vestibular input to counteract the visually induced self-motion. It was assumed that faster chair speeds would be required to cancel more compelling illusions of self-motion.

2.1.4 *Procedure.* Initially subjects were seated inside the rotating drum with a pair of earphones placed over their ears. On the first trial, they initially closed their eyes while the *chair* was accelerated to a constant speed of 13°/s. After opening their eyes and being exposed to full-field binocular stimulation for 40s, subjects were then asked to assign a number to their speed of rotation (ie the modulus of the speed rating measure). On the next trial, they again closed their eyes while the *drum* was accelerated to a constant speed of 13°/s. After opening their eyes and being exposed to full-field binocular stimulation for 40s, subjects were asked "Do you feel as if

you are moving or stationary?". If their answer was "moving", subjects were asked to rate their speed of self-motion (compared to the modulus). Subjects were then told to "set yourself until you feel stationary using the hand-control - when you feel that you are stationary, I'll get you to tell me". As soon as they reported feeling stationary, a reading of the chair speed was taken from the tachometer. These preliminary trials were followed by 16 experimental trials presented in random order - each had the same format as the first drum rotation trial. Some trials had full-field stimulation, while others restricted the motion stimulation to central, mid-peripheral or far-peripheral locations. Before restricted vision trials, a large cardboard mask was mounted on the framework attached to the rotating chair. When subjects were told to open their eyes in a restricted vision trial, they were instructed to look at the point where the two incomplete diagonal lines would meet if they were complete<sup>4</sup>. In monocular viewing conditions, an eye-patch was placed over each subject's non-dominant eye. Between each trial there was a 40s inter-trial interval to prevent vection aftereffects. At the completion of experimentation, subjects filled out a questionnaire before they were debriefed.

## 2.2 Results

*2.2.1 Control Measures.* Several statistical tests assessed whether the novel measure - nulling chair speed - was acting as an index of vection strength. Consistent with this notion, a simple regression found that a significant proportion of the variability in subjects' speed ratings (36%) could be predicted by their nulling chair speeds ( $F_{1,478} = 266.11$ ,  $p < 0.05$ ). Also consistent with this notion, the nulling chair speed data was found to replicate the well established finding that larger areas of motion stimulation produce more compelling illusions of self-motion. Specifically, full-field stimulation was found to produce significantly faster nulling chair speeds compared to 25° diameter areas of stimulation ( $F_{1,29} = 15.80$ ,  $p < 0.0006$ ). This area effect was also replicated by the speed rating data - speed ratings produced by full-field stimulation were significantly faster than those produced by 25° diameter areas of stimulation ( $F_{1,29} = 8.43$ ,  $p < 0.01$ ).

*2.2.2 Eccentricity Findings.* Repeated measures analyses of variance were performed on both the speed rating and nulling chair speed data (Geiser-Greenhouse corrections were applied to all

contrasts to prevent type one errors). Contrary to the findings of Brandt et al and Post, central stimulation was found to produce significantly faster speed ratings than equal area mid- or far-peripheral stimulation ( $F_{1,29} = 36.42$ ,  $p < 0.0001$  - see Figure 1A). Central stimulation also required significantly faster chair speeds to null the resulting vection compared to equal area mid- or far-peripheral stimulation ( $F_{1,29} = 26.32$ ,  $p < 0.0001$  - see Figure 1B). While mid-peripheral stimulation produced faster mean speed ratings than far-peripheral stimulation, this difference did not achieve significance ( $F_{1,29} = 2.11$ ,  $p > 0.05$  - see Figure 1A). However, nulling chair speeds were significantly faster for mid-peripheral stimulation than for far-peripheral stimulation ( $F_{1,29} = 5.13$ ,  $p < 0.04$  - see Figure 1B). These eccentricity findings were consistent for both binocular and monocular viewing, as well as clockwise and anticlockwise drum rotations. However, binocular viewing was found to produce significantly faster speed ratings ( $F_{1,29} = 42.51$ ,  $p < 0.0001$ ) and nulling chair speeds ( $F_{1,29} = 21.42$ ,  $p < 0.0001$ ) than monocular viewing.

<INSERT FIGURE 1 ABOUT HERE>

*2.2.3 Post-Hoc Questionnaire data.* 19 of the 30 subjects were surprised to learn that they were stationary in the drum rotation trials, before they gave their speed ratings. Similarly, 25 of these subjects were surprised to learn that the drum was rotating at the same speed in every trial. Importantly, 16 subjects reported that in far-peripheral conditions stripes seen through the two different holes appeared to be rotating about separate axes (even though all stripes were in fact rotating about the same axis - the subject's vertical axis - see Figure 2). This shall henceforth be referred to as the 'far-peripheral' illusion.

### 2.3 Discussion

Contrary to previous findings of peripheral dominance and eccentricity independence, the current experiment found that central stimulation induced more compelling circular vection than either mid- or far-peripheral stimulation (ie central superiority). Taken together with the previous findings, these results suggest that certain stimulus differences selectively facilitated the vection induced by central vision or selectively impaired the vection induced by peripheral vision. The common occurrence of the 'far-peripheral' illusion suggests that the latter alternative is the most

likely candidate - since peripherally-mediated vection must have been impaired by a failure to perceive the peripheral motion as grouped into related motion about a single axis.

What stimulus difference/s could have selectively impaired the vection induced by peripheral vision? Table 1. compares stimulus conditions of this experiment with those of previous studies.

<INSERT TABLE 1 ABOUT HERE>

It was unlikely that the viewing distance in the current experiment (which fell mid-way between those in the Brandt et al and Post studies) would have impaired peripherally-induced vection relative to previous findings. Similarly, luminance differences between the experiments were unlikely to have been responsible for such an impairment, since reducing luminance levels to near scotopic levels has little effect on the magnitude of full-field vection (Leibowitz et al 1979). The slightly smaller stimulus area used in the current experiment was also an unlikely candidate (eg Brandt et al 1973; Johansson 1977). Thus, the most probable causes of a peripheral impairment in the present experiment were its smaller stripe widths, its slower stimulus speed, or the combination of these two factors. The above characteristics, in turn, produced the spatial and temporal frequency differences shown below in Table 2. The probable role of these frequencies is supported by the following findings.

<INSERT TABLE 2 ABOUT HERE>

De Graaf et al (1988) have shown that that reducing the spatial frequency of a moving pattern - while keeping its temporal frequency constant - increases circular vection magnitude. Conversely, Brandt et al (1973) found that increasing the temporal frequency of the motion stimulation - while keeping its spatial frequency constant - resulted in more compelling circular vection. Thus, it was hypothesised that the higher spatial frequencies and/or lower temporal frequencies used in the present experiment impaired peripheral vection to a greater extent than central vection, resulting in the novel finding of 'central superiority'.

### **3 Experiment 2**

This experiment examined the notion that the spatial and/or temporal frequency of the motion stimulation interacts with its eccentricity to determine vection. Specifically, it examined whether the finding of ‘central superiority’ would persist when the spatial and temporal frequencies of the motion stimulation were reduced. If the central superiority found in experiment 1 was due to the low temporal frequency of its motion stimulation (2.6Hz compared to 4.2Hz in previous studies), then this finding might persist in the current experiment, which had an even lower temporal frequency (1.4Hz). Alternatively, if the central superiority was due to the high spatial frequency of its motion stimulation (0.2c/deg compared to 0.07c/deg in previous studies), this effect should be reduced/destroyed in the current experiment, which had a lower spatial frequency (0.11c/deg) than that of the previous experiment.

### 3.1 *Method*

The design, data collection and procedure were identical to those of the previous experiment.

3.1.1 *Subjects*. An additional thirty university students (14 males and 16 females, with a mean age of 20.4 years) participated in this experiment. Their monocular/stereoscopic acuity criteria and vection experience were identical to those of experiment 1.

3.1.2 *Apparatus*. The apparatus was identical to that used in the previous experiment, with the following exception. The widths of the black and white stripes were doubled (ie each subtended a visual angle of  $4^{\circ}24'$ ) by inserting a new cardboard inner wall just inside the pre-existing drum wall. As the rotating drum was lit from without, this resulted in an overall decrease in illumination. The mean luminance of the black and white stripes dropped from 2 and 35cd/m<sup>2</sup> to 1 and 12cd/m<sup>2</sup> respectively. Similarly, the Michelson contrast ratio decreased slightly from 0.88 to 0.85.

### 3.2 *Results*

3.2.1 *Control Measures*. As in experiment 1, a simple regression found that a significant proportion of the variability in subjects’ speed ratings (31%) could be predicted by their nulling chair speeds ( $F_{1,478} = 220.91$ ,  $p < 0.05$ ). However, only the nulling chair speed data was found to replicate the well established area effect in this experiment. Full-field stimulations produced

significantly faster nulling chair speeds ( $F_{1,29} = 7.10$ ,  $p < 0.02$ ), but not significantly different speed ratings ( $F_{1,29} = 0.60$ ,  $p > 0.05$ ) compared to  $25^\circ$  diameter stimulations.

*3.2.2 Eccentricity Findings.* Repeated measures analyses of variance were performed on both the speed rating and nulling chair speed data (Geiser-Greenhouse corrections were applied to all contrasts to prevent type one errors). Contrary to the findings of experiment 1, mid- and far-peripheral stimulations were found to produce significantly faster speed ratings than equal area central stimulation ( $F_{1,29} = 34.73$ ,  $p < 0.0001$  - see Figure 3A). Furthermore, both mid- and far-peripheral stimulations required significantly faster chair speeds to cancel vection compared to equal area central stimulation ( $F_{1,29} = 13.51$ ,  $p < 0.002$  - see Figure 3B). Mid-peripheral stimulation produced significantly faster speed ratings than far-peripheral stimulation ( $F_{1,29} = 4.64$ ,  $p < 0.05$  - see Figure 3A). However, it did not produce significantly faster nulling chair speeds compared to far-peripheral stimulation ( $F_{1,29} = 2.13$ ,  $p > 0.05$  - see Figure 3B). These findings were consistent for both monocular and binocular viewing conditions and over both directions of drum rotation.

<INSERT FIGURE 3 ABOUT HERE>

*3.2.3 Post-Hoc Questionnaire data.* None of the subjects reported experiencing the ‘far-peripheral’ illusion found in experiment 1. As in the previous experiment, the majority of the subjects (21 of 30) reported that they were surprised to learn that they were stationary in the drum rotation trials, before they gave their speed ratings. Similarly, 23 of the subjects also reported that they were surprised to learn that the drum was rotating at the same speed in every trial.

### 3.3 Discussion

The previous finding of central superiority did not persist in this experiment - suggesting that the lower temporal frequencies used in experiments 1 and 2 (ie compared to the Brandt et al and Post studies) did not interact with stimulus eccentricity to determine vection. Rather, both mid- and far-peripheral stimulations were found to produce more compelling illusions of self-motion than central stimulation. This pattern of results was similar to the original Brandt et al study, with mid-peripheral stimulation producing the most compelling vection, followed by far-

peripheral stimulation, and then central stimulation. These findings, along with the absence of the ‘far-peripheral’ illusion in the current experiment, suggested that peripherally-mediated vection favours lower spatial frequency moving patterns as inducing stimuli. In contrast, centrally-mediated vection appeared to be impaired by the low spatial frequency moving pattern - suggesting a preference for the higher spatial frequency stimuli used in experiment 1.

Since the contrast ratios of the stripe patterns used in experiments 1 and 2 were quite close (0.88 and 0.85 respectively), it was unlikely that this ‘peripheral dominance’ was enhanced by the lower luminance levels present in this experiment (which might have selectively impaired vection induced in central vision). It would also appear that the novel nulling chair speed measure provided a more robust index of circular vection magnitude than the traditional speed ratings. While both measures correlated well, only nulling chair speed replicated the well-known area effect on vection in this experiment. The fact that this measure involved a task rather than a judgement might have rendered it a more accurate and less susceptible to cognitive factors/biases.

#### **4 Statistical Comparisons of the Data from Experiments 1 and 2**

To further investigate the notion that spatial frequency differences were responsible for the differing effects of eccentricity in experiments 1 and 2, two cross-experimental analyses of variance were performed on the speed rating and nulling chair speed data. The speed ratings and nulling chair speeds were first modified to control for overall vection differences in the two experiments. In the case of the former, each subject’s mean binocular full-field speed rating was subtracted from their central, mid-peripheral and far-peripheral speed ratings. In the case of the latter, each subject’s mean binocular full-field nulling chair speed was subtracted from their central, mid-peripheral and far-peripheral nulling chair speeds. As in the previous analyses, Geiser-Greenhouse corrections were applied to all contrasts to prevent type one errors.

##### *4.1 Results*

*4.1.1 Control Measures.* Consistent with the notion that the above modifications removed extraneous overall vection differences, experiment 1 was not found to produce significantly

different modified speed ratings ( $F_{1,58} = 1.54$   $p > 0.05$ ) or modified chair speeds ( $F_{1,58} = 0.08$   $p > 0.05$ ) compared to experiment 2.

*4.2 Eccentricity.* Significant two-way interactions between experiment and eccentricity were found for both modified speed ratings ( $F_{2,116} = 33.23$   $p < 0.0001$  - see Figure 4A) and nulling chair speeds ( $F_{2,116} = 17.80$   $p < 0.0001$  - see Figure 4B). In the first experiment (high spatial frequency moving stripe pattern), central stimulation produced speed ratings and nulling chair speeds which were quite close to those produced by full-field stimulation, whereas mid- and far-peripheral stimulation produced speed ratings and nulling chair speeds which were substantially less (especially far-peripheral stimulation). Conversely, in the second experiment (low spatial frequency moving stripe pattern), this pattern of results was reversed. Mid- and far-peripheral stimulation produced speed ratings and nulling chair speeds which were similar to those produced by full-field stimulation, while central stimulation produced speed ratings and nulling chairs speeds which were substantially less.

### *4.3 Discussion*

The above analyses showed that as the spatial frequency of the moving stripe pattern decreased (ie from 0.2c/deg in experiment 1 to 0.11c/deg in experiment 2) there was a corresponding increase in mean peripheral vection - which was independent of the overall increases in speed ratings and nulling chair speeds in the second experiment. This finding supported the notion that the high spatial frequency moving pattern used in the first experiment impaired peripherally-mediated vection by reducing the subject's ability to organise the optic flow into related motion about a single axis - which should be necessary on the basis of ecology for the visual perception of self-rotation. However, this theory cannot account for the fact that mean central vection decreased markedly as the spatial frequency of the stripe pattern was lowered (note: this decrease was inconsistent with the overall increase in speed ratings and nulling chair speeds in experiment 2). Thus, it would appear that decreasing the spatial frequency of the moving stripe pattern not only improved peripheral ratings/settings, but also impaired central ones.

## 5 Conclusions

The current experiments provided little support for the simple notions of peripheral dominance or eccentricity independence. On the contrary, the results appeared to show that there is a complex division of labour between central and peripheral vision in perceiving self-motion. Specifically, centrally-mediated vection was found to be more compelling for high spatial frequency optic flow patterns, whereas peripherally-mediated vection was found to be more compelling for flow patterns with lower spatial frequencies. This interaction between spatial frequency and eccentricity did not appear to be due to simple/early limitations of central and peripheral vision, since the spatial frequencies used were well above these region's thresholds for detection and motion direction at the stimulus speed of 13s (Burr and Ross 1982; Kelly 1979; Nakayama 1990; Rovamo and Virsu 1979). Rather, the results suggested that the spatial frequency of a moving pattern plays a more complicated role in the visual perception of self-rotation - it affects our ability to organise optic flow into related motion about a single axis. In the most extreme case, far-peripheral exposure to a high spatial frequency moving stripe pattern appeared to cause subjects to organise the visual field into independent local regions of motion, which impaired the induction of vection (since such an organisation would have biased them to perceive object-, not self-, motion).

The above results provide further support for Andersen and Braunstein's (1985) two mode model of ambient processing, which posits that self-motion can be perceived by either: (a) a primitive visual mode: primarily sensitive to low spatial frequencies, insensitive to refractive error and variations of illumination, and requiring a large area of peripheral involvement; or (b) a higher visual mode: sensitive to more complex optic flow patterns (eg containing depth variations) and mediated by central vision. According to this model, the central superiority of experiment 1 reflects the preference of the higher ambient mode for high spatial frequencies, while the peripheral dominance of experiment 2 reaffirms the preference of the primitive ambient mode's for low spatial frequencies.

In conclusion, it would appear that high spatial frequency mechanisms are not restricted to focal processing (such as object recognition, identification and perceiving object motion). The current experiments demonstrate that both high and low spatial frequency mechanisms are involved in ambient processing - in this case the visual perception of self-rotation - with their activities depending on the nature and eccentricity of the motion stimulation.

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**Footnotes**

<sup>1</sup>The visual stimulus for self-motion perception has been termed ‘optic flow’ and 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).

<sup>2</sup>One reviewer correctly noted that since the far-peripheral displays lay outside the region of binocular overlap, they were not subject to binocular cues to depth. However, monocular cues to depth (such as dynamic occlusion) would have ensured that these displays were always perceived to be background surfaces (relative to the foreground mask).

<sup>3</sup>This is similar to Carpenter-Smith et al’s (1995) inertial acceleration measure of linear vection. While exposed to optic flow displays simulating forwards or backwards self-motions, their subjects were physically moved forwards or backwards. Carpenter-Smith and his colleagues found that for more compelling vection displays, subjects needed much greater amplitudes of whole-body inertial acceleration to correctly identify their direction of self-motion.

<sup>4</sup>Unlike previous experiments, a distant stationary fixation spot was not superimposed on the motion stimuli presented to central vision. Pilot research suggested that for the purposes of the current study, the incomplete diagonals would sufficiently restrict subjects’ eye movements. Like the fixation points used previously, these incomplete diagonals did however provide a stationary reference for judging the motion of central, but not peripheral, displays.

## Table and Figure Captions

	Experiment 1	Brandt et al (1973)	Post (1988)
<b>Viewing Distance</b>	65cm	76cm	39cm
<b>Stripe Luminance</b>	35 and 2cd/m <sup>2</sup>	Unknown	58 and 4cd/m <sup>2</sup>
<b>Stimulus Area</b>	25°	30°	30°
<b>Stimulus Speed</b>	13°/s	60°/s	60°/s
<b>Stripe Width</b>	2.2°	7°	7.5°

Table 1. A list of the differences in the three stimulus eccentricity studies (Experiment 1; Post 1988; Brandt et al 1973).

	<b>Experiment 1</b>	<b>Brandt et al (1973)</b>	<b>Post (1988)</b>
<b>Spatial Frequency</b>	0.2c/deg	0.07c/deg	0.07c/deg
<b>Temporal Frequency</b>	2.6Hz	4.2Hz	4.2Hz

Table 2. Spatial and temporal frequencies used in the three stimulus eccentricity experiments (Experiment 1; Post 1988; Brandt et al 1973).

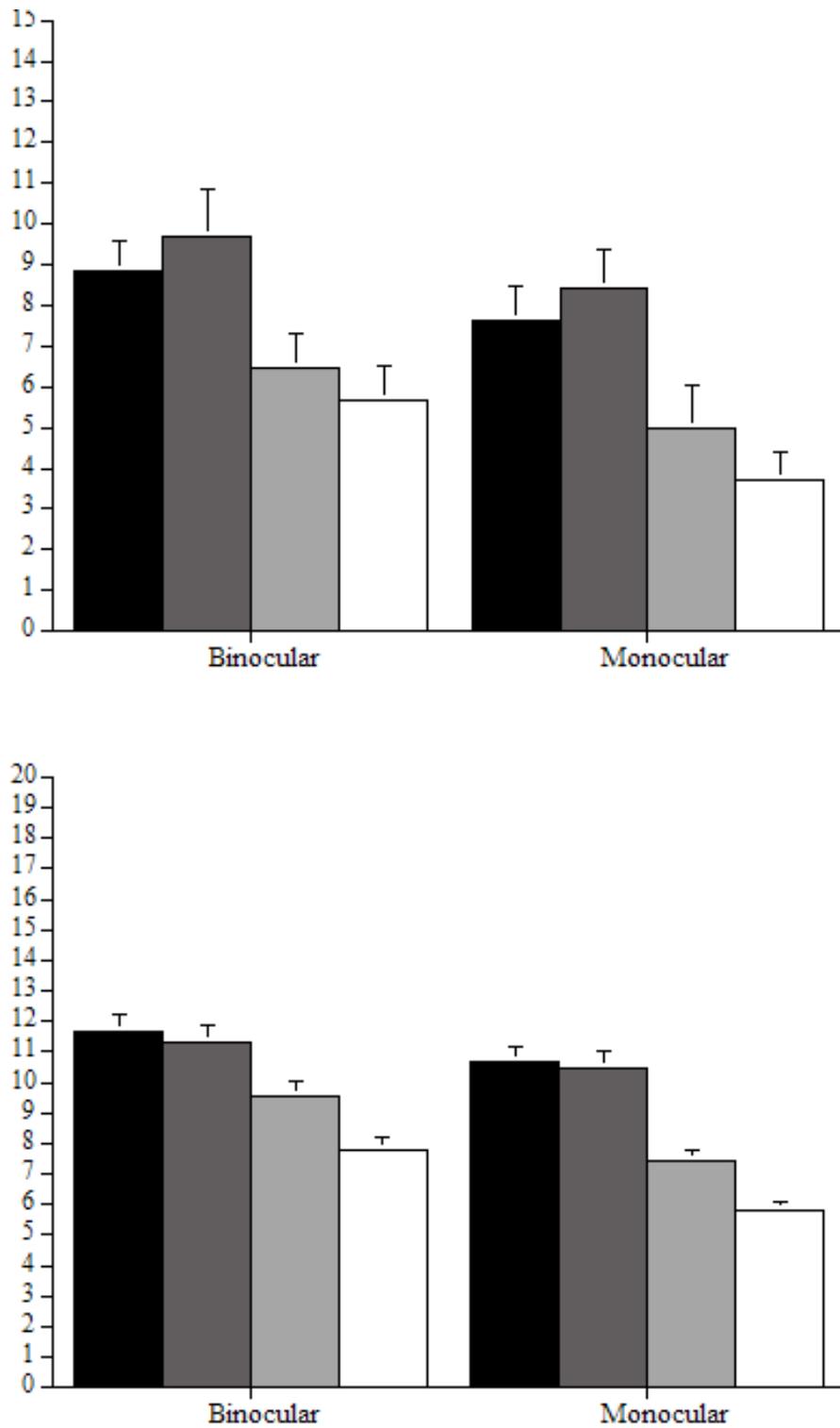


Figure 1. The effect of stimulus eccentricity on (A) the rated speed of circular vection (Top Figure) and (B) the chair speed required to cancel circular vection (bottom figure) (Experiment 1). Error bars represent the standard errors of the mean.

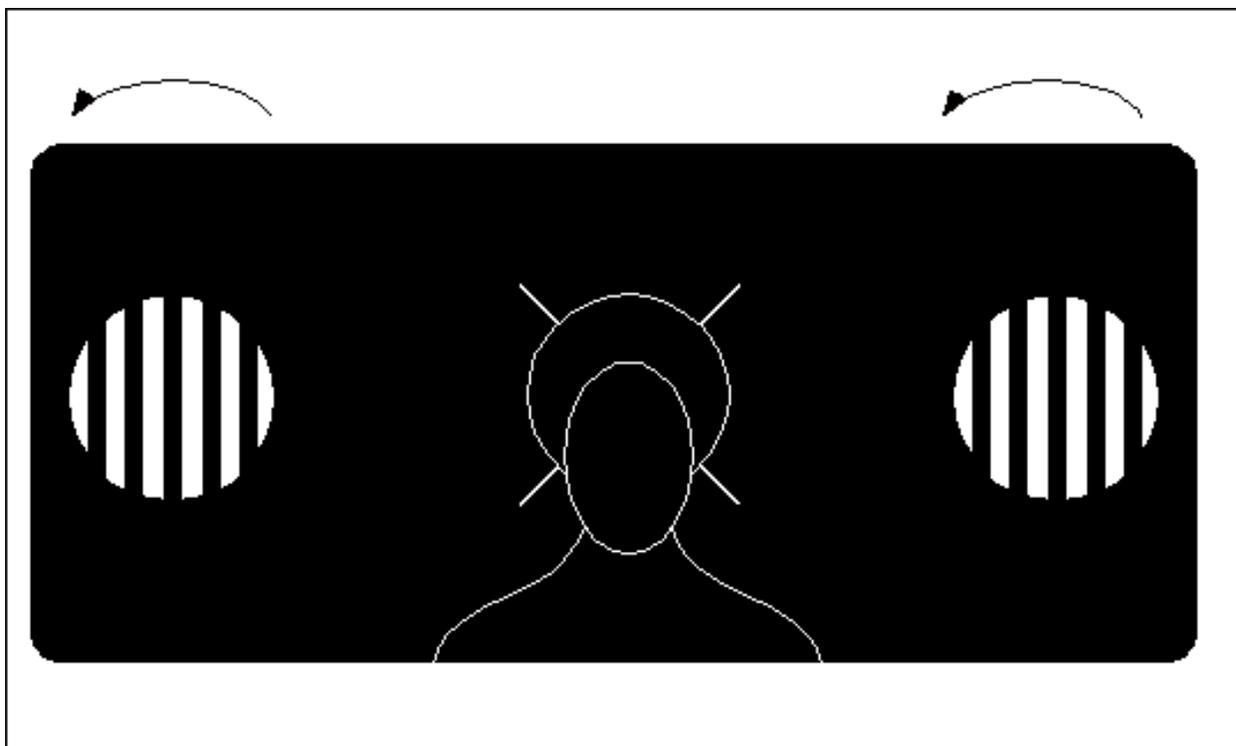


Figure 2. Schematic diagram depicting the 'far-peripheral' illusion. The subject was presented with two 25 diameter areas of moving stripes, located 75° to the left and right of the mask's central point. In these conditions, subjects reported that the stripes seen through the two holes appeared to be rotating about different axes (even though they were actually rotating about the same axis - the subject's vertical axis).

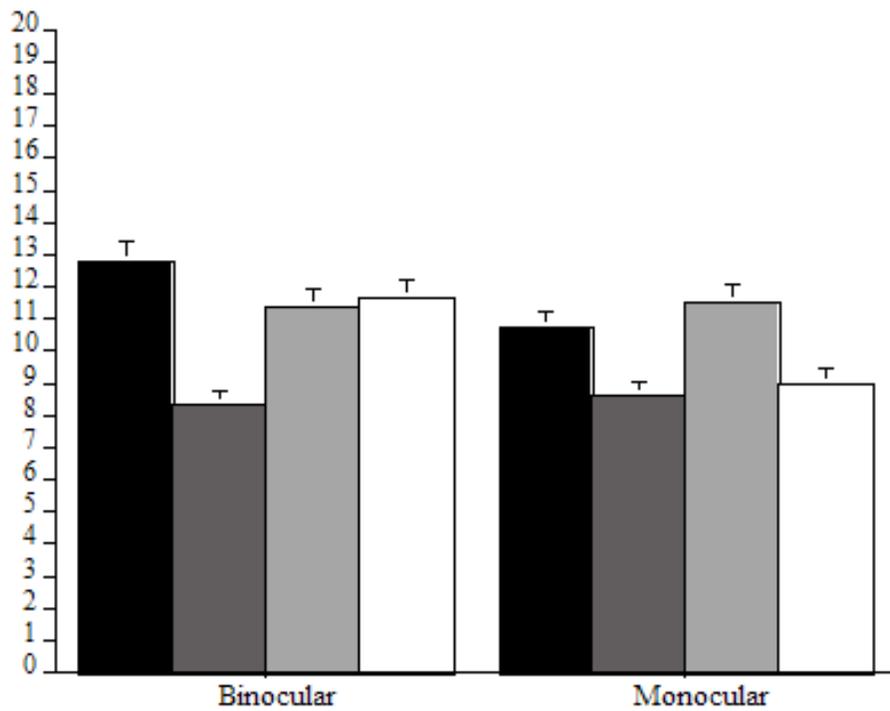
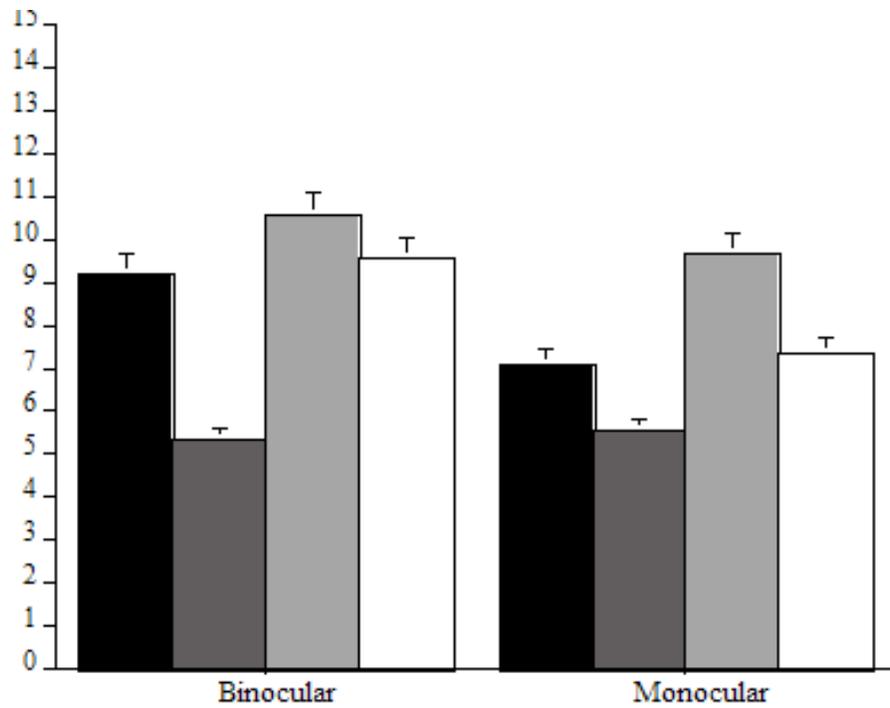


Figure 3. The effect of stimulus eccentricity on (A) the rated speed of circular vection (Top Figure) and (B) the chair speed required to cancel circular vection (Bottom Figure) (Experiment 2). Error bars represent the standard errors of the mean.

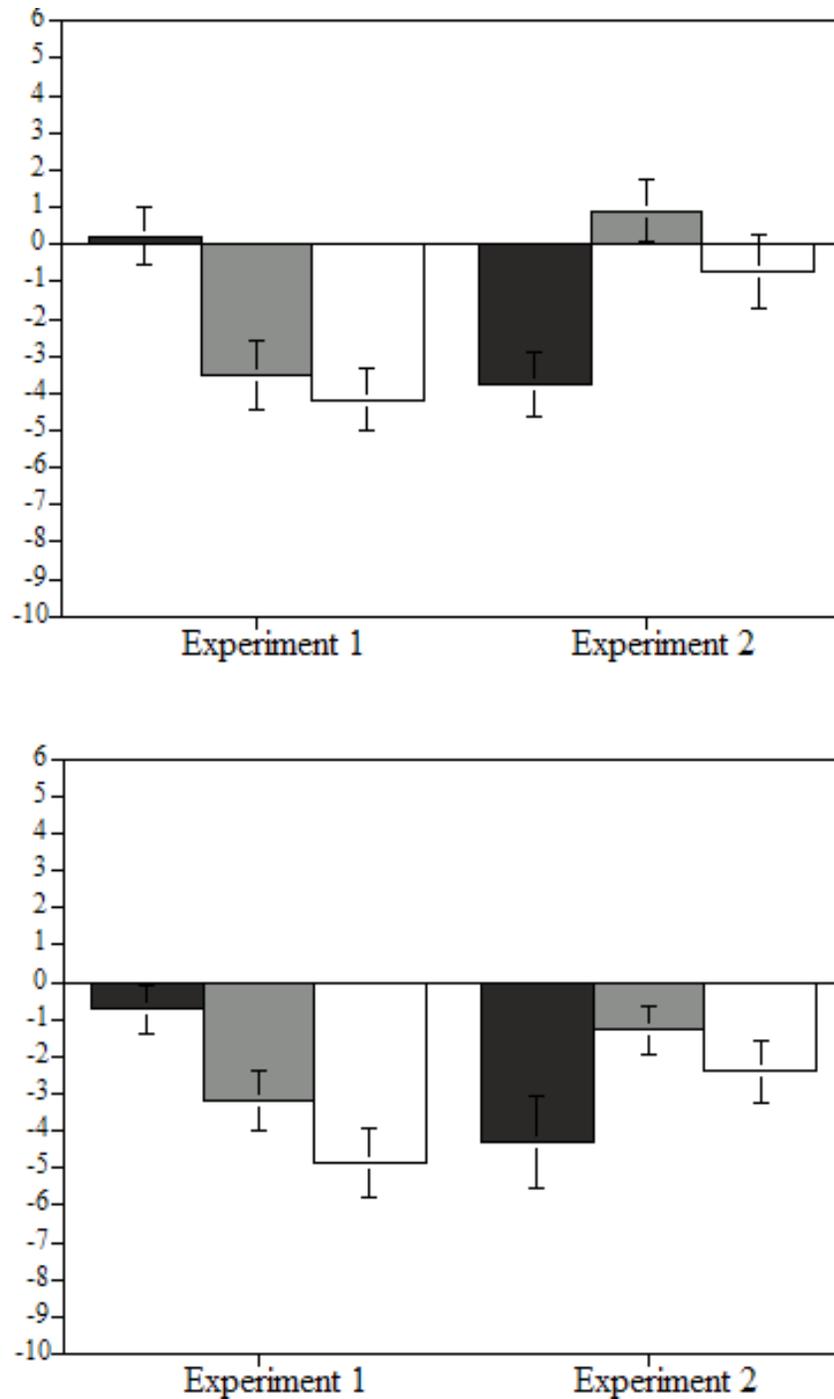


Figure 4. The interaction between spatial frequency and stimulus eccentricity for (A) modified speed ratings (Top Figure) and (B) modified nulling chair speeds (Bottom Figure) Experiments 1 and 2 combined). A positive value indicates that the eccentricity condition produced faster speed ratings/nulling chair speeds than the full-field condition, while a negative value indicates that it produced slower speed ratings/chair speeds than the full-field condition. Error bars represent the standard errors of the mean.