

Linear vection as a function of stimulus eccentricity, visual angle, and fixation

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Abstract. The effects of stimulus eccentricity, visual angle, and fixation on linear vection (sensation of self-translation induced by large moving scenes) were examined in healthy young people. Three aspects of vection were measured: latency, total vection time, and strength. The results showed that when peripheral and central stimuli are equal in area, they induce similar vection, but only when they are presented with a fixation cross. When presented without a fixation cross, peripheral stimuli are more effective in inducing vection than central stimuli. In addition, central stimuli with a fixation cross elicited more vection than central stimuli without a fixation cross. Fixation had no influence on the vection induced by peripheral stimuli. These findings indicate that statements about the role of central and peripheral stimuli of equal area in inducing vection should be made only in conjunction with reports about whether these stimuli are presented with or without fixation.

Keywords: Linear vection, self-induced motion, eccentricity, central vision, peripheral vision, stimulus size, fixation

1. Introduction

When a stationary observer is exposed to a large visual scene that moves uniformly, a sensation of self-movement in the opposite direction from that of the scene is induced. This phenomenon is known as vection and is explained by the fact that vestibular and visual inputs converge in the vestibular nuclei, which contain cells that respond to both visual motion inputs and vestibular signals arising from body motion in the opposite direction. These cells cannot tell the difference between activities arising from the two kinds of inputs [7]. When an observer is moved at a constant velocity, the sensation of self-motion is maintained most-

ly by the visual input because the vestibular system responds only to self-acceleration. It follows that the movement of large scenes is the natural cue for constant self-movement. Thus, when the visual motion of a large scene is presented in the absence of body motion, the sensation of self-motion in the opposite direction may be induced [7,8].

Studies have shown that smaller stimuli can induce vection as well. There has been some interest in whether central and peripheral stimuli differ in their ability to induce vection but the results have not always been consistent. For example, in a frequently cited paper Brandt et al. [3], who tested circular vection by placing their participants inside a rotating drum with the walls painted in black and white stripes, claimed that peripheral vision was more effective than central vision in inducing circular vection, even when controlling for stimulus size. The authors used masks to cover different parts of the stimuli, offering control over stimulus size and eccentricity. They showed that a central

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stimulus with a diameter of 30 deg induced less vection than a stimulus equal in size centered at 45 or 75 deg in the periphery. They also showed that vection increased with stimulus size. While the later finding has been consistently replicated, the former has been challenged by subsequent research [8,10–12]. The main criticisms of the study were that no data analysis was provided and claims were made based only on the height of the bar graphs describing the perceived vection intensity and velocity in each condition.

Post [12] tested some conditions from Brandt et al.'s [3] study and provided a proper data analysis of the results. Specifically, he examined circular vection induced by a central stimulus with a diameter of 30 deg, a peripheral stimulus equal in size and centered 45 deg to the right of fixation, and both central and peripheral presented together. Contrary to Brandt et al., Post found that there was no difference in the magnitude of the perceived vection intensity and velocity between the central and peripheral stimuli. This was the case even when the peripheral stimulus was centered at 75 deg to the right of fixation. He concluded that both central and peripheral vision are equally effective in inducing circular vection when stimulus size is the same. However, the peripheral stimulus was presented to the right of fixation at all times, posing the problem of preferential selection of the retinal area stimulated. Brandt et al. [3] showed that "horizontally moving surroundings stimulation of a horizontal streak 30 degrees in height invariably induces circular vection whereas stimulation within a vertical streak is less effective" (p. 484). That is, a peripheral stimulus presented to the right of fixation may be more effective in inducing vection than a peripheral stimulus situated above or below the point of fixation.

In a separate study, Howard and Heckmann [8] investigated the role of central and peripheral stimuli (concentric to the central stimuli) in inducing circular vection, taking into account the relative distance between them. The authors used a rotating drum as well, but in their experiment the central stimulus was either in front (centre-near condition) or beyond the surrounding stimulus (centre-far condition). Howard and Heckmann showed that, in the centre-far condition, when the central and peripheral stimuli had equal areas, vection induced by central motion was the same as that induced by peripheral motion. This was not the case in the centre-near condition, in which the peripheral stimulus was much more effective in inducing vection than the central stimulus. Thus, equality in vection effectiveness between central and peripheral stimuli of similar

sizes was achieved only when the central stimulus was perceived as background.

In Howard and Heckmann's [8] study the stimuli were never presented alone; when the peripheral stimulus was tested, it was presented concurrently with a still central stimulus, and vice versa. Therefore, in the centre still condition (testing the peripheral stimulus) there was the possibility that the participants might have fixated on the central stimulus. This would have been difficult to do in the surround still condition, in which the central stimulus was moving. It has been subsequently shown that vection is influenced by fixation. For example, Howard and Howard [9] showed that fixation leads to an increase in vection when the stimulus moves at a low velocity and there are no other stationary points in view except for the point of fixation. This has also been shown to be true for stimuli moving with higher velocities [2,4,5].

Palmisano and Gillam [11] showed that a central stimulus could be more effective than a peripheral stimulus of equal area in inducing circular vection, depending on the spatial frequency of the moving stripes. The authors used a similar methodology as the one described in Post's [12] study, but they controlled for the perceived depth of the inducing display by always presenting the stimuli as background using masks mounted half-way between the observer and the wall of the drum. In addition to stimulus eccentricity, the spatial frequency of the black and white stripes was varied. Interestingly, Palmisano and Gillam found that stimulus eccentricity interacted with spatial frequency to determine vection: central stimuli were more effective than peripheral stimuli in inducing circular vection at high spatial frequency, while the opposite was true at low spatial frequency.

Nakamura and Shimojo [10] manipulated both the size and the eccentricity of stimuli when studying linear vection. The authors used a peripheral stimulus that was supposedly equivalent in size and concentric to the central stimulus. The two kinds of stimuli were presented with a fixation cross in the middle, on a flat projection area. Consistent with previous research, Nakamura and Shimojo found that duration and strength of vection increased with stimulus area for both peripheral and central stimulation. They also found that central and peripheral stimuli of equal size had the same effect in inducing linear vection. In this respect, their results agree with Post's [12] findings. But, a closer examination of the methodology of their study revealed a serious error in the calculation of the stimulus area of the stimuli. It seems that the authors treated the diam-

eter as radius, making the reported areas of the central stimuli much larger and those of the peripheral stimuli much smaller than what they actually were. The areas we calculated, based on the diameter sizes provided in the study (25, 35, and 45 deg) using the formula $\pi * \text{diameter}^2 / 4$ are 491, 964, and 1590 deg² respectively, and not 1963, 3603, and 4965 deg² as reported. (The areas of the peripheral stimuli are also different.) If the authors really meant to report the radius and 25, 35 and 45 deg were the values, then the diameters are double the values reported in the study, and two out of the three central stimuli fall outside the 60 deg × 90 deg projecting area. Therefore, the areas of the central and peripheral stimuli in the Nakamura and Shimojo study were not comparable and the results of their study should be interpreted with caution.

The aim of the present work was to provide further insight into the effect of stimulus eccentricity on linear vection, while manipulating stimulus size and fixation. In this study spatial and temporal frequencies were held constant across conditions. Our methodology was similar to that of Nakamura and Shimojo [10] and we hypothesized that eccentricity has no effect on linear vection, but that stimulus size does. Because a fixation point facilitates vection, we predicted that stimuli presented with fixation would be more effective for inducing vection than stimuli without fixation. We also examined the interaction between eccentricity and fixation.

2. Method

2.1. Participants

Fifteen young volunteers (mean age = 23.18 years, SD = 6.65) with a near visual acuity of 20/20 or better were tested in the Ocular Motor Laboratory at the Toronto Western Hospital, University Health Network. The participants had no history of neurological or vestibular diseases, or cognitive impairment. Informed consent was obtained from all participants. The research was approved by the University Health Network Research Ethics Board and by the York University Human Participants Review Committee, and conducted in accordance with the tenets of the Declaration of Helsinki.

2.2. Apparatus and stimuli

Stimuli were random dot patterns with a dot size of 2 deg, presented at a viewing distance of 40 cm, moving from left to right on a black background with a velocity of 60 deg/s. The dot density was 0.022 dot/cm² in all conditions. Once the dots appeared from the right of the testing area, they were continuously present until they disappeared on the left. The dots were white with a luminance of 59 cd/m² and the background had a luminance of 0.82 cd/m². The Michelson contrast ratio of the pattern was 0.97. The stimuli were generated using VPixx, a graphics and psychophysical testing software (VPixx Technologies, Inc., Montreal, QC) and rear-projected on a large flat screen. There were two stimulus eccentricities (central and peripheral). The central, or disc, stimulus had a diameter of either 20 deg or 30 deg. The peripheral stimulus, or annular surround, was a ring with an inner diameter of 20 deg or 30 deg, and an outer diameter calculated so that its area was equal to that of the central disc (28.28 deg and 42.42 deg, respectively) at the fixed viewing distance of 40 cm. There was also a large central or full-field stimulus covering the whole projecting area (192 deg × 146 deg) and a similar large peripheral stimulus but with the central 30 deg area missing. All stimuli were presented with and without a 1.5 deg white fixation cross in the middle of the screen (see Figs 1 and 2). The cross was computer-generated and had the same luminance as the white dots. There were twelve conditions in total: Central and peripheral stimuli, with and without fixation, in three sizes each, presented in random order. Each condition was presented for 2 minutes. A USB button-response box connected to a laptop computer recorded vection latency (the time between stimulus onset and the participant's first response) and total vection time (the total time self motion was perceived during each condition).

2.3. Procedure

The participants were seated on a high stool, with their feet off the ground, in front of the screen. They were tested binocularly at a viewing distance of 40 cm, with the room illumination turned off. This set-up assured that other objects in the room were not in the participants' field of view during testing. The experimenter stayed behind the participants at all times. The participants either looked at the fixation cross positioned at eye level on the projecting area (fixation conditions) or straight ahead with a relaxed gaze (no

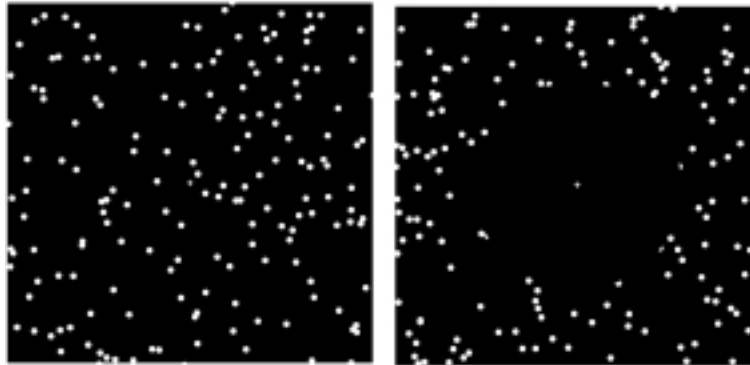


Fig. 1. Large central and peripheral stimuli with fixation cross.

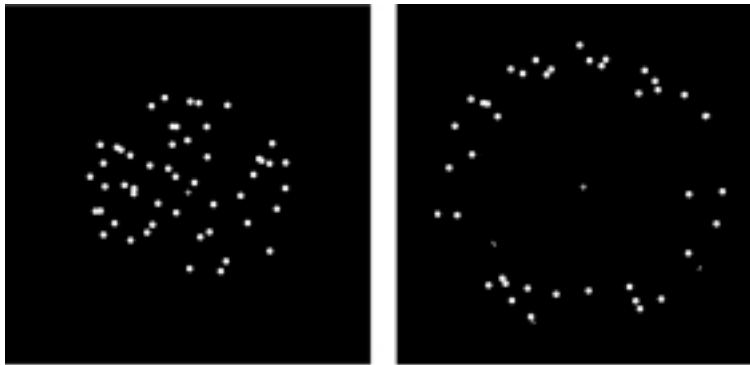


Fig. 2. Central and corresponding peripheral stimuli with fixation cross.

fixation conditions). They were instructed to press the button of the response box as soon as they perceived themselves to be moving (latency measure) and to keep the button pressed as long as they experienced vection (total time measure). Each participant was given one practice trial with the full-field stimulus. At the end of each trial (one per condition), the participants were asked to estimate the strength of vection on a scale from zero (no sensation of self-motion) to 10 (compelling sensation of self-motion).

2.4. Data analysis

Separate analyses of variance were performed to evaluate the effect of stimulus eccentricity, stimulus size and fixation on vection latency, total vection time (measured in seconds), and vection strength. The within-subjects factors were 1) Eccentricity with two levels (central and peripheral), 2) Size with three levels (large, 30 deg, and 20 deg), and 3) Fixation with two levels (fixation, no fixation).

In order to simplify the interpretation of the results, the analyses of each dependent variable was carried out

in two steps: First, with a 2 (Eccentricity) \times 3 (Size) within-subject analyses of variance with and without fixation. Second, the effect of Fixation was evaluated with a more complex 2 (Eccentricity) \times 3 (Size) \times 2 (Fixation) within-subject analysis of variance. The focus of the second analysis was on the effect of Fixation since the other results had already been reported with the initial simpler analysis.

Main effects and interactions were assessed using the multivariate criterion of Wilks's lambda in order to avoid the effects of violations of the sphericity assumption; however, the same results and comparable power were found using univariate tests with the Geisser-Greenhouse conservative F statistic. We controlled for familywise error rate across the tests for simple effects with the Bonferroni approach [13].

3. Results

3.1. Vection latency – No fixation

The Eccentricity ($F(1, 14) = 6.73, p < 0.05$) and Size ($F(2, 13) = 15.98, p < 0.05$) main ef-

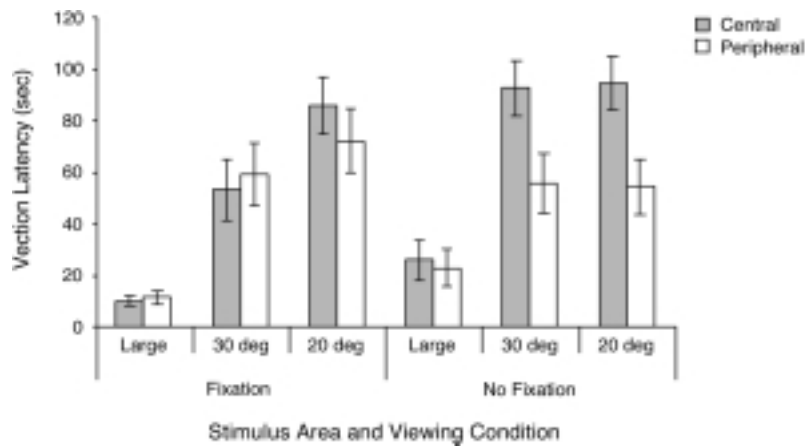


Fig. 3. Mean vection latency (± 1 SE).

facts were significant, as well as their interaction ($F(2, 13) = 6.91$, $p < 0.05$). Follow-up analysis of the simple effects showed that the latency of vection to the central stimulus was significantly longer than that to the peripheral stimulus ($p < 0.05$) at the 30 deg and 20 deg levels. The latencies of vection to the central and peripheral stimuli were not different when the size was large. Overall, vection to the central stimuli had a longer mean latency than that to the peripheral stimuli ($p < 0.05$). In summary, the results show that, although central and peripheral stimuli were equally effective in inducing vection when the stimuli were presented on a full screen, peripheral stimuli induced vection sooner than the central stimuli when their sizes were smaller.

3.2. Vection latency – Fixation

The main effect of Size ($F(2, 13) = 26.92$, $p < 0.05$) was the only significant result. Pairwise comparisons showed that the vection induced by large stimuli had a shorter latency than that induced by the 30 deg or 20 deg stimuli, regardless of eccentricity. When stimuli were presented with a fixation point, central stimuli were as effective in inducing vection as peripheral stimuli. Latency increased with stimulus size, but there was no significant difference between central and peripheral conditions.

3.3. Vection latency: Comparison between fixation and no fixation conditions

Differences in vection latency between the fixation and no fixation conditions as a function of stimulus size and eccentricity were explored with a 2 (Eccentricity) \times 3 (Size) \times 2 (Fixation) within-subject analysis of

variance. The Eccentricity \times Fixation interaction was significant ($F(1, 14) = 6.83$, $p < 0.05$). Follow-up analysis of the simple effects showed that vection induced by central stimuli with a fixation cross had shorter latencies than that induced by central stimuli without a fixation cross ($p < 0.05$), but that fixation had no effect on the vection latencies of peripheral stimuli. The Eccentricity \times Size \times Fixation interaction was also significant ($F(2, 13) = 4.56$, $p < 0.05$) and tests of simple effects revealed that vection induced by the central 30 deg stimulus with fixation had a shorter latency than the vection induced by the same stimulus without fixation ($p < 0.05$). The results are shown in Fig. 3.

3.4. Total vection time – No fixation

The analysis revealed a significant main effect of Size ($F(2, 13) = 30.06$, $p < 0.05$). Large stimuli induced longer vection than smaller stimuli, regardless of eccentricity. Follow-up tests showed that the mean of the total vection time induced by the peripheral stimulus was larger than that induced by the central stimulus at 20 deg ($p < 0.05$).

3.5. Total vection time – Fixation

There was also a significant main effect of Size ($F(2, 13) = 84.45$, $p < 0.05$) and pairwise comparisons showed that the total vection time induced by the large stimuli was longer than that induced by the 30 deg stimuli and that both were longer than the total vection time induced by the 20 deg stimuli ($p < 0.05$). Total vection time decreased with stimulus size, but there were no differences between central and peripheral stimuli.

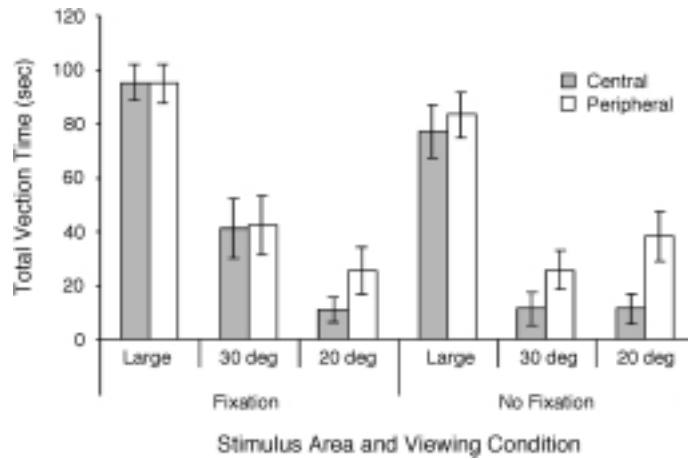


Fig. 4. Mean total vection time (± 1 SE).

3.6. Total vection time: Comparison between fixation and no fixation conditions

Differences in total vection time between the fixation and no fixation conditions as a function of stimulus size and eccentricity were explored with a 2 (Eccentricity) \times 3 (Size) \times 2 (Fixation) within-subjects analysis of variance. The Fixation main effect was significant ($F(1, 14) = 4.60, p = 0.05$). Total vection time induced by the stimuli with a fixation cross was greater than that induced by the stimuli without a fixation cross. There was also a significant Size \times Fixation interaction ($F(2, 13) = 7.84, p < 0.05$). The test of simple effects revealed that the large and the 30 deg stimuli with fixation induced a greater total vection time than those without fixation ($p < 0.05$). Also, central stimuli with fixation induced greater total vection times than central stimuli without fixation ($p < 0.05$). The results are shown in Fig. 4.

3.7. Vection strength – No fixation

The two-way repeated measures analysis showed that there was a main effect of Size ($F(2, 13) = 45.95, p < 0.05$). Pairwise comparisons revealed that the vection produced by large stimuli was perceived as stronger than that produced by smaller stimuli ($p < 0.05$). Peripheral stimuli tended to produce stronger vection than central stimuli, but this effect was only marginally significant ($F(1, 14) = 4.03, p = 0.06$). Pairwise comparisons showed that peripheral stimuli were rated as stronger than central stimuli at 20 deg size ($p < 0.05$). Thus, vection strength decreased with stimulus size.

3.8. Vection strength – Fixation

Similar results were obtained for the conditions with fixation. Size was the only significant main effect ($F(2, 13) = 315.76, p < 0.05$) and there was no interaction of size and eccentricity. Pairwise comparisons showed that vection strength decreased significantly as stimulus size decreased ($p < 0.05$). There was no difference between the vection strength of the central and peripheral stimuli.

3.9. Vection strength: Comparison between fixation and no fixation conditions

A 2 (Eccentricity) \times 3 (Size) \times 2 (Fixation) within-subject analysis of variance was performed in order to evaluate the effect of fixation on vection strength. Since most of the results are already reported, the focus of this analysis was on the effect of Fixation. There was a significant Eccentricity \times Fixation interaction ($F(1, 14) = 5.71, p < 0.05$). Follow-up analysis of simple effects showed that central stimuli with fixation were rated as stronger than central stimuli without fixation ($p < 0.05$). In addition, there was a significant Size \times Fixation interaction ($F(2, 13) = 5.73, p < 0.05$). The tests of simple effects showed that large stimuli with fixation were rated as stronger than large stimuli without fixation. The results are shown in Fig. 5.

4. Discussion

We investigated the effects of stimulus eccentricity on vection latency, total time, and strength as a func-

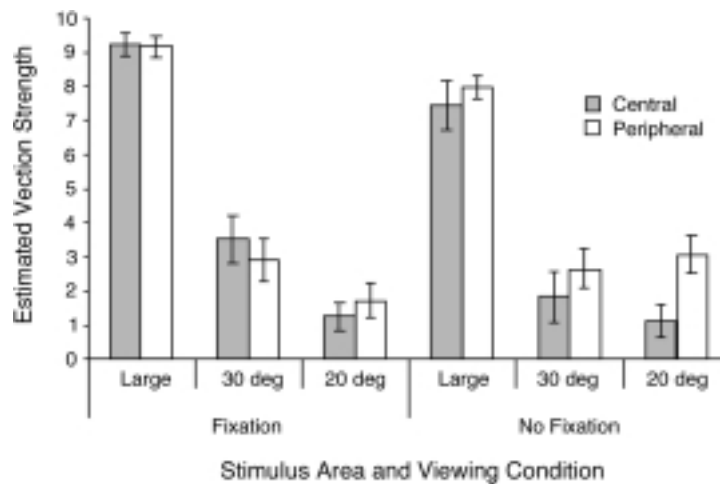


Fig. 5. Mean vection strength (± 1 SE).

tion of stimulus size and fixation. Consistent with previous research, the three measurements revealed that vection increases with increasing stimulus size in all conditions [8,10,12].

We found no difference in vection between central large (i.e., full field) and peripheral large stimuli (full-field minus a 30 deg central area). The absence of the central 30 deg in the full field stimulus does not affect vection latency, total time or strength. It seems that when an observer is exposed to a large moving visual field, central vision makes little contribution to the perception of self-motion. It may be that the main contribution to the perception of motion is made by peripheral vision, which is usually responsible for spatial orientation and locomotion, rather than central vision, which is more useful for object recognition and identification [1].

Yet, when an observer is exposed to smaller visual fields, central and peripheral stimuli of similar size are equally effective in inducing vection, but only if a fixation cross is provided. These results contradict Brandt et al.'s [3] finding that peripheral stimuli are more effective than central stimuli of equal size even when a fixation point is shown, and agree with Post's [12] and Nakamura and Shimojo's [10] results. However, when observers view small stimuli without fixation, peripheral stimuli have a stronger effect than central stimuli, provided their areas are equal. This is particularly evident in the 20 deg condition where all three vection measurements yielded the same result. In the 30 deg condition only vection strength, the measurement considered the most subjective, does not show a difference between the central and peripheral stimulus; total vection time and vection latency do. The lack of sta-

tistical power might have prevented us from finding a significant difference in this condition.

A more complex statistical analysis revealed that fixation does not influence, in any way, the vection induced by peripheral stimuli. Fixation does not make the three measurements of vection neither stronger nor weaker; it only affects the vection induced by central stimuli. Overall, central stimuli with fixation are stronger than central stimuli without fixation and this result is consistent across all measurements of vection.

The finding that central stimuli with fixation induce more vection than central stimuli without fixation is not all that surprising. It has been shown previously that circular vection is stronger when it is induced by large visual fields with a fixation point than without a fixation point [2,4,5]. This phenomenon is analogous to the Aubert-Fleischl paradox, according to which "a stimulus is estimated as faster (by a factor of about 1.5) when the stimulus is perceived with fixed gaze as compared to when followed by the eyes" [4, p. 845]. De Graaf et al., showed that the Aubert-Fleischl paradox holds for circular vection as well, with a somewhat lower factor between 1.1 and 1.4. Our data match these findings; we obtained factors of 1.43 for vection latency, 1.48 for total vection time, and 1.35 for vection strength.

Two explanations of the superiority of vection induced by stimuli with fixation are available. First, fixation on a target suppresses optokinetic nystagmus (OKN), causing the stimuli to sweep across the retina. It seems that "afferent recordings of visual motion (retinal slip signals) benefit from a larger gain than efferent ones (eye movement efference copy)" [2, p. 557]. This is the classical explanation of the Aubert-Fleischl

paradox. Second, the fixation cross in our study may have served as a cue to depth (interposition). The cross was fixed and the random dot pattern appeared to move behind it. Thus, the central stimuli with fixation may have been perceived as a background, whereas the central stimuli without the fixation cross may have been perceived as a foreground. Howard and Heckman [8] showed that a central stimulus induces more vection when it is perceived as background than when it is perceived as foreground.

What is the reason that fixation did not have an effect on the peripheral stimuli? Participants in our study were instructed to look straight ahead, with a relaxed gaze, when the stimuli were presented without a fixation cross. That is, when the peripheral stimuli were presented, our participants either fixated on the cross on a central black disc surrounded by the moving dot pattern (peripheral stimulus with fixation), or they just gazed at this disc (peripheral stimulus without fixation). In the latter condition, the black disc of 20 deg or 30 deg may have served as a fixation area; it may be that the peripheral stimuli failed to induce OKN. This idea is supported by the findings that central vision plays a crucial role in eliciting OKN. Howard and Ohmi [6] showed that OKN is severely reduced when the central retina is occluded, and this becomes more evident at stimulus velocities above 30 deg/s. Alternatively, both peripheral stimuli (with and without fixation) may have been perceived as background and no difference in their effectiveness in inducing vection was perceived.

In conclusion, the present study shows that peripheral and central stimuli that are equal in area induce similar vection, but only when presented with fixation. Peripheral stimuli are more effective in inducing vection than central stimuli when viewed with a relaxed gaze. In addition, central stimuli with fixation elicit more vection than central stimuli without fixation. This is not true for peripheral stimuli. Therefore, we suggest that care should be taken when making statements about the effectiveness of central and peripheral stimuli of equal areas in inducing vection, as they depend on whether these stimuli are presented with or without fixation.

Acknowledgments

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