Apparent movement and change in perceived location of a stimulus produced by a change in accommodative vergence*

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The apparent movement of stimuli which accompanies accommodative vergences can be explained by Hering's principles of visual direction with an additional postulate. The model predicts that the extent of movement is determined by the orientation of the two eyes and the location of the egocenter. Experiment 1 demonstrated the importance of phoria and the possible importance of the location of the egocenter in determining movement. In Experiment 2, the convergence error for one stimulus was eliminated. The change in procedure produced changes in movement consistent with the model. The fact that phorias of both eyes affect the extent of movement cannot be reconciled with Walls's hypothesis that the visual system monitors only the efference to one eye.

Apparent lateral movement of a stimulus is sometimes produced by a change in accommodative vergence. The usual stimulus condition consists of two lights on the optic axis of one eye with the other eye occluded. When accommodative vergence is changed from one light to the other, apparent movement in the frontal-parallel plane is sometimes seen. Walls (1951) saw the apparent movement with only one of his eyes and suggested that the visual system monitors efference to only one eye. This hypothesis has remained unchallenged and has recently been restated by Rubin and Walls (1969, pp. 359-370).

In a preliminary study replicating Walls's experiment, we found that six Ss saw movement with both eyes and one S saw no movement with either eye. This result is at variance with Walls's finding, and an alternative hypothesis based upon Hering's principles of visual direction (1942) was formulated. Two experiments were designed to test the alternative hypothesis.

Restated, Walls's hypothesis requires that (1) the visual system monitors the orientation of the dominant eye and the retinal locus of the stimuli, and (2) S makes directional judgments from a point located in that eye. In contrast, the present formulation hypothesizes that (1) the orientations of both eyes are monitored, together with the retinal locus of the stimuli, and (2) the point

from which S makes directional judgments is located somewhere in the head. This hypothesis can be formally stated by reference to Hering's principles of visual direction, summarized by Howard and Templeton (1966), with an additional postulate: *Principle 1*: "Objects producing superimposed retinal images for a given position of the eye are judged to be in alignment." *Principle 2*: "All visual lines of both eyes are judged to point to one and the same projection center." *Postulate*: *Objects on the visual axis of either eye are judged to be on the line passing through the projection center and the point of intersection of the visual axes.*¹ (The projection center has been called the cyclopean eye or the egocenter; in this paper, the term egocenter will be used.) Principle 1 states that the retinal loci of the stimuli are one of the determinants of visual direction. Principle 2 states that there is a common origin (egocenter) for judgment of visual direction. The postulate implies that the orientations of both eyes are monitored.

Hering's principles and the postulate describe the predicted differences in visual direction of stimuli that will result from a change in accommodative vergence. This difference is described by an angle at the egocenter. If the stimulus is at a particular perceived distance, then the angle subtended by the two visual directions will allow the prediction of the extent of apparent movement. The three premises imply that change in orientation of the occluded eye, or eccentricity of the egocenter, or both, will systematically affect the difference in visual direction of the stimuli and the extent of apparent

movement. The degree of change in orientation of the occluded eye is determined by the convergence errors on the two stimuli. Convergence errors can hence reduce or increase the change in orientation of the occluded eye which accompanies a change in accommodation. The smaller the change in orientation of the occluded eye, the smaller the difference in visual direction and perceived movement. Furthermore, eccentricity of the egocenter leads to differences in the extent of movement perceived with the right and left eyes.

In the two experiments to be described, the extent of apparent movement and the difference in visual direction of stimuli were measured as accommodative vergence was changed. In Experiment 1, the stimuli were viewed monocularly and these two scores for each S were related to estimates of his change in vergence and to the position of his egocenter. The prediction was that the individual differences in the two scores would be consistent with the principles and the postulate. In Experiment 2, the amount of convergence error was experimentally reduced by having S view one light binocularly and the other light monocularly before a change in accommodative vergence. The prediction was that the reduction in convergence error would systematically affect the extent of perceived movement and the difference in visual direction of stimuli.

EXPERIMENT 1

Figure 1 illustrates how the change in convergence and the position of the egocenter affect apparent movements and apparent locations of two stimuli. The two stimuli are on the optic axis of the nonoccluded eye, and the far stimulus is slightly vertically displaced above the near one. Figure 1a shows the predicted apparent locations of two stimuli for two states of accommodative vergence, when the egocenter is the point which bisects the interocular axis and the right eye is occluded. In this example, S correctly perceives the distance of the stimuli and has no convergence error. When S accommodates to the near stimulus (N), he will see it on the objective median plane, because he is symmetrically converged and the egocenter is central (postulate). Because the images of N and FR (the far-right stimulus) stimulate the same retinal location, FR will have the same visual direction as N and hence will be seen at FR_N (Principle 1). (The subscripts N and F designate accommodative vergence to the near and far stimuli, respectively.) When S changes accommodative vergence to FR, he sees it where it is

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Fig. 1. Illustrations of Hering's principles of visual direction with an additional postulate: (a) no fixation error and central egocenter, (b) no fixation error and eccentric egocenter, and (c) fixation errors of θ and ϕ and eccentric egocenter. The heavy solid lines show where S actually converges when he attempts to fixate the near light (N), and the thin solid lines show where he converges when he attempts to fixate the far-right light (FR).

(postulate). However, he now sees N at N_F because N_F is on the line from the egocenter to FR and because FR and N stimulate the same retinal locus (Principle 2 and Principle 1). When S changes accommodative vergence from N to FR, both stimuli should appear to move through the angle α . Changing accommodative vergence from FR to N should reverse the direction of motion. If the occluder is now placed over the left eye and if the far stimulus is at FL, then changes in accommodative vergence from N to FL would produce apparent movement of both stimuli through the same angle (α).

In Fig. 1b, when the egocenter is not centrally located and S accommodates to N, he sees N where it is (N_N) and sees FR at FR_N . With a change in accommodative vergence from N to FR, the apparent movement will be through angle β . If the left eye is occluded and S accommodates to N, FL will also be seen at FR_N because FL is on the same visual line as N and because that line passes through the egocenter. Thus, if the egocenter were located asymmetrically, the extent of apparent movement seen by each eye would differ (e.g., FR_N to FR_F and FL_N to FL_F).

The situation in which there are

convergence errors of the occluded eye is illustrated in Fig. 1c. When S is asked to accommodate to N, his eyes in fact converge on C_N because of the convergence error ϕ . According to Principle 2 and the postulate, he sees N at N_N on the line EC_N (E here referring to egocenter). According to Principle 1, FR_N is seen in the same visual direction as N_N . When S attempts to accommodate to FR, he has a convergence error θ and sees FR at FR_F and N at N_F . The stimuli are thus seen to move through the angle γ (i.e., FR_N to FR_F or N_N to N_F) when S changes accommodative vergence. (In this example, the S is exophoric when accommodating to N and esophoric when accommodating to FR.)

The hypothesis tested in Experiment 1 was that the convergence errors (ϕ and θ) and the position of the egocenter determine the apparent movements (FR_N to FR_F and N_N to N_F) and the difference in visual direction (γ). The extents of the apparent movements and the differences in visual direction of two stimuli were measured under a condition in which the near stimulus tended to produce large exophorias and the far stimulus little phoria. The phorias associated with two stimuli

were measured, and the location of the egocenter was determined. These measurements were taken for different Ss, and the analysis of results tested the adequacy of the hypothesis in explaining the individual differences.

Method

Apparatus. The basic unit of the apparatus served several functions. It was used to present stimuli during the experimental session and the practice session, to record the apparent locations of the stimuli, and to measure the location of the egocenter for each S.

The stimulus lights were mounted on a 1-m optical bench on top of a table. The near light, N in Fig. 1, was vertically above the center of the optical bench. The far lights, FL and FR, were mounted on a channel normal to the optical bench and were so positioned that they were just visible to S over the top of the near light. The sources for all the lights were 6-V incandescent bulbs. The light was transmitted to holders by lengths of fiber-optic cable. The S saw the round cross section (2 mm) of one end of the fiber-optic cable.

A lathe tool carriage and cross feed were mounted at the edge of the table and held a biteboard. An occluder was also mounted on this instrument; by means of a pulley system, it could be moved horizontally. All or part of the field of view of either of S's eyes could be occluded.

Six holes were drilled in the table top; a rod, which served as the practice stimulus, could be placed in any of these holes so that its top was at the height of the lights and its bottom protruded through the table. Four of the six holes were at the distance (56 cm) of the far lights used in the experimental sessions, and were symmetrically placed about the optical bench at 6 and 18 cm to either side. The other two holes were at the distance (14 cm) of the near light and were 4 cm on either side of the optical bench. The S's task was to fixate the top of the rod and to try to place a pen on the tip of the rod under the table. After each response, E could guide S's hand and the pen to the correct position.

The S marked the apparent locations of stimuli on a roll of paper, 82.4 cm wide, which ran through guides under the table.

To measure the location of the egocenter, there was one movable light and one fixed light. The single movable light (in the channel) could be driven by an electric motor controlled by S's right hand. The S's task was to adjust the movable light in any given trial until the imaginary straight line between the two lights

pointed straight at himself. For half of the trials, the movable light was closer than the stationary light. The near stationary lights were positioned 10 cm on either side of S's median plane and the far stationary lights were 25 cm to either side. The near light (movable or stationary) was always 33 cm in front of S, and the far light was 53 cm in front.

Two other apparatuses were used. The S held a 30-cm rod unseen in his lap and manually set the distance between the collars on the rod to report the extent of seen movement. A variable prism and Maddox rod was used to measure phoria. The principle of the Maddox rod is that the monocular view of a stimulus is optically modified so that the two monocular images are so dissimilar as to produce no fusion reflex. The power of prism required to superimpose the images phenomenally from the two eyes indicates the extent of phoria.

Experimental design. There were four experimental sessions. In Session 1, the apparatus was adjusted for S and training was given for the different tasks involved in Sessions 2 and 3. In Sessions 2 and 3, measures of the following three variables were taken: the phorias associated with the near and far stimulus, the apparent locations of a stimulus before and after a change in accommodative vergence, and the extent of apparent movement of a stimulus produced by eye movement. The measures were obtained, using a three-way factorial design in which the factors were (1) occlusion of right or left eye, (2) change in accommodative vergence from the near to the far target, or vice versa, and (3) reports of apparent location and apparent movement of the near or far target. The four combinations of Factors 2 and 3 were counterbalanced by a Latin-square design. Different Latin squares were presented in Sessions 2 and 3. For half of the Ss, the eye order was right-left for Session 2 and left-right for Session 3. The eye order was reversed for the other Ss.

In Session 4, the egocenter was located by a "direct egocenter" method (Howard & Templeton, 1966). The S binocularly lined up two lights so that the imaginary straight line between them pointed straight at himself. Four lines were determined. The measures were obtained using a two-way factorial design: the stationary light was (1) nearer or farther than the movable light and (2) to the left or right of S's median plane. The trials in which the near or far lights were stationary were run in a block. Half of the Ss were presented with the near stationary lights first.

Within a block were eight presentations of the stationary light on the left side and eight on the right side. The right and left stationary lights were presented randomly within the block.

Procedure. In Session 1, S was shown how to use the instrument to measure phoria. A light was placed approximately 30 cm from his eyes, the room was darkened, and, for practice, S adjusted the prism three times for each eye. The S then practiced marking the location of stimuli. Five responses were made for each of the six positions. After each response, feedback was given as to the correct position. For practice in reporting apparent movement, S manually estimated the movement of a pointer which E moved. The range of movement was $\frac{1}{2}$ to 6 in. at a distance of about 40 cm. After each trial, S was allowed to see how much movement he had marked and was told how accurate he was. Eleven movements were presented three times each.

After the practice, S was positioned in the apparatus. The bite was adjusted so that both of S's eyes were at the same height as the two far lights. A screen with a small aperture vertically above the optical bench was placed between S and the far lights. The bite was further adjusted so that when the far lights were equidistant from the optical bench, S could see each of the far lights through the aperture with his contralateral eye. When this could be done for two different consecutive positionings of the aperture, S was in position with the optical bench on his objective median plane. Then the near light was placed on the optical bench 14 cm in front of the interocular axis. The two far lights, on the channel, were set 42 cm behind the near light. The far lights were then moved along the channel until the right light, the near light, and the nodal point of S's left eye were in line (as in Fig. 1) and until the left light, the near light, and S's right eye were also in line.

At the start of Sessions 2 and 3, S briefly practiced marking locations and estimating movements once each for the 6 positions and the 11 movements. Then the experimental trials began. The measurements of the variables followed the same sequence in each trial. The following is an example of a trial in which the right eye was occluded, the change in accommodative vergence was from near to far, and the apparent movement and apparent location of the far light were measured. The room lights were extinguished so that the room became completely dark. The near light was switched on, and S was asked to focus on it while holding the Maddox rod before his right eye. He

appropriately adjusted the prism, which was then removed. The far-right light was switched on, and S occluded his right eye. He continued to focus on the near light and marked the apparent location of the far light. He was then instructed to change focus to the far light and report the perceived movement of the far light. Then, maintaining focus on the far light, he again marked its apparent location. The near light was then extinguished. The S then removed the occluder and again set the prism with the Maddox rod before his right eye. From these measures, the change in convergence and the change in the visual direction of the light with different fixation distances could be calculated. A measure of perceived movement was also obtained. In each session, 16 experimental trials were run for each eye.

Throughout Sessions 2 and 3, the importance of maintaining focus on the appropriate light was emphasized. The S was told that when he reported the apparent location and the apparent movement, he should disregard any knowledge of the actual location of the light and should report only what he "saw." When reporting the extent of apparent movement, S was to estimate only the component in the frontal parallel plane.

In Session 4, the position of S's egocenter was measured. The two lights were never simultaneously on, in order to prevent S from symmetrically positioning the single image of one light between the diplopic images of the other light. The S signaled E to switch off one light and to switch on the other. These alternations were accomplished with as little delay as possible. This procedure was continued until S was satisfied with the position of the movable light, at which point its position was recorded and the next trial begun.

Subjects. Three women and six men from the university community participated in the experiment. The age range was 21-40 years.

Results and Discussion

The experiment yielded measures of convergence error and the position of the egocenter for each S. These measures can be used to predict how much movement, or difference in visual direction (DVD), each S should see. The primary analysis was to determine how well these predicted scores matched the obtained scores and how much each S's phorias and the position of his egocenter predictably influenced his judgments. Each S's egocenter was defined as the point at which the sum of the squared perpendicular distances to the four lines was minimal.² Each line passed

Table 1
Means and Standard Deviations for Different Measures in
Terms of R + L and R - L in Experiment 1

		Predicted DVD (Deg)	Obtained DVD (Deg)	Apparent Movement (Cm)	Exophoria Near (Δ)	Exophoria Far (Δ)
R + L	Mean	10.17	9.25	3.91	23.99	.42
	SD	4.81	7.56	4.63	14.80	4.64
R - L	Mean	-2.95	1.16	.39	1.29	-.91
	SD	1.88	3.61	.99	1.67	2.12

Note—Δ = prism diopters

through the position of one of the stationary lights and the respective mean positions of the movable light. The mean phorias, for each eye, associated with accommodation to the near and far lights were computed. The predicted DVDs of the stimuli were calculated, for each eye, using the location of the egocenter and the appropriate mean phorias. The predicted DVDs were expressed as angles at the egocenter (γ in Fig. 1c).

There were two sets of dependent variables, obtained DVD and apparent movement. The obtained DVDs, like the predicted DVDs, were expressed as angles at the egocenter. For each trial, the angle between the marked locations of the target, before and after the change in accommodative vergence, was calculated. There were no systematic differences in the means of these angles for near and far targets. Therefore, the means of all angular scores for the left and right eyes separately were computed to yield a mean obtained DVD for each eye. The mean apparent movement was also calculated for each eye. The apparent movement obtained in this way combined the apparent movement of the near and far lights. The reported results are limited to the combined scores, but in every case the separate analysis of the results from the far and near lights revealed the same degree of correlation as the combined scores.³

The predicted and obtained values for the right and left eyes are not statistically independent; hence, the data from the two eyes of each S were combined to form two sets of predicted and obtained scores. The first set was the sum of the predicted scores for left and right eyes (predicted R + L), which was compared with the sum of the obtained scores (obtained R + L). The second set was the difference between the predictions for the two eyes (predicted R - L), which was compared to the difference between the obtained scores (obtained R - L). As will be discussed later, the correlation between predicted and obtained R + L scores would show how much each S's phoria predictably influenced his judgments, whereas the correlation between predicted and

obtained R - L scores would show how much the position of the egocenter predictably influenced his judgments. The group means and the standard deviations of predicted and obtained scores in terms of R + L and R - L are presented in Table 1, together with the mean phorias associated with the far and near lights.

The degrees of association between the predicted and obtained scores are shown in Table 2, expressed as Pearson *rs*. Also presented in Table 2 are *rs* between the dependent variables and phoria scores. These *rs* represent the relationship between phoria and the dependent variables without taking into consideration the position of the egocenter. The phoria score for each eye was computed by subtracting the phoria associated with the near light from that associated with the far light. Exophorias were given a positive sign, and esophorias were given a negative sign. The phoria scores for the right and left eye of each S were computed, and the R + L and R - L phoria scores were derived to relate to the dependent variables.

The R + L scores will be considered first. Two results emerge. The most important results were the significant *rs* between predicted DVD and apparent movement and between predicted DVD and obtained DVD. Predictions of the two dependent variables were equally successful, and consistent with this result is the *r* of .899 between the two obtained scores.

The second result was that the *rs* between the phoria scores and the dependent variables are very similar to those obtained between the predicted DVD scores and the dependent variables. These *rs* suggest that phoria played a major role in the predicted R + L scores, whereas the location of

the egocenter played a minor role. This minor role is further indicated by the high *r* (.988) between R + L phoria scores and R + L predicted DVD, which can be interpreted to mean that variability in the phoria scores contributed 98% ($r^2 \times 100$) of the variance of the predicted DVD scores (McNemar, 1962, pp. 129-132). Individual differences in the location of the egocenter contributed almost nothing to the variability of the R + L predicted DVD scores.⁴ Hence, the significant correlation between predicted and obtained R + L DVDs is not relevant to the hypothesis about the importance of the egocenter. However, the four significant correlations demonstrate the importance of the phorias in predicting the individual differences.

Eight of the nine Ss saw apparent movement with both eyes, and one S saw no movement. Furthermore, the DVD scores were in the predicted direction for both eyes in all Ss. These results and the correlations discussed above strongly support the proposition that the orientations of both eyes are monitored by the visual system.

The prediction of the R - L scores was not as successful. The conventional level for rejecting a null hypothesis at $p < .05$ required an *r* of .582, which is slightly larger than those obtained. However, a nonparametric test (Spearman's rank order correlation) yielded values of .617 and .650 for the DVD and apparent movement scores, respectively. These correlations are statistically significant ($p < .05$, one-tailed).

Table 2 shows that the *rs* between R - L phoria scores and the dependent variables were low. These results suggest that phoria played a minor role in predicting R - L scores. This minor role is further indicated by an *r* of .260 between R - L predicted DVD and R - L phoria scores, which indicates that the individual differences in the R - L phoria scores contributed only 8.4% to the variability of the predicted R - L DVD scores. Hence, most of the variability in the predicted R - L DVD scores was due to the individual differences in the location of the egocenter. However, the fact that the

Table 2
Correlations (Pearson *rs*) Between Predicted and Obtained Scores and
Between Phoria and Obtained Scores in Experiment 1

	R + L		R - L	
	Obtained DVD	Apparent Movement	Obtained DVD	Apparent Movement
Predicted DVD	.814	.722	.553	.554
Phoria Scores	.833	.771	.108	.124

Note— $r = .750$ ($p < .01$, one-tailed)

$r = .582$ ($p < .05$, one-tailed)

$df = 7$

success in predicting R - L dependent variables was marginally significant calls for a postponement of a decision on the importance of the location of the egocenter in predicting individual differences. Also, the point should be made that the concept of egocenter itself is ill-defined. There is no general agreement as to the operational definition of egocenter, and furthermore, the procedure used to measure egocenter in this experiment differed from the procedures used by the other investigators, such as Funaishi (1926) and Roelofs (1959). The present procedure is similar to what Howard and Templeton (1966) called the "direct" egocenter method, but the details differed. To avoid S's setting the movable light between the diplopic images of the stationary light, the two lights were never on simultaneously (as would be the comparable case if a rod were used). A different method of measuring the egocenter may have been more appropriate. The present results suggest that the position of the egocenter may play some role in determining the extent of DVD and apparent movement, but the results are merely suggestive and no firm statement can be made.

The foregoing analysis and discussion of the results were concerned with the combination of scores from right and left eyes. However, an important feature of Walls's hypothesis is that there will be significant differences between the scores for the two eyes. The relationships between the results of the different eyes will be briefly described here. The *rs* between the right and left eyes across Ss were .635 and .947 for the obtained DVD and the apparent movement scores, respectively. These two *rs* indicate that a S who perceives large apparent movement and DVD with one eye tends to perceive large apparent movement and DVD with the other eye. This finding is not what would be expected from Walls's hypothesis. The *rs* between the phoria of the left and the right eyes were .817 and .979 for the far light and near light, respectively. The results described in this paragraph further substantiate the interpretation that the success of predicting the R + L scores is primarily due to the individual differences in phoria. These results imply that our success in predicting the R + L scores did not depend upon the contribution of phoria, DVD, or apparent movement scores from only one eye, and furthermore, these results suggest that few, if any, of our Ss gave evidence of having a "sighting dominant" eye by perceiving movement with only one eye.

EXPERIMENT 2

In Experiment 1, the near stimulus was so close to S that it usually produced large exophoria. The principles and the postulate predict that if this convergence error were reduced, the apparent movement and the difference in visual direction would be greater. In terms of Fig. 1, if phoria were reduced, the situation would become closer to that of Fig. 1b than to that of Fig. 1c. In Experiment 2, an attempt was made to test this prediction. Two conditions were used. In one condition, the large exophorias were reduced by having S binocularly fixate the near stimulus until the change in accommodation. In the second condition, S viewed both stimuli monocularly and the convergence error was not reduced. The hypothesis was that the first condition would yield greater mean apparent movement and difference in viewed direction. In addition to testing these hypotheses about the ordinal relationship between the results of two conditions, the magnitudes of the two dependent variables in two conditions were examined. The magnitudes of predicted difference in visual direction and predicted apparent movement were calculated for the binocular condition, with the assumption that there was no convergence error. The phoria measurements recorded in Experiment 1 were used to calculate predicted magnitude of the change in apparent location when convergence errors were not prevented. The magnitudes of obtained scores were compared to the magnitudes of predicted scores.

Method

The apparatus, the stimulus arrangements, and procedure were similar to those in Sessions 2 and 3 of Experiment 1.

There were two experimental conditions, the partial occlusion and the complete occlusion conditions. Within each condition, there were two kinds of trials: right eye occluded and left eye occluded. All four types of trials were presented within each of four blocks. The blocks differed in whether the partial occlusion condition preceded the complete occlusion condition and in whether right-eye occlusion preceded left-eye occlusion in each condition. The four blocks of trials were presented four times, and the order of presenting the blocks comprised a Latin-square design. There were 64 trials.

In all the trials, S always changed accommodative vergence from the near light to the far light and always marked the location and the movement of the far light. No phoria measurement was taken. Otherwise,

the complete left and complete right trials were the same as the trials in Experiment 1, where both lights were occluded from one eye. In the partial trials, the far light was occluded from one eye, but the near light was viewed with both eyes at the beginning of a trial. For example, in a partial right trial, the near light and the far-right light were turned on and S was asked to partially occlude his right eye so that he could see the near light with both eyes but the far-right light with only the nonoccluded eye. The S was asked to fixate the near light and to mark the apparent location of the far light. Then S was asked to change his fixation, when the signal "now" was given by E, and to report the apparent movement of the far light. When E said, "Now," he simultaneously occluded S's right eye from both lights. The reason for this procedure was to avoid diplopic images of the near light during and after the eye movement. The S was then asked to maintain his focus on the far light and to mark the apparent location of the far light.

The Ss for Experiment 2 were eight of the nine who had participated in Experiment 1. One S who participated in Experiment 1 was unable to converge to the near light in the partial occlusion condition. He did not participate in Experiment 2.

Results and Discussion

In the first analysis, the results of the partial occlusion condition were compared with the results of the complete occlusion condition. As in Experiment 1, there were two conceptually equivalent dependent variables: the apparent-location and the apparent-movement data. The apparent locations obtained before and after the change in accommodative vergence were transformed into angular scores, using the egocenter from Experiment 1. Then for each S, the means of the scores were converted to obtained R + L DVD scores for each condition. Also computed for each S were the obtained R + L apparent movement scores for both conditions. As in Experiment 1, the obtained R + L apparent movement score was the sum of the means of apparent movement obtained from the right and left eyes.

The group means and standard deviations of the R + L apparent movement scores and the obtained R + L DVD scores are presented in Table 3. An examination of the table reveals that the means from the partial occlusion condition are larger than those from the complete occlusion condition. The hypothesis that the reduction of convergence error (exophoria of near light) would

Table 3
Means and Standard Deviations of R + L
Apparent Movement and R + L Obtained
DVD for Two Conditions in Experiment 2

		Partial	Complete
Apparent Movement (Cm)	Mean	6.82	5.35
	SD	5.31	5.28
DVD (Deg)	Mean	11.95	8.93
	SD	4.80	5.14

increase the apparent movement and DVD finds statistical support. The t tests between the means of the two conditions yielded $t(7) = 4.47$ ($p < .0025$, one-tailed) and $t(7) = 2.36$ ($p < .025$, one-tailed) for the apparent movement scores and the DVD scores, respectively.

The second analysis was concerned with the exact magnitudes of predicted and observed DVDs and apparent movements. The mean magnitudes of the R + L predictions were computed for the two dependent variables in the two conditions. The stringent hypothesis predicts a mean R + L DVD of 18.30 deg, with a standard deviation of 1.60 deg in the partial occlusion condition. The predicted mean apparent movement is 17.91 cm, with a standard deviation of 1.63 cm based on the assumption that the egocentric distances of the stimuli were correctly perceived. In the complete occlusion condition, the mean predicted DVD and the mean apparent movement were 11.95 deg ($SD = 4.16$ deg) and 11.73 cm ($SD = 4.33$ cm), respectively.

The results did not fit the prediction based on the stringent hypothesis. Comparison of the obtained apparent movement scores and the obtained DVD scores with the predicted values shows that the obtained scores (see Table 3) were considerably smaller. The discrepancy suggests that other factors, not considered in the formulation, were involved. Possibly the Ss' knowledge of the actual location of the light biased their responses towards this location, thus producing smaller obtained scores than predicted. If a procedure were used in which the Ss did not obtain this information, the results might have been closer to those predicted from Hering's principles and the postulate.

GENERAL DISCUSSION AND CONCLUSIONS

The chief results of the two experiments were: (1) the apparent movements and changes in visual direction of two stimuli which accompany accommodative vergence covaried across different individuals

and across different experimental conditions, (2) the individual differences in the apparent movement and the perceived change in visual direction were related to the individual differences in the phorias and possibly to the locations of egocenters, and (3) the apparent movement and the perceived change in visual direction were increased by eliminating the convergence error when the near light was fixated.

The following conclusions were drawn from these results: (1) the apparent movement and the perceived change in visual direction are determined by the same factors, (2) the orientations of the occluded eye and the nonoccluded eye together determine the apparent locations of the stimuli, and (3) incorporating Conclusions 1 and 2 with Hering's principles of visual direction and the postulate accounts for most of the results related to the apparent movements and the perceived changes in visual direction.

These results and conclusions are not consistent with Walls's hypothesis that the visual system monitors efference to only one of the eyes. His theory says that "in any individual who has a 'sighting dominant' eye, the dominance really is made obvious by the fact that it is only the muscles of that eye whose innervations are 'recorded' and employed for directionalizing purposes [Rubin & Walls, 1969]." In describing the role of one eye, Rubin and Walls argue that the term "directional dominance" or "directionalizing eye" should be used. The results of the present experiment provided no support for this hypothesis. Admittedly, the present sample was relatively small, but none of the nine Ss in the present experiment or the seven in the preliminary study provided evidence for the directionalizing eye. In our sample, some Ss saw apparent movement with both eyes and some with neither eye, but no one saw movement with only one of his eyes.

Rubin and Walls are not explicit about what proportion of the population should have this directionalizing eye. However, the fact that they report that 93% of the population have sighting dominance implies that finding people with a directionalizing eye should be the rule rather than the exception. The results of the present study suggest the opposite. The person with a directionalizing eye or the person who sees movement with only one eye should be rare. The fact that Walls observed apparent movement with

only one eye does not contradict the present formulation. The present hypothesis predicts that some Ss would see movement with one eye if the egocenter was located in one eye or if phorias of two eyes were unbalanced in certain ways. Whether the egocenter and phorias of an observer such as Walls fit the requirement of the formulation remains an interesting question.

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NOTES

1. Howard and Templeton (1966) have stated a principle similar to the postulate. In discussing Hering's principles of visual direction, they assumed that the projection center was located midway between the eyes, also pointed out that the actual location was the subject of empirical investigation. The postulate assumes that there are individual differences in the locations of the projection center and makes explicit the importance of the angular positions of the two eyes in the sockets. The postulate and the principles, in their present form, apply only to stimuli on the visual axes, but more general forms of the predictions of direction from the three premises are possible. Such general statements would include the predictions of apparent locations of the stimuli not on the visual axes. For corollaries, see Howard and Templeton (1966).

2. The method used to locate the egocenter is very similar to that used to measure sighting dominance. In measuring sighting dominance, two binocularly viewed objects are aligned and the line connecting the two is projected onto the interocular axis. In our results, the range of different egocenter locations was much less than that expected from the notion that the egocenter was in either the right or left eye.

3. Eight Ss who saw movement consistently judged the far light to have greater apparent movement: the mean ratio of the far apparent movement to the near apparent movement was 2.19, $t(7)$ against unity = 3.74 ($p < .01$). The ratio of the distances to the near and the far lights was 4:1.

4. The reason for this is shown in Fig. 1b. The farther the egocenter is to the left of the median plane, the smaller will be the DVD (FR_N to FR_F) when the right eye is occluded; but when the left eye is occluded, the DVD (FL_N to FL_F) becomes larger. Therefore, the predicted sum will remain almost the same.

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