BINOCULAR EYE MOVEMENTS

BINOCULAR EYE MOVEMENTS
IN
UNSTRUCTURED VISUAL FIELDS

By

PAUL FOSTER NELSON, B.S.

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the Requirements
for the Degree
Master of Arts

McMaster University
May 1968

MASTER OF ARTS (1968)
(Psychology)

McMASTER UNIVERSITY
Hamilton, Ontario.

TITLE: Binocular Eye Movements in Unstructured Visual Fields

AUTHOR: Paul Foster Nelson, B.S. (University of Washington)

SUPERVISOR: Professor R. M. Pritchard

NUMBER OF PAGES: v, 49

SCOPE AND CONTENTS:

The purpose of this study was to examine binocular eye movements in humans with two types of unstructured visual fields, diffuse light and darkness, and to compare these conditions to normal binocular vision. Variability of eye movements, both monocular and binocular, increased markedly in unstructured fields. This effect was especially evident for movement in the horizontal plane. The findings are interpreted in terms of recent evidence of the neurophysiological conditions for binocular fusion in cats.

TABLE OF CONTENTS

TABLES

FIGURES

INTRODUCTION

During binocular fixation an approximate alignment is maintained between the two eyes by highly correlated simultaneous saccadic movements of the eyes. These movements keep the image of the visual stimulus within the small area of each retinal fovea that is associated with greatest visual acuity. Failure of the system to maintain close binocular correspondence produces disparity, or misalignment of the two retinal images, which results in a breakdown of binocular fusion, i.e. diplopia or double vision, when it exceeds some critical value.

The eyes are never absolutely still. Slow drifting movements carry the image of the stimulus out of the center of the fovea and are terminated by corrective saccades or flicks. Random high frequency and low amplitude ocular tremor is superimposed on the drifting movements. Further instability in the positioning of a fixated image upon the retina may arise from movements of the head and not from the eyes themselves. Thus, because the head moves and the eyes are under constant independent motion, an exact geometric point-to-point imagery in the theoretical center of each fovea is impossible. In addition, there is no true neurophysiological point-to-point correspondence of the two retinae. A visual receptor in the right eye has more than a single receptor in the left eye which has the same visual direction or locus in space. There is no exact foveal fixation point and slight deviations of the visual axes do not prevent fusion. Thus it is more meaningful to speak of identical retinal areas as opposed to identical retinal points. Finally, information of the position of the eyes in their orbits is available to the brain from either an innervational or proprioceptive sense in the ocular muscles. However, it is not considered to be essential for the fine corrective movements that are associated with the maintenance of normal fixation.

What is the relationship between the availability to the two eyes of patterned correlated visual stimulation and the variability of the binocular eye movements? Recent neurophysiological evidence on the mechanisms underlying binocular fusion in cats suggests that the eye movement control system is continuously hunting for positions of the eyes which optimize certain goals, i.e. maximal cortical excitation confined to the least possible cortical area. When such a system is confronted with visual fields that prevent such maximization strategy, e.g. homogeneous visual fields, it well might be expected to increase both the variability of movement of the individual eyes, and the variability of their separation, in an attempt to meet these impossible goals. Knowledge of effective methods of disrupting the eye movement control system and binocular alignment might offer behavioral evidence on the underlying physiological mechanisms involved in fixation and awareness of the position of objects in space and the eyes in their orbits.

The experiments reported here examine binocular eye position variability in diffuse light, in darkness, in binocular fixation, and in various combinations of these situations. Before considering the study itself the earlier experimental evidence relevant to the problem will be considered in greater detail.

HISTORY

Much of the experimental evidence reported in the literature that is relevant to the problem at hand has come from studies of eye movements during periods of fixation on a steady target. The major methods used for measuring small eye movements are: (1) recording by means of direct attatchment to the eye, (2) the contact lens method, (3) direct photography of the eyes, and (4) recording of the corneal reflection. Comparisons show that widely different methods lead to concordant results and the persistent small involuntary eye movements reported are not artifacts of the apparatus employed in their measurement.

Huey (1899) used a modified kymograph attached to a cap mounted on the cornea to measure eye movements during reading and later modified the system to measure reaction time. He found it necessary to reduce his measures for reaction time due to the fluctuations of the baseline of his kymograph record during steady fixation. About the same time, Orchansky (1898) reported a method of measuring eye movements that utilized essentially the same principle as a majority of the modern methods of measuring eye movements; he fashioned a shell to fit over the eye and attached a plane mirror to it. This device, which the subject could see through, was mounted to the eye and a beam of light was reflected off the mirror and photographed on a continuously moving strip of film. Orchansky did not present any results from his method. McAllister (1905) used photography of a drop of pigment on the corneal surface to record eye movement during fixation and reported a range of movement of about one degree. Dodge (1907) used fixation to attempt to keep an afterimage motionless and again reported movement of the eyes during fixation. The magnitude and frequency of the involuntary eye motions while attempting to fixate a target were recorded by Marx and Trendelenburg (1911) using a mirror fastened on an aluminum shell. They reported that most of the movements found were under five and one half min. arc. and there were no differences between the horizontal and vertical components of movement. Further, they measured head movements and reported there was no relationship between head and eye movements. Adler and Fleigelman (1934) offer the first real quantification of the type and extent of movements during fixation. They used a mirror fastened to the cornea with the same type of optical lever method as Orchansky (1898) and Marx and Trendelenburg (1911). Adler and Fliegelman reported saccades of 12.5 to 17.5 min. arc., waves of 2.5 to 5 min. arc., tremor of 50 to 150 cycles per second, and a mean movement of 2 min. 14 sec. of arc. Lord and Wright (1948), using corneal reflection of ultraviolet radiation to a photomultiplier, report essentially the same findings as Adler and Fliefelman except that they found no tremor. Ratliff and Riggs (1950), Ditchburn and Ginsborg (1953), and Fender (1955), using tight fitting contact lenses with plane mirrors attached, employed the optical lever method with improved resolving power to clarify the nature of the movements. Barlow(1952) using reflection of light off a drop of mercury on the corneal surface to measure movements during fixation, reported that the eye is essentially steady during intersaccadic intervals, despite his further report of slow drift and intermittent tremor in the interval.

The major feature of eye movement records obtained by the above workers is that during fixation the eyes are constantly in motion. There are essentially three types of movement, but not all of these types are distinguished by the above workers because of the lack of sensitivity of their respective methods or because the movement is obscurred by the contamination introduced by head movement. The three types of movement distinguished are: (1) rapid flicks or saccadic motion occurring at irregular intervals with the interflick period, usually between 0.5 and one second, very characteristic of an individual, and with the amplitude of the motion varying between 1 and 30 min. arc., (2) slow drifting movements during the interflick period of amplitude up to 5 min. arc. and (3) high frequency tremor superimposed on the slow drifting motion which has a frequency range of 1 to 150 cycles per second with an amplitude range of 0.1 to 1 min. arc. The three types of incoluntary eye movement have horizontal, vertical and torsional components.

How do the above movements function in maintaining fixation on a stationary point? Ditchburn and Ginsborg (1953) observed that saccades are usually directed toward the mean position of the record and that large overshoots are usually corrected very soon by a saccade in the other direction. They suggest that the system maintaining the retinal image of the fixation point in the "central territory" (Polyak, 1941) is under visual control. Cornsweet (1956), in an analysis of the stimuli leading to the saccadic and drift movements in monocular fixation, compared the stabilized image at different flicker rates with normal fixation. The manipulation of the flicker rates varied the proportion of time that the stimulus was visible. Cornsweet suggested three possible stimulating conditions for any type of movement: disappearance of the target, displacement of the retinal image from the central area of the retina, and instability of the oculomotor system. In the first case, movement would be expected to vary with the percentage of time that the stimulus was visible, the second could be tested by the relationship of the displacement of the eye from its mean position during fixation to the occurrence of movement, and the elimination of the first two would seem to leave the third as the only possibility. Cornsweet found that there is essentially no relationship between the visibility of the stimulus and either saccadic or drift movements. Neither is drift related to displacement from the mean position of the eye. For the saccadic movements, however, direction, magnitude, and probability of occurrence of saccades are a function of displacement of the eye from its mean position. Furthermore there are significantly fewer saccades during stabilized image viewing than during normal viewing which also indicates that, since there is no displacement of the retinal image during stabilized viewing, initiation of saccadic movements is a function of displacement of the retinal image from some optimal area of the retina. Cornsweet concludes that drift is a manifestation of instability of the oculomotor apparatus which allows the retinal image of the point of regard to fall off from the area of highest acuity in the fovea. This error is corrected by a saccade which returns the retinal image back to this area; again, visual control of saccades. Cornsweet's analysis was limited to the horizontal component of movement. Nachmias (1959, 1961) analyzing both vertical and horizontal components of motion of the eye (but not torsional) comes to much the same conclusions, but finds some evidence for visual control of drift in some situations, as well.

Cornsweet (1956) reports one further experiment which is pertinent to eye position control in homogeneous visual fields. The fixation mark was extinguished and eye movements were measured in the dark. The mean absolute deviation from the mean increased almost linearly as a function of time. Cornsweet suggests this is due to the removal of visual control and, thus, the randomization of magnitude and direction of saccades. He found no difference in drift rate in the dark and in fixation, offering this as further evidence for the lack of visual control of drift movements. Nachmias (1961), in the study above, also measured monocular eye movements in the dark but reports an increase in drift when the fixation mark was extinguished.

The studies above on monocular fixation have had the other eye occluded and unobserved. In a consideration of binocular eye position control, the question might arise of just what this occluded eye is doing and what is happening to its relationship with the fixating eye. Ditchburn and Ginsborg (1953), in an experiment on binocular eye movements, completely occluded one contact lens and then measured binocular eye movements while the other eye was fixating. They report that there was no significant difference from binocular fixation. Ditchburn (1955), commenting on this study in a later article, concludes that at least part of the maintenance of binocular fixation is probably due to proprioceptive, or some other type of non-visual control.

What, then, of eye movements in binocular fixation? One of the first studies of this problem is that above by Ditchburn and Ginsborg (1953). Both the horizontal and vertical component of movement were recorded. They report that the saccades occur simultaneously in the two eyes, and that magnitude and direction of the saccades are similar but not necessarily the same for the two eyes. Both conjugate movement and convergence-divergence waves are found in the drift. The extreme variations in the separation of the visual axes was found to be usually within 15 min. arc. Despite this movement, the image of the fixation point on the retina was confined to an area 100 micra in diameter, saccades probably being responsible for the control of fixation.

A later study of eye movements during binocular fixation by Krauskopf, Cornsweet and Riggs (1960) gives a more quantatative analysis, measuring just the horizontal component of movement, however. Saccades are reported to occur in synchronous pairs and simultaneously in the two eyes. Very high (.76+) correlations are found for the directed magnitudes of saccades in the two eyes. As was reported by Cornsweet (1956) for monocular fixation, direction, magnitude, and probability of occurrence of saccades are dependant on the position of the individual eyes. These two findings would seem to rule out both independent maintenance of monocular fixation and a system based on correction of vergence errors. Another finding by Krauskopf et al. reinforces the latter conclusion. Neither probability of occurrence or magnitude of the vergence component of the saccade pairs are a function of the deviation in vergence from the mean, although direction of the vergence component was a function of this. Drift in the two eyes is unrelated. Krauskopf et al. conclude that binocular fixation is maintained in the following way. Random drift causes the retinal image of the fixation point to fall off from the ideal area in both retinae. A saccade is initiated for one of the eyes, due to this drift. Since probability of occurrence of saccades is a function of displacement of the eyes from this ideal position, this saccade will most often be initiated by the eye with the greatest deviation. Any saccade is accompanied by a simultaneous and somewhat smaller saccade in the other eye. This system would result, generally, in an indirect reduction of vergence errors. Further evidence for such a system is given in the findings that fewer saccades occurred during monocular than binocular fixation and that the saccades are larger during monocular than during binocular fixation. This would seem to conflict with the observation by Ditchburn and Ginsborg (1953) that binocular eye movements are essentially the same in monocular and binocular fixation. However the differences found by Krauskopf et al. are so small that they would have been impossible to detect in the absense of a statistical analysis of the records.

Ditchburn and Ginsborg (1953) report one additional finding of interest. Fixation marks were extinguished and binocular eye movements were recorded for five second periods in near darkness with the subject trying to hold his eyes as steady as possible. The magnitudes of drifts and saccades were found to increase by a factor of approximately four. Variability of the separation of the visual axes increased markedly also, to 35-75 min. arc. and monocular variability increased to 40-75 min. arc.

Further evidence for the visual control of eye movements has come from Fender and Nye (1961) and Fender (1964), who apply the techniques of systems analysis to the oculomotor control system, Using the stabilized image technique to place the visual feedback from displacement of the retinal image under experimental control, Fender compared the tracking responses of the eye to moving stabilized images with the tracking response of the eye to a normal moving stimulus and found that the system functions in the same way as does a servomechanism with negative feedback, in that eliminating the feedback to the system causes an increase in gain. Reversing the sign of the feedback through prisms that reverse the direction of retinal image motion causes the eye to go through wild fluctations even with a stable target. Fender also reports that central depressants have no effect on the fixation reflex, and suggests that this may be a retinal function.

By the original theory of the identity of corresponding retinal points (Muller, 1826; Panum, 1858; Nagel, 1861; Hering, 1879) when images from a point in space fall on corresponding points, the stimulus is seen single. If receptors with different visual directions are simultaneously stimulated by the same object, the object will appear in two different visual directions in space. Diplopia or double vision is then the result. Panum (1858) showed that the images will, within certain limits, fuse even if these images do not fall on exactly corresponding points. The area of one retina which still permits binocular fusion with a stationary point in the other retina despite a different visual direction is called a Panum's area and is smallest in the fovea. The size of Panum's area in the fovea has been calculated to be about 6 min. arc. Further, there is a lack of point-to-point correspondence of the visual axes and fusion can still be maintained when the images of the entire visual field are displaced. This phenomenon is commonly observed and reported when using a stereoscope (Lau, 1921) or haploscope (Ames and Gliddon, 1928). The difference in fixation of the two eyes which will still permit binocular fusion is called the angle of fixation disparity. It is also known as retinal slip (Ames and Gliddon, 1928) and cortical slip (Lancaster, 1932).

No single retinal point is continuously stimulated for more than an instant because of the persistant involuntary eye movements. When considering the stimulation of a retinal element, the statistical mean position about which the eye movements fluctuate should be noted. Thus involuntary eye movements extend the concept of visual direction or corresponding retinal points to corresponding retinal areas (Gertz, 1935). Some proprioceptive mechanism is present in the ocular muscles of man (Breinin, 1957) but this does not imply that the mechanism necessarily provides an awareness of the position of the eyeball in space. Irvine and Ludvigh (1936) suggest that muscular activity forms the basis for the judgement of direction when the eyes are moved, but this "judgement is not founded on the actual contraction of the muscles but upon the will to move them." This is an innervational sense rather than a proprioceptive sense theory. Merton (1961), investigated the accuracy of directing the eyes in the dark, using an afterimage technique for measuring the deviation from the target and found the standard deviation of the mean to be approximately one degree in both the horizontal and vertical dimensions. When this is compared to the standard deviation of eye movements during fixation of generally less than 10 min. arc., it gives an indication of the inadequacy of proprioception for fine control of eye movement.

A recent study (Burns and Pritchard, 1968) presents neurophysiological evidence from the visual system of the cat which is relevant. Burns and Pritchard discuss the problem of binocular fusion and present evidence from studies of the distribution of neuronal excitation across the visual cortex when a light dark edge is present in the visual field. They find that when edges are presented in both visual fields in a critical alignment the cortical gradient of excitation is sharply peaked for the visual cortex corresponding to that part of the field. The cortex exhibits a marked summation effect; the response to the two eyes together is much greater than the sum of the two eyes separately. Burns and Pritchard suggest that this phenomenon is the basis for binocular alignment, accomodation and the fixation reflex. They speculate that the visual system is continually hunting for conditions which maximize the sharp definition of these peaks across the cortex. The implications of their theory for this experiment is that the visual system should markedly increase its variability in an attempt to meet these impossible goals.

METHOD

Subjects

The subjects used for these experiments were one male (MR) and two female (SA and LW) graduate students and one female research assistant (LN), all from the Psychology Department at McMaster University.

Apparatus

Measurement system The optical system used to measure involuntary eye movements is illustrated schematically in Figure 1. Light from the point sources S_1 and S_2 falls on two matched lenses L_1 and L_2. Since the sources and the lenses are separated by the focal length of the lenses, light emerges from the lenses in two columns of parrallel light rays. A plane mirror can be placed in these columns of light (as in Figure 1) so that it reflects this incident light back through the lenses. The reflected beams of light are also parallel and will be focused as images of the sources (see S_1' and S_2' in Figure 1) at distances from the lenses of their focal length. Any rotation α of the mirror will cause a deflection of 2α in its reflected beam (see Figure 2), since the rotation causes a change of α in the angle of the mirror with its incident beam and an additional change of α in the reflected beam since these are equal. Rotations of the mirror, therefore, can be be recorded by placing a sheet of photographic film, with two small holes in it for the light sources, in the plane indicated in

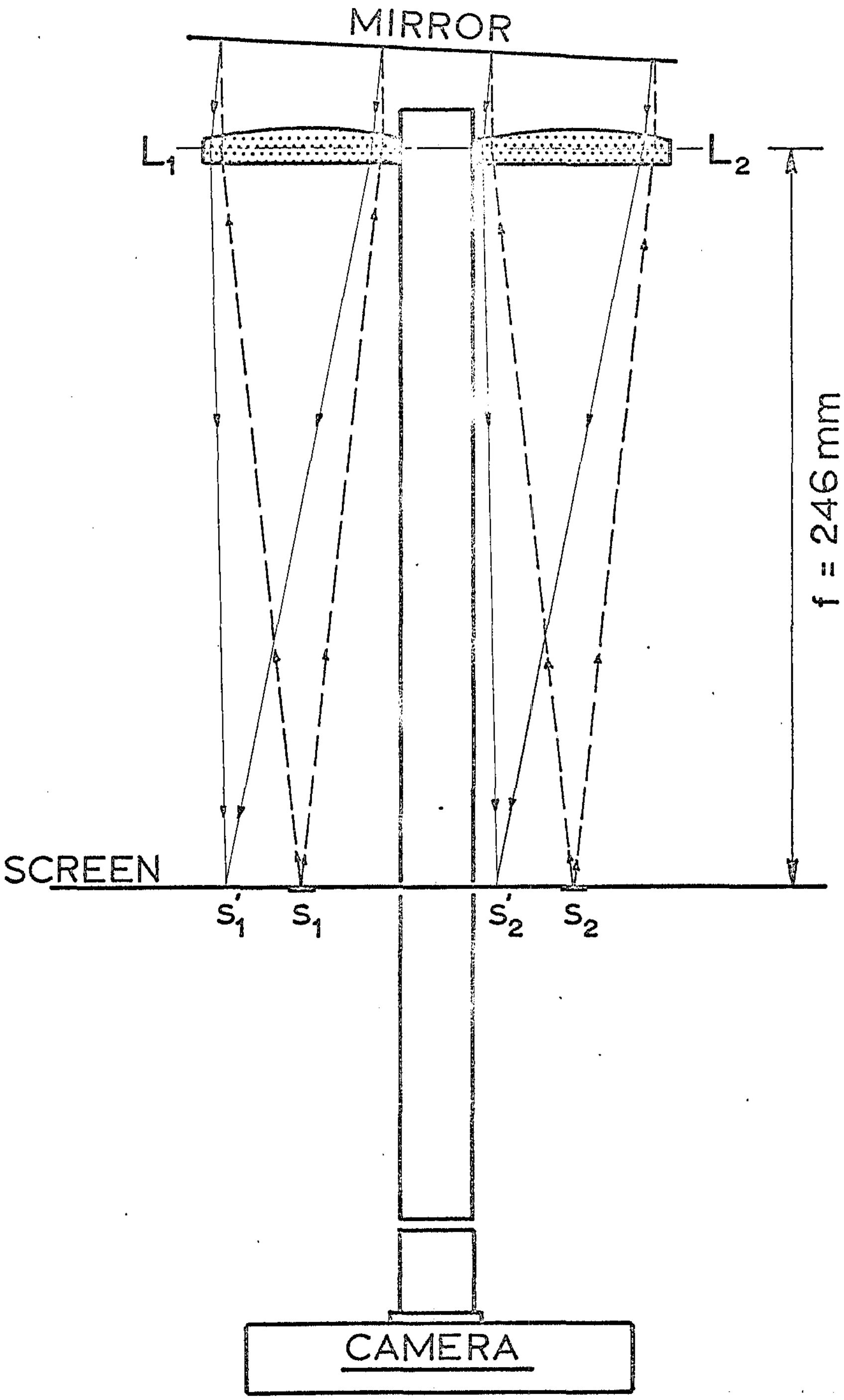

Fig. 1. Schematic diagram of eye movement measurement apparatus.

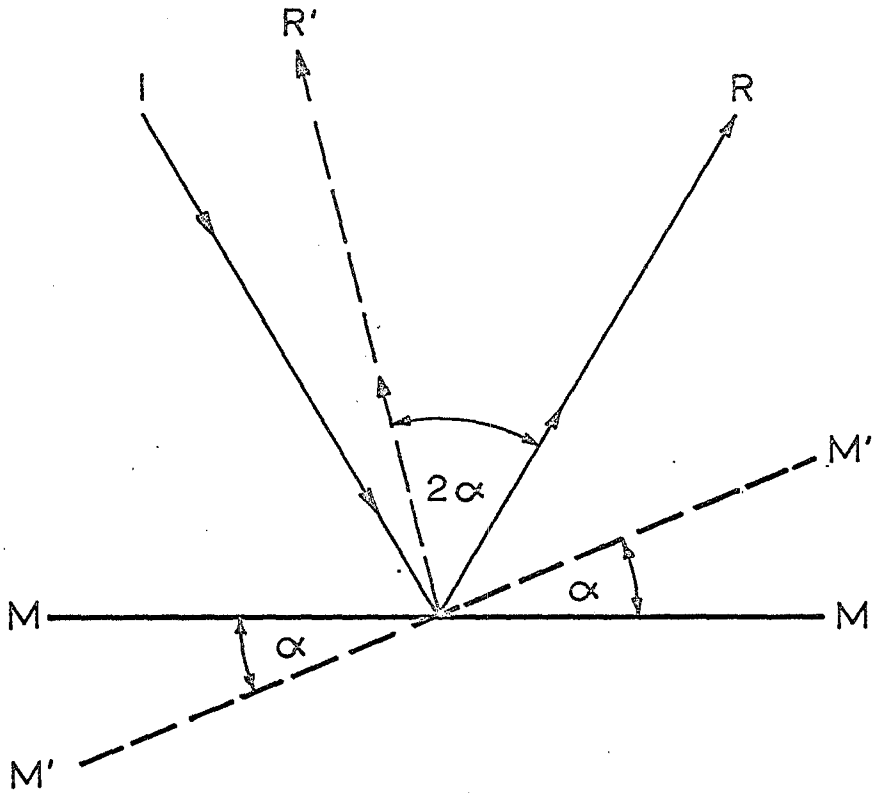

Fig. 2. Effect of the rotation of a mirror on the angle of reflection of an incident beam of light.

Figure 1 by the screen. The reflected images would be clearest and in focus very near to the sources and would become slowly defocused as they moved further from the sources because of the slight increase in distance between the lens and the film. This difficulty merely limits the range of movement that can be effectively measured by the system, however.

One problem with the above optical system is the lack of a time calibration. Replacing the film plate with a screen on which the images are focused and photographing the configuration of light spots on the screen at regular intervals is one way of correcting this problem. When this alignment mirror (as in Figure 1) is replaced by smaller mirrors mounted on contact lenses which accurately follow rotations of the subjects eyeballs, then the optical system will measure rotations of the subjects eyeballs. The subject's head must be maintained fixed relative to the system to eliminate any effects of torsional head rotations. Horizontal or vertical translations of the head will not contaminate the measures of eye movements.

Figures 3 and 4 illustrate the actual physical setup of the system. The apparatus shown in Figure 3, which is used in the conditions of diffuse light and darkness, is referred to below as system type 1. The subject is seated in front of the apparatus with his head held firm and approximately vertical by biting on an impression of his teeth in the previously prepared biting block held rigid in space by a heavy iron frome which is bolted to the table. Directly in front of the frame is an optical bench on which the two collimating lenses are mounted. The recording screen, a sheet of

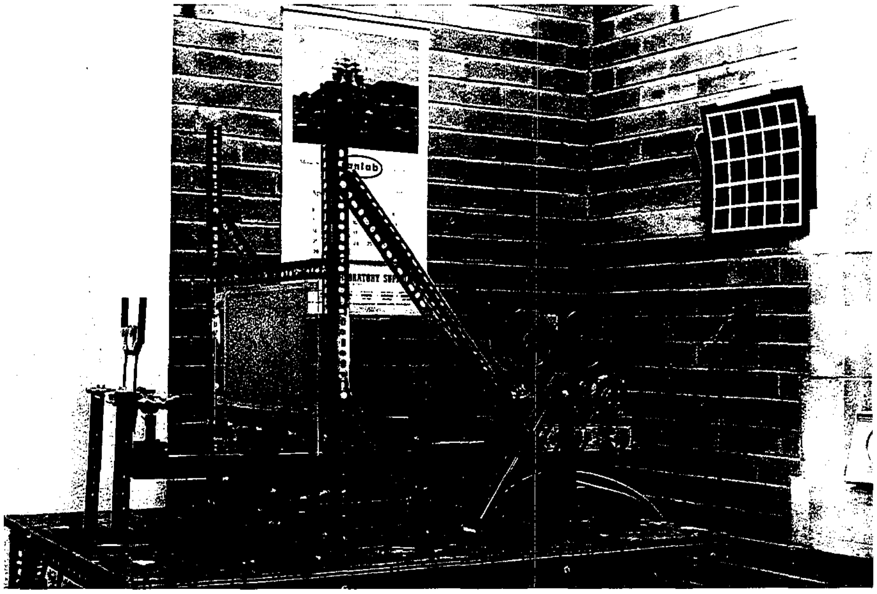

Fig. 3. Photograph of eye movement measurement system type 1.

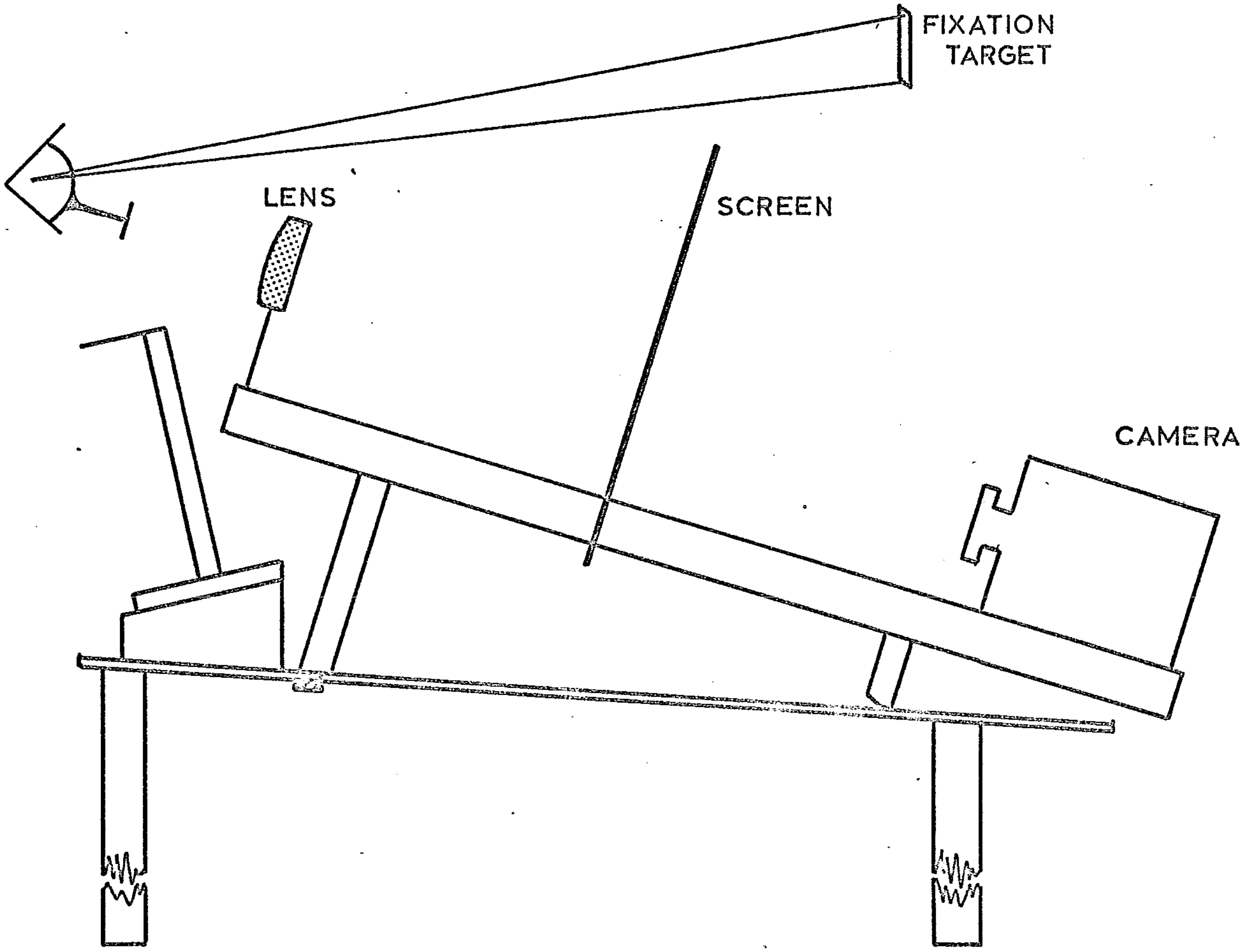

Fig. 4. Diagram of differences between eye movement measurement systems type 1 and 2.

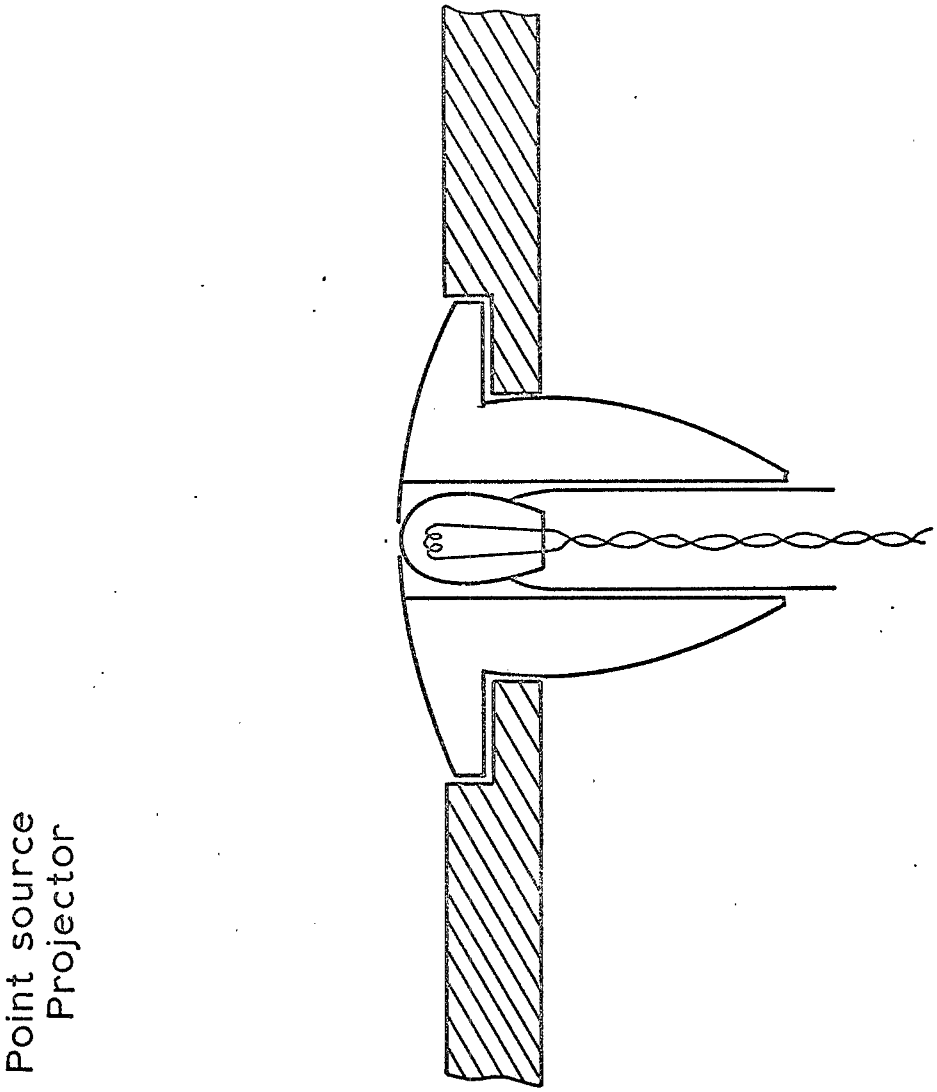

Fig. 5. Projector used as optical point source in eye movement measurement system.

1/8" perspex (for rigidity) covered with a sheet of diffuse surfaced plastic film (for the reflected beam to focus upon), is held vertical to the optical bench in a separate frame which is free to slide along the length of the bench. Mounted in the screen in the same plane as the screen surface are the two sources, small projectors made from miniature lamps mounted behind a .040" hole in a metal snap (see Figure 5). The camera sits behind the screen on the optical bench. Since some light projects out behind the sources, the camera photographs four spots of light on the screen, two of which are constant as reference points. The device used to record eye movements during binocular fixation (Figure 4) is the same as above except for five alterations: the table was raised 1 1/2" on the subjects end (or about 3°), the screen and optical bench were canted an additional 4° in the opposite direction, the bite bar frame was raised 3" and rotated toward the subject 6°, the subjects' chair was raised to compensate for these changes in the height of the mouth piece, and fixation marks were added as needed.

Camera A Grass C-4 Oscilloscope Recording Camera is used to record the data, using a setting for continuous discrete frames (Frames 1, film speed 25mm/sec., 1/100 sec. exposure) which are taken every 0.9 second. Kodak Linagraph Ortho film (clear base) was exposed at F2.

Contact Lenses The contact lenses used are illustrated in Figure 6. They are universal fitting Titmus Low Vacuum Diagnostic Fundus Lenses which are held onto the sclera of the eyeball by a negative hydrostatic pressure created by the weight of a column of saline leading down from the saline filled cavity between the

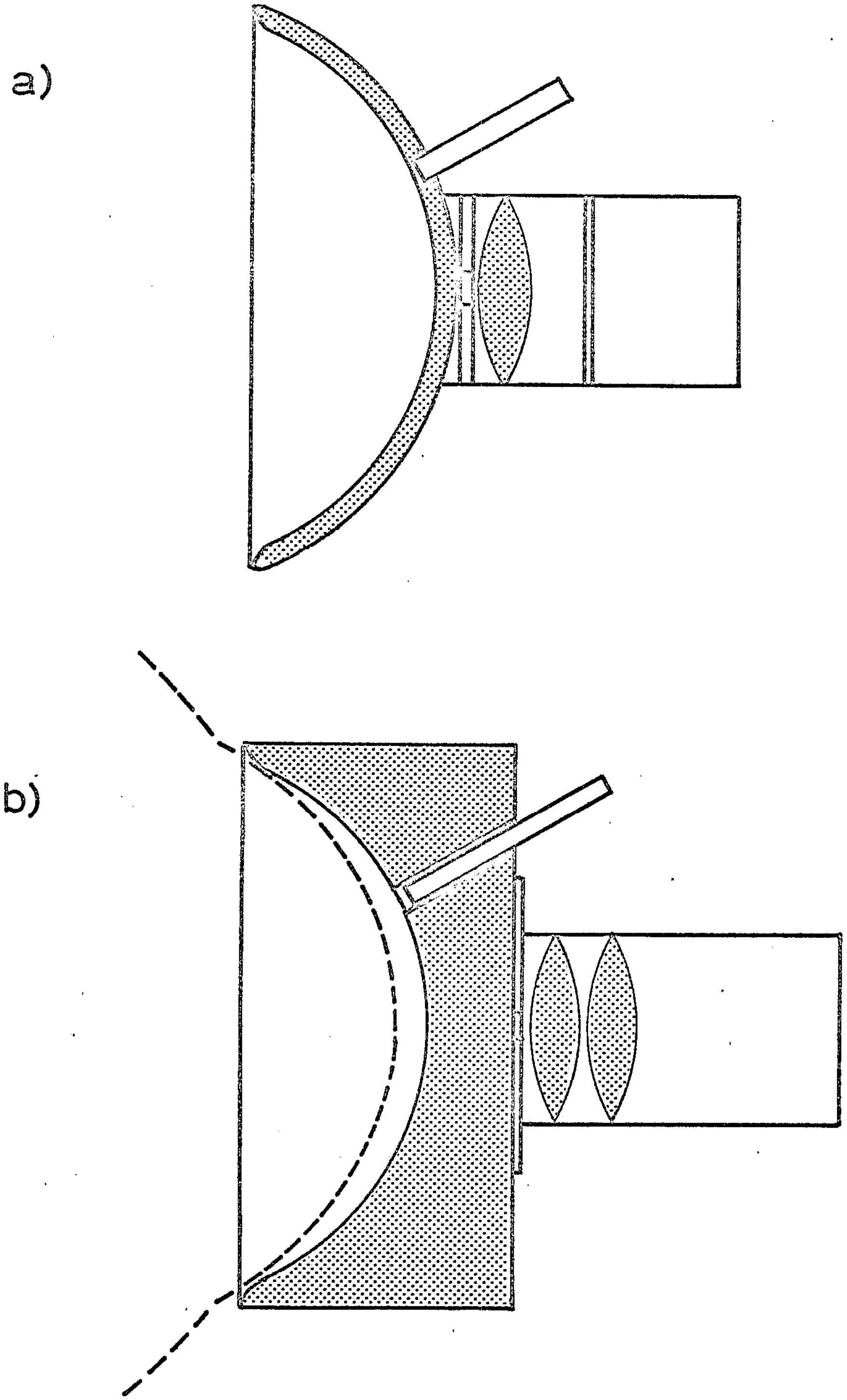

Fig. 6. Types of contact lenses used for eye movement measurement in the experiment.

cornea and the contact lens.

Fixation Targets The small fixation target used is a black cross on an illuminated yellow background, with the background subtending approximately 60 x 70 min. arc and the lines making up the figure subtending approximately 1 min. arc. The other target is a 12" square matrix of five vertical and five horizontal 1/4" white lines evenly spaced on a black background, subtending a total visual angle of approximately $7^\circ \times 7^\circ$.

Calibration and data analysis The measurement system is calibrated by placing a mirror in front of the collimating lenses (as in Figure 1) and aligned so that the reflected image (S') falls close to the point source (S). The screen, together with the light sources, is shifted along the optical bench until the reflected beams are imaged on the screen as sharply focused images of the light sources. When this condition holds, the distance from the lens to the screen is the focal length of the lens. Recalibration of the system before each experimental session insures that the components of the system are separated by known distances so that positions of the reflected spot can be converted to angular measurements.

The raw data is in the form of strips of clear 35 mm film, each frame of which has four images of the light sources and the reflected images. This film can be enlarged and projected onto a measuring surface such as a sheet of graph paper, converting each frame into a horizontal and vertical separation from the light source for each of the two eyes. Since the focal length of the lenses is known, these measurements can be converted to the horizontal and vertical components of the angle which the reflected beam makes with the incident beam. Since the angular rotation of the reflected beam is double that of the eyeball, these measurements are halved. The photographic frames were all enlarged to the same size, which was calibrated by the separation of the sources, thereby enabling these measurements to be readily converted into angular separations.

Experimental Procedure

Prior to insertion of the contact lenses, a topical anesthetic (0.5% tetracaine HCl) was applied to the corneal surface (except for SA who used no anaesthetic and who inserted her own lenses). The contact lenses were then attached by the experimenter. After the subject was comfortably installed in the apparatus, the lens mirrors were aligned and recording sessions were begun. Each photographic run was one minute long (67 frames), with a short rest from the bite block between each run. The recording session was terminated by a timer preset at 25 minutes of wearing time of the contact lenses, or else at the first indication by the subject of discomfort.

Diffuse light Type a (Figure 6) contact lenses were used for this experiment with the viewing fields containing white paper targets. The diffuse fields created by this were approximately 40° in visual angle but were quite unstable in appearance and often disappeared. Eye position was measured by optical system type 1.

Darkness The same contact lenses and measurement system were used for this experimental condition as in the diffuse light condition with the addition of opaque patches occluding the viewing fields of the lenses.

Binocular fixation Type b (Figure 6) contact lenses were used for this condition which gave the subject a clear view of a 20° visual field. The measurement system was modified to enable the subject to fixate on a distant target. The lens could be occluded by placing a precut circular piece of tape over the end of the optical system.

Bright complete field of diffuse light Type b contact lenses with a segment of table tennis ball replacing the optical system which was used during fixation were used for this condition together with the fixation measurement apparatus (optical system type 2). Additional light sources were mounted in the position where the fixation mark was usually placed (Figure 4).

Large field binocular viewing The same lenses and measurement apparatus as the binocular fixation condition were used with the exception that the small fixation mark usually viewed was replaced by the large square matrix mounted on the wall (See Figure 3).

Instructions The subjects were instructed to look straight ahead in all the unstructured field conditions. In all the fixation conditions the subjects were instructed to fixate on the fixation target as steadily as possible, except for the large field binocular viewing condition where the subject was instructed to sweep his eyes along the horizontal lines of the matrix from top to bottom at a comfortable speed.

MILLS MEMORIAL LIBRARY
McMASTER UNIVERSITY

RESULTS

The mean standard deviations of eye position differences for the three conditions of the main experiment are presented in Figure 7. Each score is the mean of five recording sessions for each of the four subjects. The standard deviations for each session are illustrated for each of the subjects in Figures 9-12. The mean correlations (product-moment) between the positions of the two eyes are shown in Figure 8. Differences between each of the two unstructured field conditions and the binocular fixation condition were tested by the median test (Siegel, 1956) for both the standard deviations and the correlations. The results of these tests are presented in Table 1.

TABLE 1

Test results for main experiment

	Standard Deviation		Correlation	
	H	V	H	V
Diffuse vs. Fixation	.001	.001	ns	.01
Darkness vs. Fixation	.001	.001	ns	.01

The sign test (Siegel, 1956) was used to test for differences between the horizontal and vertical components of movement on both the standard deviation of the difference in eye position and the correlations between the individual eye positions. The results of these tests are presented in Table 2.

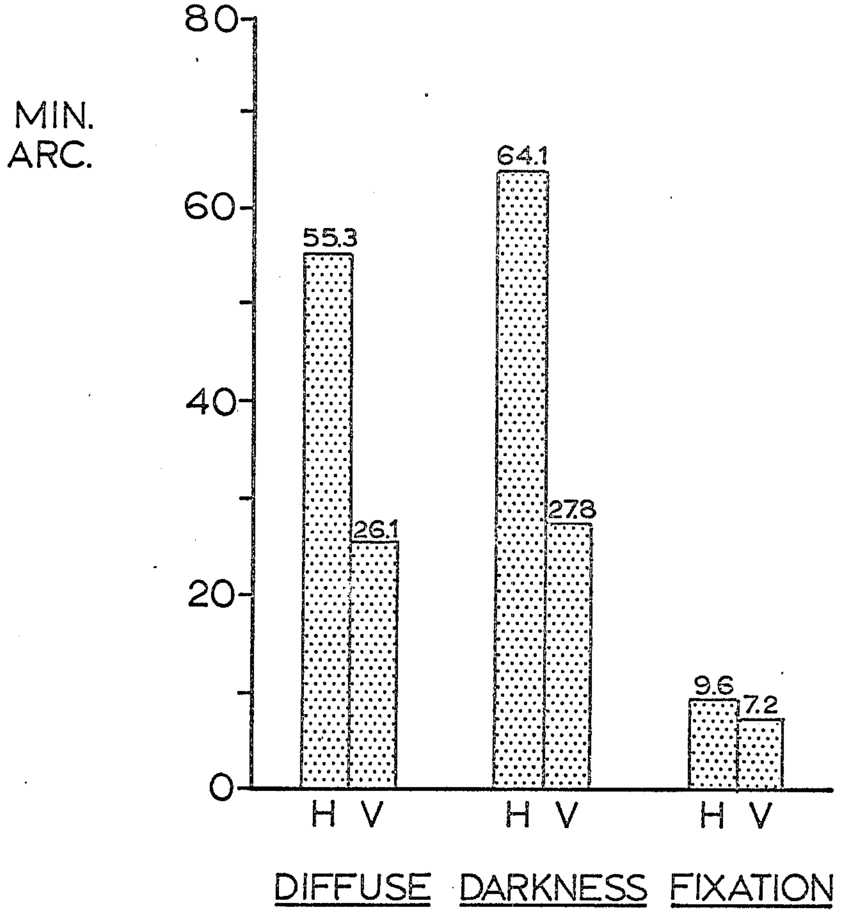

Fig. 7. Average standard deviation from the mean of differences in the positions of the two eyes.

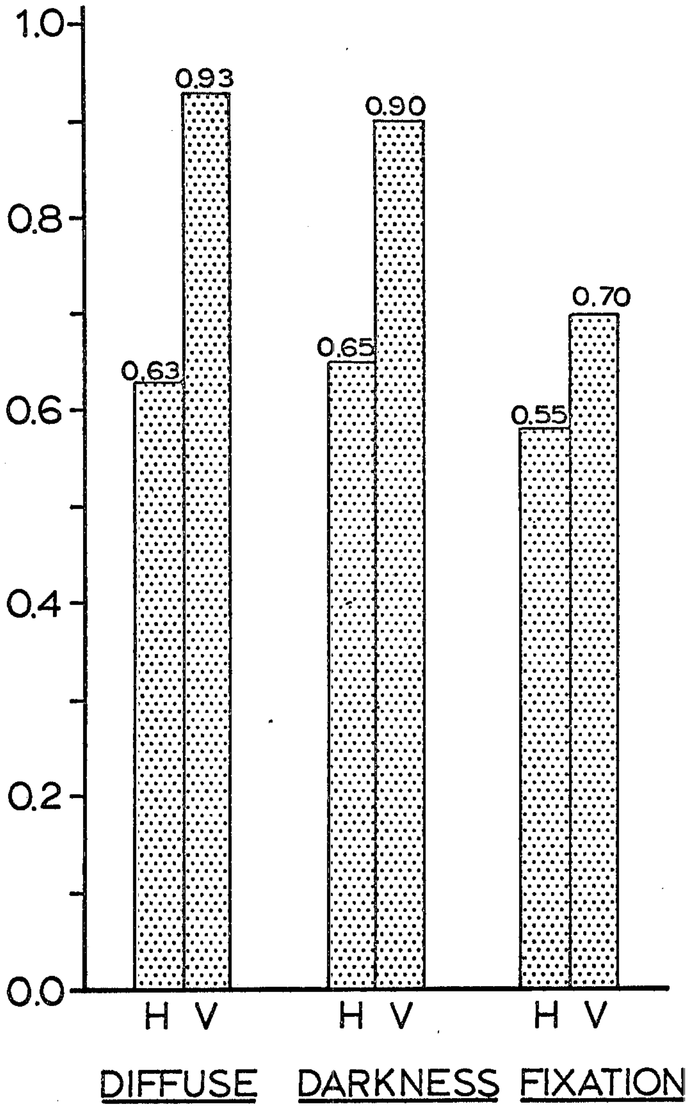

Fig. 8. Average correlation coefficient between the positions of the two eyes.

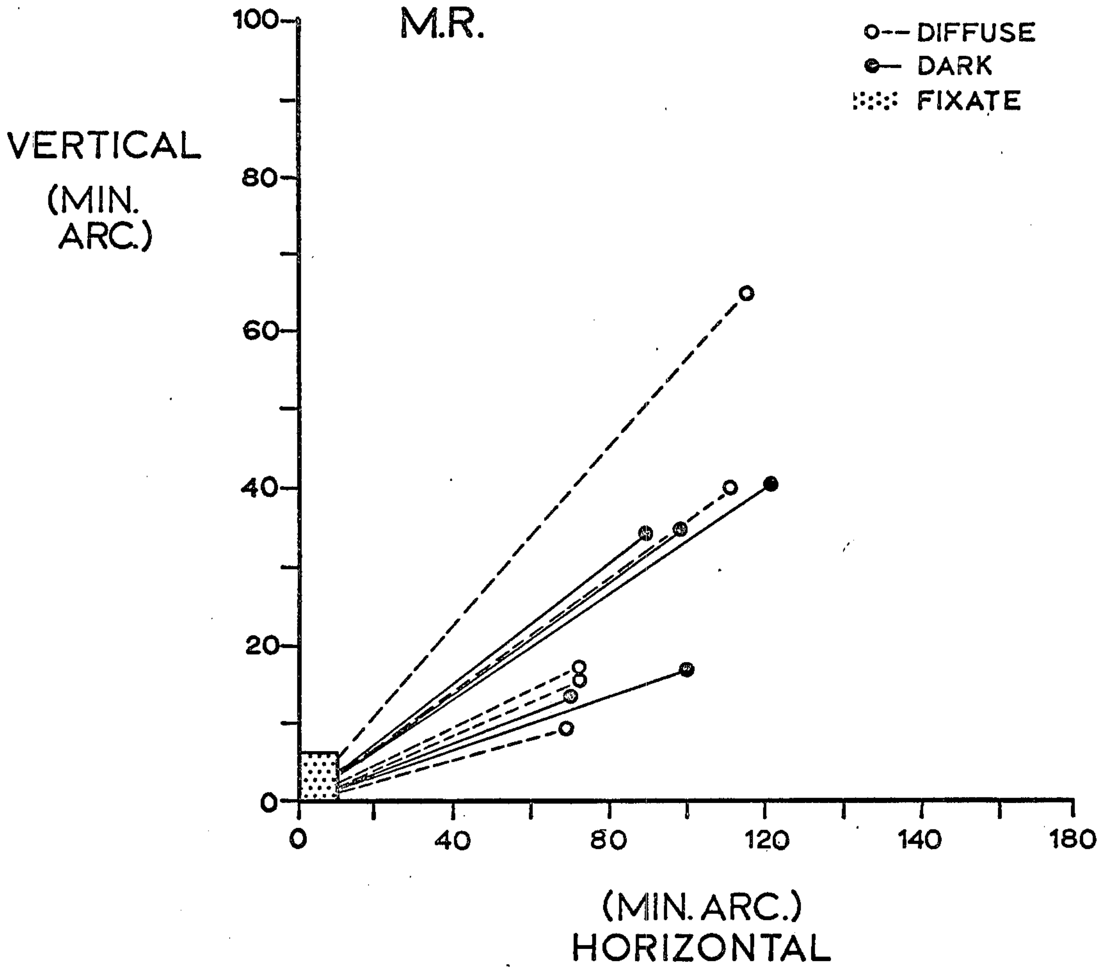

Fig. 9. Standard deviation of the differences in the position of the two eyes for subject MR.

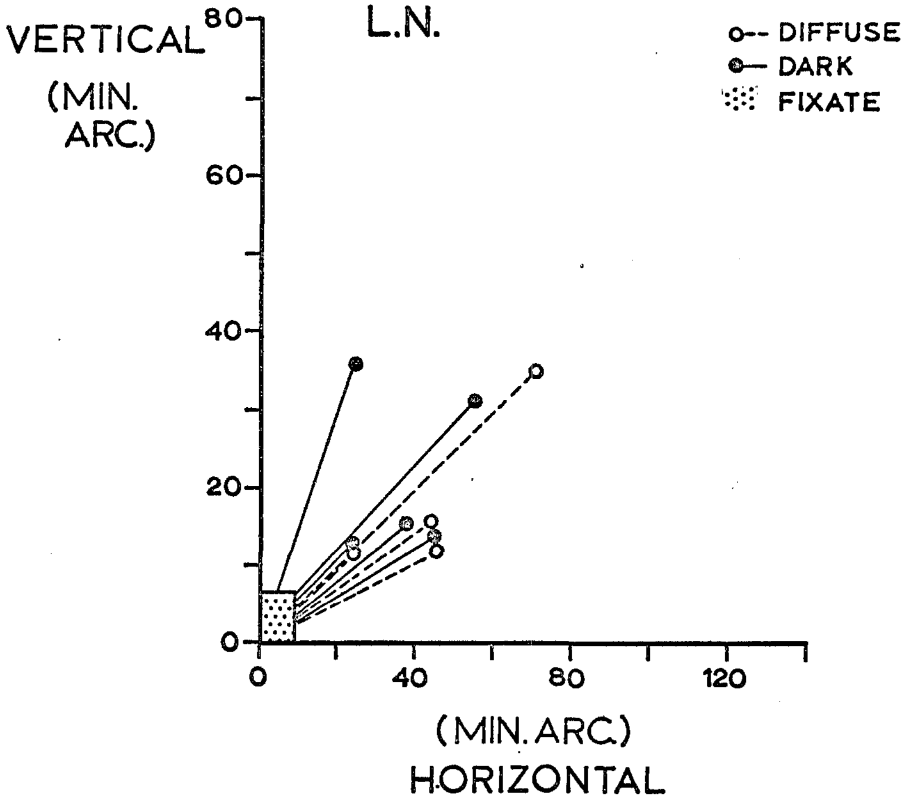

Fig. 10. Standard deviation of the differences in the position of the two eyes for subject LN.

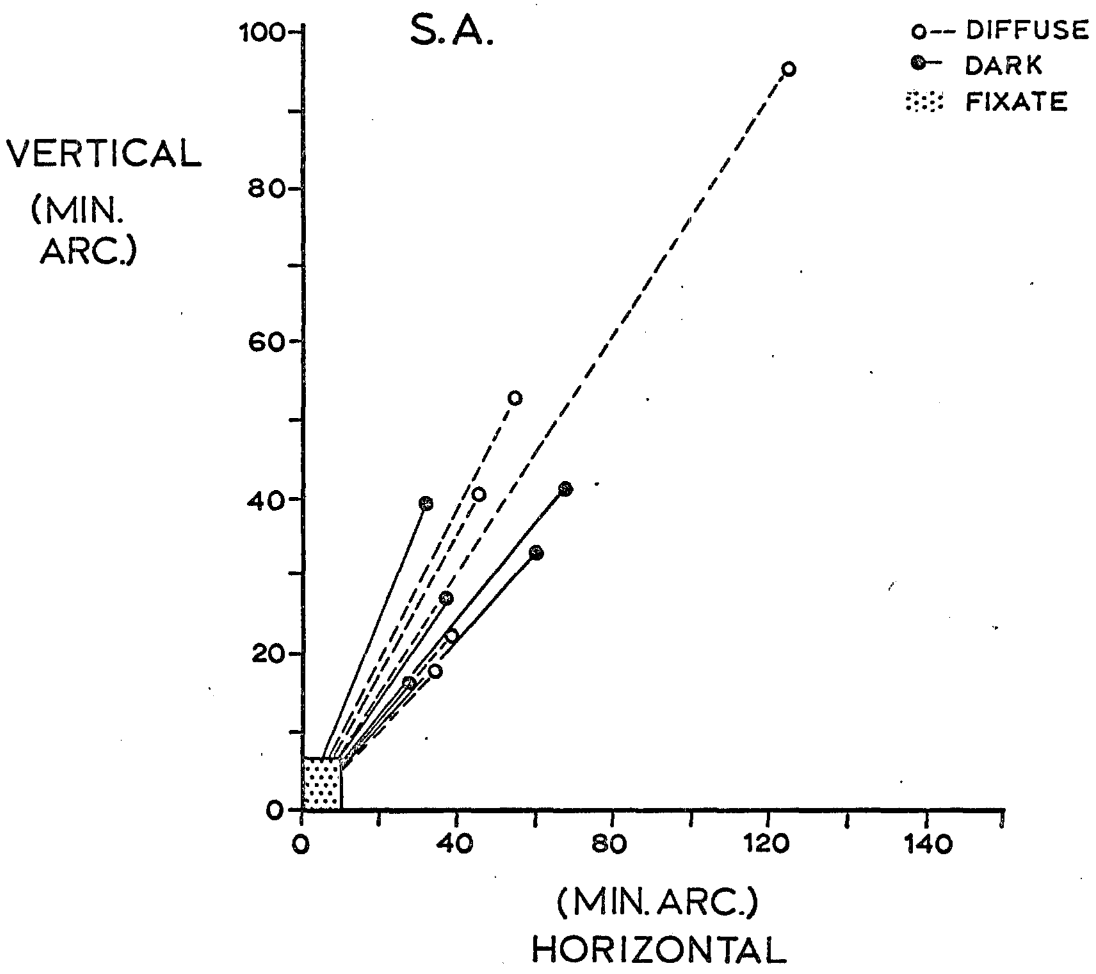

Fig. 11. Standard deviations of the differences in the position of the two eyes for subject SA.

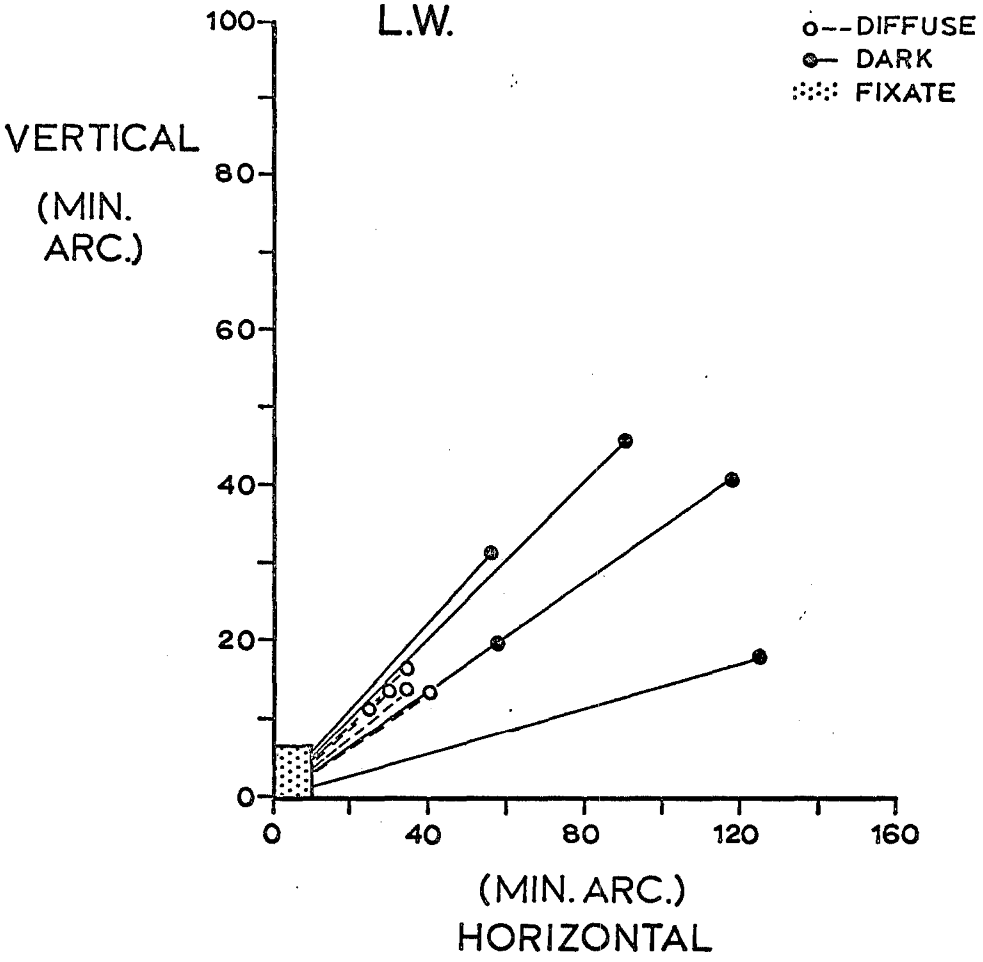

Fig. 12. Standard deviation of the differences in the position of the two eyes for subject LW.

TABLE 2

Test results for differences
between horizontal and vertical components

	Diffuse	Darkness	Fixation
Standard deviation	.001	.001	ns
Correlation	.001	.001	ns

Tables 3-5 present the results of the four subsidiary experiments which were run on single subjects. Table 3 presents the standard deviations of the left and right eyes for five sessions with one subject (LN) who fixated at the small fixation target with the right eye occluded. A sign test (Siegel, 1956) was significant at the .025 level. Table 4 presents the data from one subject (MR) whole eye movements were recorded during sessions of sweeping his vision across the large fixation target, three sessions with binocular vision and three sessions with the right eye occluded. The Mann-Whitney U test (Siegel, 1956) revealed a

TABLE 3

Standard deviation during
fixation with one eye occluded

Horizontal		Vertical	
Left eye	Right eye	Left eye	Right eye
5.5	7.4	4.1	7.5
8.6	8.3	3.9	7.6
6.0	11.4	4.8	6.9
6.3	7.6	4.7	12.2
6.3	7.7	5.4	7.5

significant difference at the .05 level for the horizontal component. The differences for the vertical component were not significant.

TABLE 4

Standard deviation of difference during large fixation target sweep

Binocular vision		Right eye occluded	
H	V	H	V
24.1	19.9	53.1	15.7
15.8	13.1	36.0	11.3
12.3	11.2	45.1	12.7

The last experiment is on one subject (LN) in the bright Ganzfeld condition. The median test was used to test for all possible differences between this condition and the subjects data in the diffuse condition. One significant difference was found out of the four which were tested, that of the vertical component of the standard deviation of the difference in eye position. The data are presented in Table 5.

TABLE 5

Results for Ganzfeld experiment

Standard Deviation		Correlation	
H	V	H	V
21.0	10.4	.73	.99
22.9	8.7	.34	.98
21.8	9.1	.63	.97
37.1	10.6	.94	.89

DISCUSSION

The single most obvious finding of the above study is the great increase in the variability of the separation of the visual axes in any unstructured visual field. While this has been suggested before for conditions of darkness (Ditchburn and Ginsborg, 1953), the fact that it seems to hold for diffuse visual fields supports other evidence in the literature concerning the similarity between diffusely lit and dark visual fields. Cohen (1958) has reported that a target viewed in a Ganzfeld gives a similar illusion of autokinetic movement to a spot of light viewed in the darkness. Another example of the functional similarity of the two types of fields is the finding by Westheimer (1957) that large and similar cyclical fluctuations in accommodation under the two types of visual fields. There are no significant differences between these two conditions on any measure used to assess the relationship of the two eyes, and the findings of this study offer substantial evidence that the two conditions are functionally equivalent to the visual system with regard to the control of binocular eye movements.

What, then, is the nature of this increase in variability? Do the eyes wander at will, being kept from completely random and independent movements and the resulting dissociation by the action of some system of non-visual feedback which prevents the oculomotor control apparatus from very gross misalignment? What are the factors operative in these highly abnormal visual situations?

The physiological evidence from Burns and Pritchard (1968) would seem to predict the increase in variability, both monocular and binocular, in the two homogeneous visual field conditions. The absence of any peaks in the pattern of excitation over the cortex would be expected to lead to an increased variability between the positions of the two eyes, hunting for some relative position which did lead to a peak response. The large movements of each eye would be accompanied by small but irrelevant changes in the cortical patterning and an increase in the amplitude of eye movements could be expected. It would seem reasonable, also, that there be no great differences between diffuse light and darkness, since there seems to be no physiological evidence for any long term cortical response to diffuse light to differentiate it from the random noise level of the visual cortex during exposure of the eyes to darkness (Burns, Heron and Pritchard, 1962).

The comparable results that have been found for the horizontal and vertical components of eye movements in this and other studies in the literature would suggest that the loss of visual control should lead to larger but still similar horizontal and vertical components of motion. The finding by Merton (1961) that the accuracy of directing the eyes in the dark was very similar for both the horizontal and vertical direction would predict the same outcome. The results of the present experiment indicate that this is not the case for eye movements over time. The highly significant differences between the horizontal and vertical components of movement on both the variability of separation and the correlation between the positions of the two eyes in the two unstructured conditions offer substantial evidence that something more than the loss of visual control of eye movements is responsible for the differences found in the above experiment.

A large part of the increase in binocular variability might be an exageration of the convergence-divergence waves reported by Ditchburn (1955) to occur in binocular fixation. Further, reports by some subjects of apparent changes in the size of the visual fields suggest fluctuations in accommodation and these certainly might be expected to lead to concomittant changes in convergence. Variations in accommodation, such as those found by Westheimer (1957) for unstructured visual fields would tend to cause such fluctuations in apparent size of visual fields. Stark, Kupfer and Young (1965), in an analysis of the eye movement control system, report evidence for a linking of the mechanisms for accommodation and for the control of vergence movements. The "accommodative convergence" phenomenon suggests that what the eye movement control system does when it is confronted with the abnormal situation of a homogeneous visual field is to "actively search" for structure, i.e. edges, in the visual field. The necessary stimulating condition for this searching pattern is the absence of sharply focused images in the visual fields. This acts as a stimulus to the system controlling accommodation. The same system controls both accommodation and alignment of the two eyes, thus the two activities are generally synchronous as Stark _et_ _al_. (1965) have found. Both these activities might be expected to be controlled by the same neurophysiological mechanism, such as that suggested by

Burns and Pritchard (1968) and Burns (1968), since they seem to work as a closely linked system.

There appears to be a relationship between the range of movement of the individual eyes and the variability of the separation of the visual axes. This is consistent with the finding that the eyes are able to maintain the low variability of binocular fixation with only one eye fixating (Ditchburn and Ginsborg, 1953). It suggests that the high variability of separation of the visual axes may be, in part, a mechanical artifact of the high single eye variability. Ditchburn (1955) suggests that the finding of no difference in binocular eye movements under monocular or binocular fixation "shows that the binocular fixation is not corrected by signals depending upon disparity of the images received by the two eyes." Ditchburn concludes from this and other experiments that fixation is under something besides visual control. This conclusion conflicts with the evidence by Cornsweet (1956) for visual control of monocular fixation and that by Krauskopf et al. (1960) for visual control of binocular fixation. It also conflicts with the finding that when disparity is experimentally introduced by placing a prism in front of one eye, this eye will align itself to correct for the new optical axis created by the prism (Ogle,1950; Hebbard, 1962). A better interpretation of the Ditchburn and Ginsborg finding might be that, since there is no disparity (due to suppression of the occluded eye) there is no stimulus to elicit a change in the relative orientation of the two eyes. In the absence of such a stimulus, and given fixation by the other eye, the eye position control system is able to keep the occluded eye close to the original position. It is suggested that fixation by the other eye is necessary to maintain this close binocular relationship. It is further suggested that this relationship might be upset by substituting a diffuse light field, bright enough to avoid suppression much of the time, for the completely dark field Ditchburn and Ginsborg used. The diffuse light field might well be the adequate stimulus for the system to hunt for fusion. Unfortunately, none of the subsidiary experiments reported above used these exact conditions. While the monocular fixation experiment did not use a completely dark occluded eye, the field was dark enough that suppression was complete. It is suggested that the control system generally suppresses or ignores the unstructured field and thus the eyes do not engage in the wide variability which is seen when viewing binocular diffuse fields. If the eye which receives the patterned input is required to use this information for tracking movements, then it would be reasonable to expect the binocular relationship to break down and show wider variability than is observed during monocular fixation. This suggestion is supported by another of the subsidiary experiments reported above. It should be emphasized, however, that these are just speculations for, although they would seem to be supported by the data, the subsidiary studies are inadequate and thus unreliable.

The subsidiary study with the bright Ganzfeld controls for the possibility that the results for the diffuse condition are, in some way, due to the presence of edges in the visual field, or to the structure of the contact lenses or of the measurement system, for all these three were changed with the same results.

Thus, the great increase in binocular variability, especially in the horizontal dimension, during viewing of unstructured visual fields offers evidence for an active search process being set into motion by the absence of detail in the visual field. This search process seems to be responsive both to alignment of the two visual fields and to the presence of edges in at least one of the visual fields. Such a search process finds additional evidence from findings in the neurophysiology of the visual system of the cat.

REFERENCES

Adler, F. H. & Fliegelman, F. Influence of fixation on the visual acuity. Arch. Ophthal., N. Y., 1934, 12, 475-483.

Ames, A., Jr., & Gliddon, G. H. Ocular measurements. Trans. Sect. Ophthal., AMA, 1928, 102-175. (cited by Ogle, 1950).

Barlow, H. B. Eye movements during fixation. J. Physiol., 1952, 116, 290-306.

Breinin, G. Electromyographic evidence for ocular muscle proprioception in man. AMA Arch. Ophthal., 1957, 57, 176.

Burns, B. D. The uncertain nervous system. London, Edward Arnold, 1958.

Burns, B. D., Heron, W., & Pritchard, R. M. Physiological excitation of visual cortex in cat's unanaesthetized isolated forebrain. J. Neurophysiol., 1962, 25, 445-463.

Burns, B. D., & Pritchard, R. M. Cortical conditions for fused binocular vision. J. Physiol., 1968, (in press)

Cohen, W. Apparent movement of simple figures in the Ganzfeld. Percept. Mot. Sk., 1958, 8, 32.

Cornsweet, T. N. Determination of the stimuli for involuntary drifts and saccadic eye movements. J. Opt. Soc. Am., 1956, 46, 987-993.

Ditchburn, R. W. Eye movements in relation to retinal action. Opt. Acta, 1955, 1, 171-176.

Ditchburn, R. W. & Ginsborg, B. Involuntary eye movements during fixation. J. Physiol., 1953, 119, 1-17.

Dodge, R. An experimental study of visual fixation. Psychol. Rev. Monogr. Suppl., 1907, 8, 1-95.

Fender, D. H. Torsional motions of the eyeball. Brit. J. Ophthal., 1955, 39, 65-72.

Fender, D. H. Control mechanisms of the eye. Sci. Am., 1964, 211, 24-33.

Fender, D. H., & Julesz, B. Extension of Panum's fusional area in binocular stabilized vision. J. Opt. Soc. Am., 1967, 57, 819-830.

Fender, D. H., & Nye, P. An investigation of the mechanisms of eye movement control. Kybernetik, 1961, 1, 81.

Gertz, H. Uber die tiefenwahrnehmung und ihre beziehung zur netz hautkorrespondenz. Acta. Ophthal., 1935, 13, 192-224. (cited by Ogle, 1950)

Hebbard, F. W. Comparison of subjective and objective measurements of fixation disparity. J. Opt. Soc. Am., 1963, 52, 707-712.

Hering, E. Der Raumsinn und die bewegungen der auge. In Hermann, L. Handbuch der Physiologie 3 (pt. 1) 1879. (cited by Ogle, 1950).

Huey, E. B. On the psychology and physiology of reading. Amer. J. Psychol. 1899, 11, 283-302.

Irvine, S. R., & Ludvigh, E. Is ocular proprioceptive sense concerned in vision? Arch. Ophthal., N. Y., 1936, 15, 1037-1049.

Krauskopf, J., Cornsweet, T. N., & Riggs, L. A. Analysis of eye movements during monocular and binocular fixation. _J. Opt. Soc. Am._, 1960, 50, 572-578.

Lancaster, W. B. Aniseikonia. _Arch. Ophthal._, 1938, 20, 907-912.

Lau, E. Neue untersuchungen uber das Tiefen- und ebenensehen. _Z. Sinnesorg._, 1921, 53, 1-35. (cited by Ogle, 1950)

Lord, M. P., & Wright, W. D. Eye movements during monocular fixation. _Nature_, London, 1948, 162, 25-26.

Marx, E., & Trendelenburg, W. Uber die genauigkeit der einstellung des auges beim fixieren. _Z. Sinnesphysiol._, 1911, 45, 87-102. (cited by Ratliff and Riggs, 1950).

Mc Allister, C. N. The fixation of points in the visual field. _Psychol. Rev. Monogr. Suppl._, 1905, 7, 17.

Merton, P. A. The accuracy of directing the eyes and the hand in the dark. _J. Physiol._, 1961, 156, 555-577.

Mitchell, D. E. Retinal disparity and diplopia. _Vision Res._, 1966, 6, 441-51.

Muller, J. _Zur vergleichenden Physiologie des Gesichtssinnes des Menschen und dur Thiere._ Leipzig, C. Cnobloch, 1826. (cited by Ogle, 1950).

Nachmias, J. Two dimensional motion of the retinal image during monocular fixation. _J. Opt. Soc. Am._, 1959, 49, 901-908.

Nachmias, J. Determiners of the drift of the eye during monocular fixation. _J. Opt. Soc. Am._, 1961, 51, 761-766.

Nagel, A. Das sehen mit zwei augen und die lehre von den identischen netzhautstellen. Leipzig, C. F. Winter, 1867. (cited by Ogle, 1950).

Ogle, K. N. Researches in Binocular vision. Phila., W. B. Saunders, 1950.

Orchansky, J. Eine methode die augenbewegungen direkt zu untersuchen (opthalmographie). Zbl. Physiol., 1898, 12, 785. (cited by Ratliff and Riggs, 1950)

Panum, P. L. Untersuchungen uber das sehen mit zwei augen. Kiel, Schmersche Burchandlung, 1858. (cited by Mitchell, 1966)

Polyak, S. L. The Retina. Chicago, Chicago University Press, 1941.

Ratliff, F. and Riggs, L. A. Motions of the eye during fixation. J. Exp. Psychol., 1950, 40, 687.

Stark, L., Kupfer, C., & Young, L. R. Physiology of the visual control system. CR 238, NASA, 1965, Biosystems, Cambridge, Mass.

Westheimer, G. Accomodation measurements in empty visual fields. J. Opt. Soc. Am., 1957, 47, 714-718.

Standard deviation of the difference between the positions of the two eyes in the three conditions

	DIFFUSE		DARKNESS		FIXATION	
	H	V	H	V	H	V
MR	72.9	14.7	121	40.3	12.3	5.5
	73.0	15.2	70.9	12.9	9.3	4.6
	67.4	8.9	97.1	34.2	14.2	8.9
	110	39.9	98.9	16.0	10.7	8.1
	115	64.4	87.0	33.8	7.9	8.4
LN	24.3	11.0	45.3	13.9	4.3	4.6
	22.9	11.6	25.1	11.9	4.7	4.5
	45.0	15.6	55.8	31.6	5.0	6.2
	44.6	12.2	37.3	14.7	3.6	4.5
	70.4	34.8	25.1	36.3	4.1	5.4
SA	37.3	22.9	37.6	27.2	21.4	5.6
	33.9	17.3	31.9	37.4	19.0	6.1
	44.3	39.3	28.1	16.9	12.7	5.6
	55.7	52.0	68.7	41.3	13.7	9.8
	124	95.2	60.2	33.5	13.0	8.3
LW	34.5	13.1	90.6	46.6	7.3	11.3
	39.6	13.6	125	18.3	6.4	11.2
	34.9	16.3	117	39.1	7.2	6.3
	31.6	13.6	57.1	19.9	7.5	9.0
	25.0	11.2	56.0	31.5	6.8	9.8

Standard deviation of the

position of the left eye

	DIFFUSE		DARKNESS		FIXATION	
	H	V	H	V	H	V
MR	80.6	75.5	80.3	301	13.7	23.5
	93.3	81.0	75.1	154	11.1	9.5
	70.8	61.4	127	97.3	17.3	11.2
	47.3	125	127	162	11.0	11.4
	113	108	63.5	134	9.1	10.6
LN	42.5	32.4	58.5	47.6	5.2	6.1
	86.0	67.3	28.4	25.8	4.2	4.7
	39.2	32.2	79.1	47.2	7.7	6.0
	58.4	40.5	36.8	40.7	6.5	4.9
	32.9	48.9	46.8	42.1	5.3	6.3
SA	67.1	61.9	91.8	70.2	8.7	17.0
	58.0	64.5	38.1	83.7	11.4	10.2
	66.5	72.0	43.5	76.9	7.7	13.4
	73.8	78.5	42.2	97.8	11.2	21.7
	123	105	29.8	98.0	8.6	12.1
LW	67.9	49.0	123	89.1	12.5	9.9
	57.5	59.4	190	40.1	9.9	7.9
	42.8	44.0	135	65.7	9.9	6.4
	60.1	67.7	56.2	39.3	16.3	10.2
	46.7	81.5	66.8	50.4	19.7	11.2

Standard deviation of the position of the right eye

	DIFFUSE		DARKNESS		FIXATION	
	H	V	H	V	H	V
MR	35.4	68.3	76.3	268	12,6	22.2
	43.5	78.0	97.1	155	10.1	9.1
	38.3	62.4	108	87.4	11.3	6.4
	107	117	113	165	10.5	8.6
	128	106	104	116	8.7	10.6
LN	33.1	32.4	77.9	45.5	5.0	6.2
	83.3	73.9	36.2	26.2	5.6	5.3
	69.9	59.6	110	60.5	7.4	3.0
	71.0	29.3	56.0	42.5	5.9	6.3
	54.9	32.2	42.2	21.4	5.3	5.4
SA	77.7	67.1	86.1	65.3	18.0	19.3
	62.9	66.4	54.7	61.9	16.9	9.9
	64.9	75.5	56.0	83.4	12.0	15.7
	53.1	87.4	37.2	65.3	13.8	21.7
	74.4	129	43.8	81.8	11.9	15.5
LW	51.6	44.3	96.6	49.9	10.4	12.2
	32.2	54.5	121	30.5	11.1	13.0
	39.2	39.0	127	45.3	10.4	5.9
	48.1	67.1	43.6	36.0	15.2	8.5
	57.4	86.4	72.7	54.8	19.6	8.7

Results of large target sweep with monocular and binocular vision

	Monocular		Binocular	
	H	V	H	V
Correlation x 100	90 95 94	100 100 100	98 99 99	99 100 100
s of difference	53.1 36.0 45.2	15.7 11.3 12.7	24.1 15.8 12.3	19.9 13.1 11.2
s of left eye	120 110 126	170 167 162	128 121 119	168 162 162
s of right eye	122 108 127	174 164 162	134 125 118	163 165 162

Results of monocular fixation and Ganzfeld conditions.

	Ganzfeld		Monocular	
	H	V	H	V
Correlation x 100	73	99	36	37
	34	98	82	43
	63	97	17	60
	94	89	70	51
			44	43
s of difference	21.0	10.4	8.1	7.2
	22.9	8.7	5.2	6.0
	21.8	9.1	11.7	6.3
	37.1	10.6	5.3	10.0
			7.2	7.3
s of left eye	30.0	61.3	5.5	4.1
	25.5	44.7	8.6	3.9
	25.5	39.1	6.1	4.8
	110	22.5	6.3	4.7
			6.3	5.3
s of right eye	27.7	61.7	7.4	7.5
	20.6	43.9	8.4	7.5
	25.2	37.4	11.4	6.9
	99.7	23.0	7.6	7.0
			7.8	8.1