THE EFFECT ON VISUAL ACUITY OF OCULAR PURSUIT DURING ROTATION AND ITS SUBSEQUENT RELATION TO TARGET ILLUMINATION

By

James Woodell Miller

A THESIS

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

1956

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THE EFFECT ON VISUAL ACUITY OF OCULAR PURSUIT DURING ROTATION AND ITS SUBSEQUENT RELATION TO TARGET ILLUMINATION

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James Woodell Miller

A THESIS ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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A survey of the literature revealed that although many problems related to the general area of visual acuity have been extensively investigated, the problem of measuring visual acuity during ocular pursuit has received very little attention. The only real attempts at measuring visual acuity with the test object moving have been made by Ludvigh (3), (4), (5), (6) and Miller and Ludvigh (7). In each of these studies however it was the target which was moved and the observer remained stationary. It was also found that although much effort has been previously devoted to determining the effect of varying target illumination on static visual acuity no similar investigations have been made with the target moving.

The present investigation was an attempt to determine the effect, on visual acuity, of rotating an observer at various constant, angular velocities with the test object remaining in a fixed position. In addition to this the effect on visual acuity of varying the intensity of target illumination was examined at each of the five angular velocities tested.

Six subjects possessing normal static visual acuity were used. The apparatus, employed to rotate the subjects, was a modified link trainer which was rotated in a horizontal plane at angular velocities ranging from 20^{o}/sec to 120^{o}/sec. The test objects used were Landolt rings. The levels of test chart illumination utilized ranged from .04 to 125.0 footcandles.

The results revealed that visual acuity deteriorated consistently and significantly as the relative angular velocity of the test object increased. Several possible reasons for this deterioration were discussed and it was suggested that as a result of imperfect pursuit movements of the eye, the gradient of retinal illumination was reduced which subsequently lead to the observed decrement of visual acuity.

The results obtained in the present investigation were compared with those of Ludvigh and it was concluded that visual acuity deteriorates in a similar manner with increases in the relative angular velocity of the test object regardless of whether it is the target or the observer which is moved. The manner in which visual acuity deteriorated with increased angular velocity of the test object was similar at each of the levels of test chart illumination employed. It was demonstrated however that increases in illumination were more beneficial for visual acuity at the lower angular velocities than at the high. Some reasons for these differences were discussed.

It was pointed out that there are large differences in the ability to resolve moving targets existing among individuals having substantially the same static visual acuity.

The general results of this investigation were compared with the results obtained by several previous workers (1), (2), (5), (6), and (7). These investigations when viewed totally seem to indicate that by the time an angular velocity of test object of 50^{o}/sec is reached the ability of the eye to adequately track a moving target is seriously impaired.

Some possibilities for future investigation of problems involving ocular pursuit were mentioned.

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Major Professor

Introduction

The general problem of visual acuity has been explored extensively by numerous investigators. One of the earliest descriptions of the resolving power of the human eye is found in Robert Smith's "System of Compleat Opticks" published in 1738, wherein he discusses the ability of the eye to distinguish distant heavenly bodies. Since that time much research has been aimed at explaining the fundamental basis of visual resolution (14), (35), (16), (2), (13).

A considerable amount of work has also been done in an effort to determine the effects of Change in illumination on visual acuity. Wilcox (39) conducted an investigation in which visual acuity was measured with illuminated bars on a dark background and conversely with dark bars appearing on a lighted background. He found that the threshold was quite large when light bars appearing on a dark background were viewed with a low level of illumination. The visual angle necessary for resolution was determined to be about two minutes of arc when the level of retinal illumination was approximately five tenths of a troland. As the level of illumination increased the threshold was found to first decrease and then to increase again. When dark bars were presented on a lighted field the threshold continued to decrease with no reversal occurring when higher levels of illumination were used. Kravkov (16) performed a series of experiments in which the ability to discriminate white objects on a black background was examined. He concluded that as the illumination increased up to five lux (.46 footcandles) visual acuity continued to be improved substantially. At higher levels of illumination the improvement was negligible, and at extremely high levels the resulting acuity was actually retarded. This reversal of threshold at high intensities agrees with the results of Wilcox discussed above. He suggested that this decrement at high intensities may be caused by irradiation as was also suggested by Wilcox.

Mazzucconi (29), in an experiment during which visual acuity was measured by determining the percentage of words which could be correctly stated at different distances from a test chart, concluded that visual acuity was aided substantially by increased illumination up to seven or eight lux (.65-.74 footcandles), but that improvement was negligible with further increases.

Ferree and Rand (9) found that increases in illumination above five footcandles did not improve visual acuity significantly. In this investigation visual acuity was measured with the aid of Landolt rings. An examination of their data discloses however that almost 75% of the total improvement occurs by the time an illumination of one footcandle is reached. Their results then are quite similar to those of Kravkov and Mazzucconi.

Several investigators have determined the minimal amount of movement required in order to be perceived (12), (15), (8). Likewise the ability to match a given target velocity visually or by a mechanical tracing method has been investigated (17), (28), (37). The physiological and neurological aspects of pursuit movements as opposed to saccadic or fixation movements have also received previous attention (11), (40).

The problem of actually determining visual acuity while the eye is pursuing a moving target and the problem of viewing stationary objects while the observer is moving, have received very little attention.

Leiri (20) in discussing the problem of visual perception when the eye is moving distinguishes between two types of eye movements, fast and slow. The slow movements are those existing when the gaze follows a moving object. This type of movement is that found in the slow phase of nystagmus. Leiri says that during this type of ocular pursuit a visual perception may take place of which the observer is fully aware. The second type, or fast movements, are those in which we regard points in the environment and allow the eye to shift fixation from one point to another. This type of movement is manifested in the rapid phase of nystagmus. Öhrwall (32) cites studies by Erdmann and Dodge which conclude that perception does not take place during changes of fixation. Leiri points out with regard to this that even though there is not a definite perception of a restricted visual field during changes of fixation, there is present the familiar experience of motion of the environment in the opposite direction to that in which the eye is moving. This awareness of environmental movement may be thought of as perception. When the eye is actively pursuing a moving target there is also commonly perceived an experience of movement of the environment in the opposite direction of eye movement. Because of the strong impression made by the object being regarded foveally, however, the impression of movement of the environs is reduced considerably and is usually prevented from becoming conscious. We may see from this then that the greater the accuracy of ocular pursuit the less rivalry there exists between the impression of the pursued object and that of the environmental background.

Dodge (7) analyzed the eye movements resulting when the eye was attempting to follow a simple object in harmonic oscillation. He determined that pursuit movements of the eye consist of a series of approximations and corrections. He pointed out that objects which are first seen peripherally are fixated in two or three saccadic jerks and in some cases there is an anticipatory reaction in the direction opposite to that of the object movement. This is followed by an approximately normal beginning reaction in the right direction consisting of a saccadic movement. As the velocity of the object increases, says Dodge, the number of saccadic movements increase and the amount of smooth pursuit movement decreases. This leads to an eventual breakdown resulting in the eye being unable adequately to follow the object at all. This analysis is supported by Westheimer (38) in a study in which horizontally induced approximately eye movements were examined. It was found that beginning at an angular velocity of 30°/sec, saccadic movements were used more frequently and smooth pursuit was not as pronounced. In this investigation light sources reflected from the cornea were recorded photographically. Westheimer concluded that two basic response patterns were involved, saccadic movements and constant velocity following movements. He concludes further that

> in the originalresponse to a moving stimulus both types of eye movements appear, and they are changed discreetly and at intervals as differences between the target direction and the eye position develop. When the target position is changed instantaneously, the response consists only of saccadic movements.

It is further pointed out by Westheimer that with familiarity of the target motion the observer may improve his pursuit of the target.

Travis and Dodge (36) attempted to determine the adequacy of ocular pursuit, when the eye was following wooden bars moving in a horizontal plane at various angular velocities. These authors found that as the angular velocity of the bars increased from 8°/sec to 52°/sec, the adequacy of pursuit, as determined by the percentage of the objective pursuit-field actually traversed by the eye, deteriorated from 95% to 10%

respectively.

In none of the studies cited thus far has an attempt been made to determine the visual acuity maintained during ocular pursuit of moving objects. The first real attempt to actually determine visual acuity during ocular pursuit were some observations of Langmuir (19) which are discussed in some detail by Ludvigh (23). Langmuir, in an attempt to estimate the speed of the deer botfly swung a piece of solder tied on the end of a string, about his head timing the speed with a telechron clock. The piece of solder became invisible at a linear velocity of approximately twenty-six miles per hour. Langmuir concluded that a speed of twenty-five miles per hour was a reasonable speed for the botfly. Ludvigh pointed out however that it is not linear velocity but angular velocity which affects visual acuity during pursuit of moving targets. In other words, there is an optimal distance and angular velocity at which a target of given size may be seen. Ludvigh, in this same paper, cites some experimental evidence showing that when Snellen letters are moved in a horizontal plane at angular velocities ranging from 0°/sec to approximately 125°/sec the visual acuity deteriorates from 20/20 to roughly 20/90 respectively.

Ludvigh (24) in a further investigation of visual acuity during ocular pursuit found that when Landolt rings were used as test objects, visual acuity deteriorated in a similar manner to that which was found when the Snellen test letters were used. Some of the practical applications utilizing the knowledge of visual acuity during ocular pursuit were mentioned.

Ludvigh (25) investigated visual acuity as determined while the test object moved in simple rotary fashion in a plane perpendicular to the line of sight. He found that the acuity deteriorated more rapidly in this case than when the movement was linear and in a horizontal plane. It was also found in this study that higher intensities of illumination are more beneficial, to visual acuity, during pursuit than when the target is stationary. It was shown that acuity continued to improve with increased intensities of illumination beyond a level of 100 footcandles as compared with data found by Ferree and Rand for static visual acuity which was presented earlier (9).

Ludvigh and Miller (27) conducted an investigation in which the visual acuity of several individuals during ocular pursuit was determined at various angular velocities ranging from 10°/sec to 170°/sec. The test objects used were Landolt rings and the movement was accomplished by means of a rotating mirror moving in a horizontal plane. These authors found that visual acuity deteriorated over this range of velocities from approximately 20/40 to 20/200 there being wide differences among individuals.

Miller and Ludvigh in a follow-up study (30) found that movement of an object in a vertical plane affects visual acuity in substantially the same manner as in the horizontal plane.

The Problem

As was indicated in the introduction, some experiments have previously been conducted in an attempt to determine the effects on visual acuity of moving a stimulus target (19), (23), (24), (25), (27), (30). In each of the studies cited however it was the target which moved and the observer remained stationary.

The purpose of the present investigation is to determine the effect on visual acuity, of rotating an observer at various constant angular velocities with the test object remaining in a fixed position.

Concomitantly with the above, the effects on visual acuity of varying the intensity of the target illumination during ocular pursuit will be examined.

Subjects

Six male subjects participated in the experiments. They were enlisted naval personnel stationed at the U. S. Naval Air Station, Pensacola, Florida. Their ages ranged from nineteen to twenty-five years. They had all been tested previously, in the usual manner, with Snellen test letters and were found to possess static visual acuity of 20/20 or better uncorrected. None of the subjects wore glasses during the experiments.

Apparatus

The apparatus employed to rotate the subjexts was a modified link trainer which could be rotated in a horizontal plane at speeds ranging from zero to twenty-six revolutions per minute (Fig. 1). Rotation of the trainer was produced by means of three vacuum motors activated by a large, water sealed, vacuum pump which was in turn activated by the experimenter from a control panel in an adjoining room (Fig. 2). This panel also contained controls for angular velocity, direction of rotation, overhead illumination, and a buzzer used in this experiment as warning signal. An Esterline Angus automatic pen recorder was used to keep a continuous record of angular velocity. The trainer occupied the center of a twelve-sided, nearly cylindrical, lightproof room. The walls were covered with a dull blue-gray, pleated fabric. In the cockpit, at the center of rotation, was an iron stanchion supporting an adjustable bite board which served to keep subject's head in a fixed position. A five inch by twenty inch front surface mirror was placed 31.1 cm. in front of the subject's eye at an angle of 30° to a line perpendicular to the line of sight (Fig. 3). One half of the mirror was covered by a lantern slide etched with acid so as to lower visual acuity approximately two Snellen chart lines. Purpose of this cover glass was to enable the subject to locate the test chart when it appeared in the mirror while, at the same time, preventing him from clearly discerning the test object itself. It may also be seen in Figure 3 that certain portions of the mirror are masked with opaque material. This masking was adjusted so that at each rotational velocity

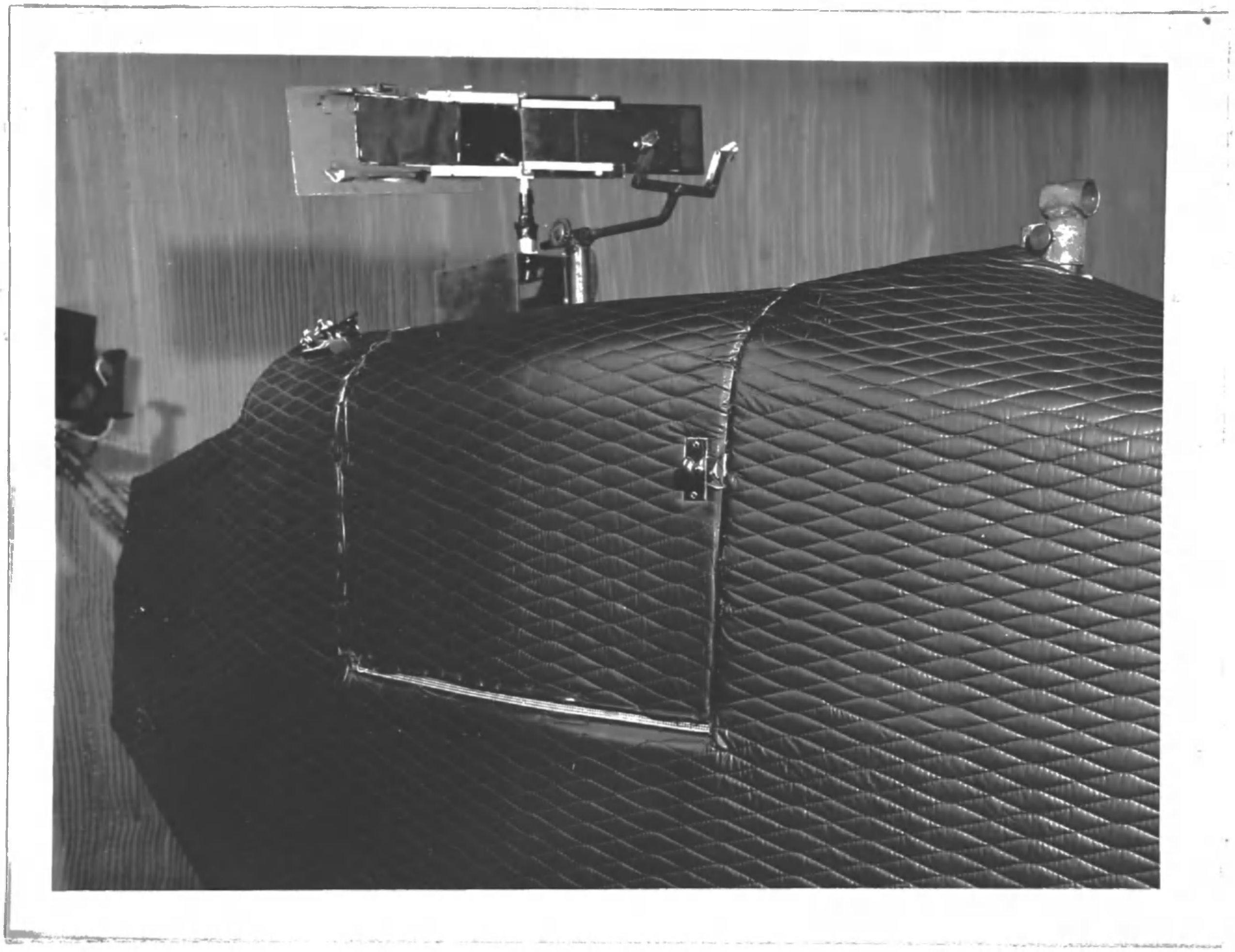

Fig. 1.

Photograph of apparatus used for rotating subjects

Fig. 2.

Photograph of control panel used for rotating link trainer

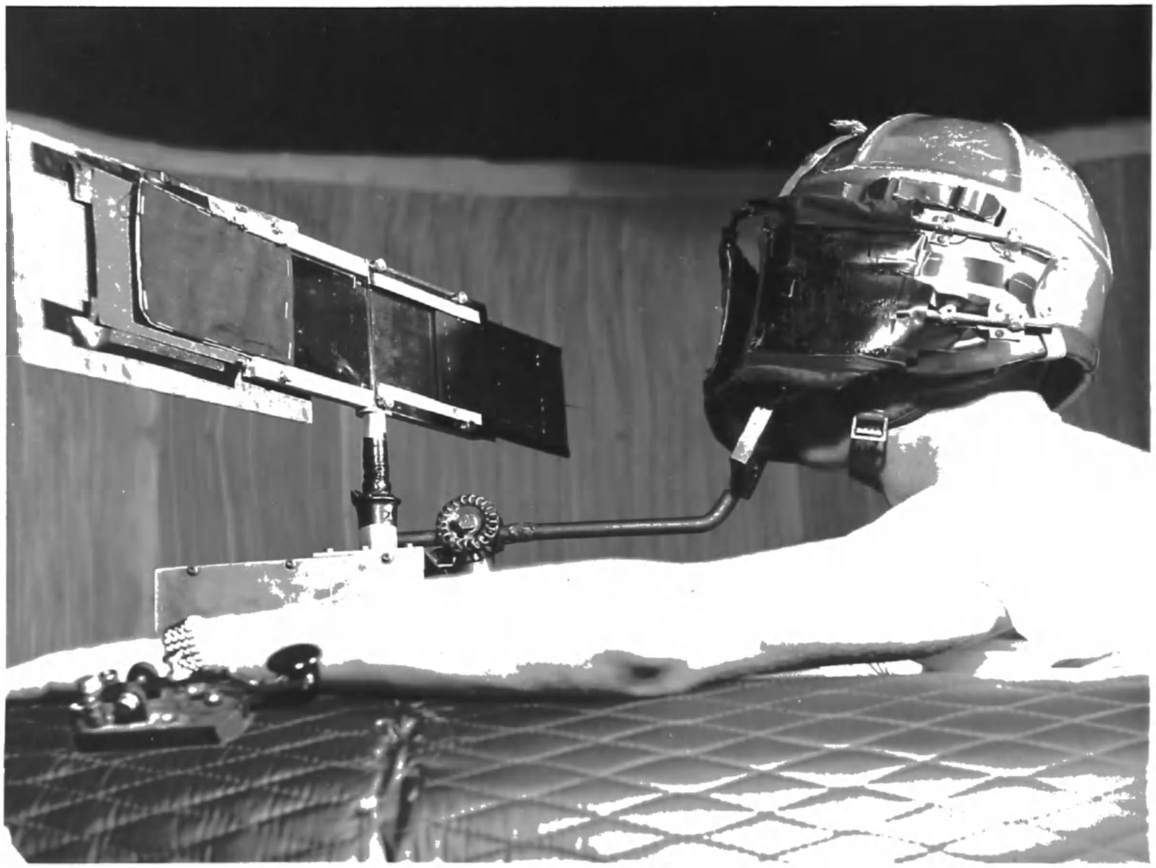

Fig. 3.

Photograph showing subject in testing position the exposure time was held constant. An additional piece of black cardboard fixed on the back of the mirror, prevented the subject from seeing the test chart other than at the desired time. A modified flying helmet, equipped with blinders, (Figs. 3 and 4) was worn by the subject in order to restrict the visual field to that reflected from the mirror.

The test chart may be seen in Figure 5. It consisted of a twelve inch by twenty inch piece of white cardboard with a reflection factor of approximately 85%. The test objects employed were Landolt rings. These Landolt rings were mounted on a wheel which could be rotated through 360° and viewed through a hole in the chart three and one-half inches in diameter. A similar hole was also cut in the wall of the experimental room.

Sixteen Landolt rings were employed during the experiment, ranging in size from .972 to 25.989 minutes of arc visual angle at the nodal point of the tested eye. In Snellen notation these values correspond to acuities of approximately 20/15 and 20/500 respectively. The ring sizes employed may be seen as Series A in Table 1. Each size Landolt ring could be rotated into any one of eight positions up, down, right, left and the four 45° positions, by an assistant experimenter from the adjacent control room as may be seen in Figure 6. The height of the chart was such that the center of the Landolt rings was at the subject's eye level. The optical distance from the subject's eye to the test object was 282.6 cm. The target was illuminated by two frosted incandescent lamps of appropriate wattage. The input to the lamps was held constant by employing the use of a voltage regulator. There were no lights on in the room during the experiment other than those illuminating the test chart. The six levels of illumination utilized were .04, .20,

Fig. 4.

Photograph showing helmet aperture and bite board

Fig. 5.

Photograph of Landolt ring mounted in test chart, and method of illumination

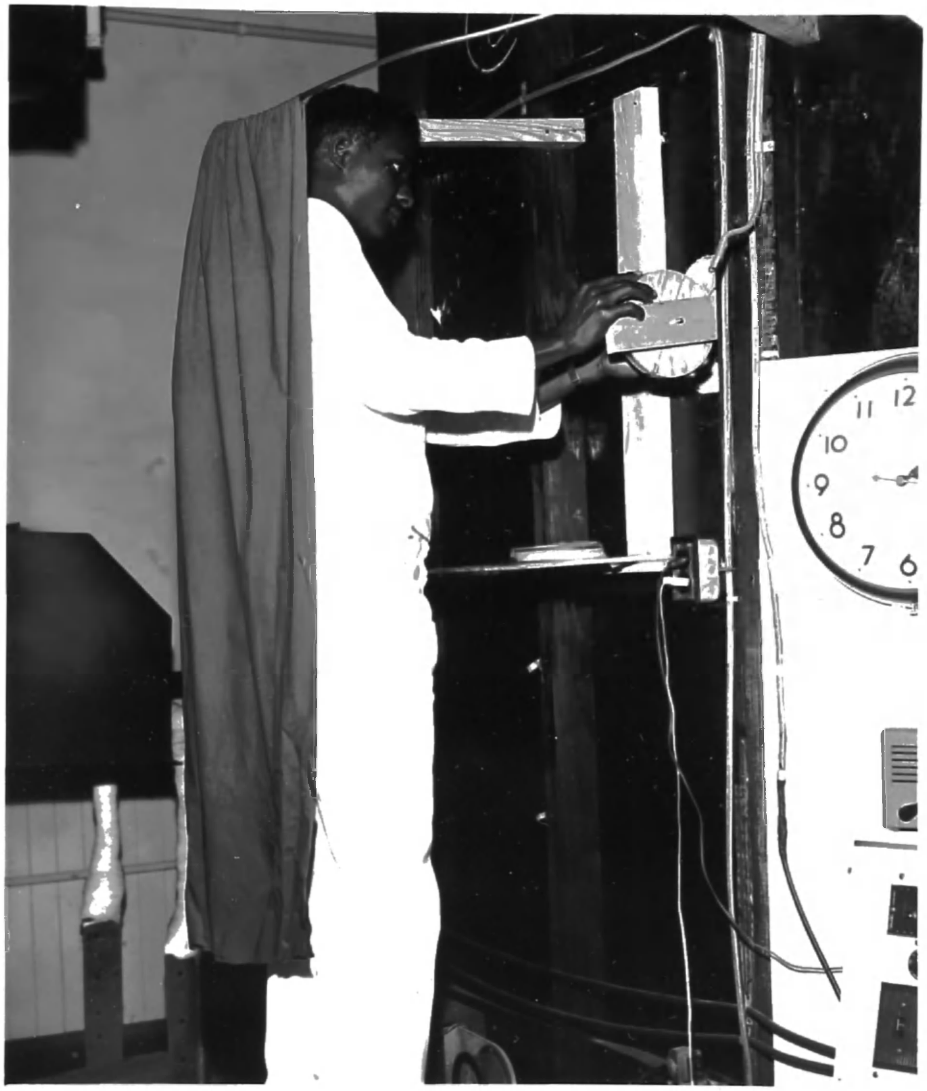

Fig. 6.

Photograph showing method of
changing ring size and position of break

TABLE 1

LANDOLT RING SIZES EMPLOYED AS TEST OBJECTS
EXPRESSED IN MINUTES OF ARC
AND IN SNELLEN NOTATION

	Series A		Series B	
	Minutes of Arc	Snellen Notation	Minutes of Arc	Snellen Notation
1.	25.99	20/519.8	15.75	20/315
2.	22.62	20/452.4	14.25	20/285
3.	20.55	20/411	12.75	20/255
4.	18.04	20/360.8	11.25	20/225
5.	15.26	20/305.2	9.75	20/195
6.	13.62	20/272.4	8.25	20/165
7.	10.82	20/216.4	6.75	20/135
8.	8.45	20/169	5.25	20/105
9.	6.65	20/133	4.50	20/90
10.	6.24	20/124.8	3.75	20/75
11.	4.97	20/99.4	3.00	20/60
12.	3.60	20/72	2.25	20/45
13.	2.92	20/58.4	1.88	20/37.5
14.	2.23	20/44.6	1.50	20/30
15.	1.80	20/36	1.12	20/22.5
16.	.97	20/19.4	.75	20/15

1.0, 5.0, 25.0 and 125.0 footcandles.

The illumination was measured by means of a Macbeth illuminometer. The level of illumination was controlled with a Variac. When the lower levels of illumination were being used, light bulbs of lower wattage were employed. Thus it was possible to operate the bulbs at a level nearer capacity, which reduced the effective color change usually associated with a reduction of line voltage.

The experiment involved the use of five different rotational velocities which were controlled by the means already described. The velocities were 3-1/3 rpm, 8-1/3 rpm, 13-1/3 rpm, 18-1/3 rpm and 20 rpm. These rates correspond to angular velocities of test object of 20°/sec, 50°/sec, 80°/sec, 110°/sec, and 120°/sec respectively. The total duration of observation throughout the experiment was four tenths of a second. The object was exposed for two tenths of a second through the etched cover glass and for two tenths of a second in the clear portion of the mirror.

Throughout the experiment the responses of the subjects were relayed to a speaker located in the adjacent conrol room via a Vocatron communicator, the pick up of which was suspended directly above the subject's head.

Procedure

The subject was seated in the Link trainer in the position indicated in Figure 3. He was first instructed to hold his head still during rotation as it was important to keep the distance from the mirror constant and also that movement of the head under such conditions frequently produced motion sickness. Next the subject was told that his task was to state in which one of the eight positions the break in the ring appeared, as he saw it reflected in the mirror. The link was then adjusted so that the subject could see the target clearly in the mirror while remaining stationary. A large ring was positioned and the subject was asked to state the location of the break. This procedure was repeated several times thus enabling the experimenter to determine whether or not the task was clearly understood by the subject. The subject was told that a warning buzzer would sound approximately two seconds before each presentation and that there would be no target visible in the mirror during any revolutions which were not preceeded by the buzzer. The subject was instructed to guess in the event that he was uncertain. A patch was then placed over the right eye and the helmet and bite board were adjusted.

The level of illumination and angular velocity were then selected from a previously compiled random series. The subject was rotated at the desired speed for one minute before the first trial was begun. This enabled him to partially adapt to the level of room illumination and also allowed the effects of acceleration to dissipate (5).

A ring providing an opening of a size judged to be easily visible at this angular velocity was presented with its opening in a position which had previously been determined by the chance selection of cards. The warning buzzer was sounded and the subject responded by stating the location of the break in the ring. The same size ring was repositioned and the procedure repeated. If the subject correctly judged both presentations, another pair of observations was taken with the next smaller size ring. If both of these observations were incorrectly judged then the value of the threshold was taken as the interpolated value between the two ring sizes employed. If the original two observations were incorrect then the next size larger ring was presented and the threshold was obtained in the same manner. If at any time one presentation of a pair was judged correctly and the other incorrectly by the subject, the threshold was recorded as corresponding to the size of ring employed. The time between presentations was fourteen to eighteen seconds throughout the experiment.

Each subject was tested at five angular velocities and examined under six levels of illumination at each velocity. Thus there were thirty experimental conditions involved. Six conditions, consisting of ten thresholds each were tested on each of five successive days.

The testing time required was approximately ninety minutes each day per subject.

An additional set of observations was taken on each subject during which the link trainer remained stationary. The object was, under this condition, viewed for two tenths of a second in the clear section of the mirror via a diaphram type shutter. The shutter, which may be seen in Figure 7, was mounted directly in front of the subject's left eye, the right eye being occluded by an opaque patch. The shutter was operated by the experimenter. The experimental conditions were otherwise the same as have been previously described. Five such thresholds were taken at the six levels of illumination for each subject.

The ten thresholds taken at each of the five angular velocities, and the five thresholds taken while the link was stationary were averaged separately for each subject to obtain mean values for the thirty-six experimental conditions. These means were subsequently averaged to obtain composite values comprised of the six subjects taken together.

A final series of observations was taken following the foregoing experiments. In this series the subject and the target remained in a fixed position and the test object was viewed through a shutter in the same manner described earlier with the exception that the exposure time in this latter instance was five tenths of a second. The same six levels of illumination were employed. The subjects used in this series were however not the same group as was used in the previous experiments as a result of members in the original group being transferred to different duty stations. This latter group however was in the same age and training level as the earlier group and likewise possessed static visual acuity of 20/20 or better uncorrected. The Landolt ring sizes used here are those found in Series B, Table 1. The reason for utilizing the additional series of ring sizes was, that due to physical conditions, the optical distance from the subject's eye could not be the same in

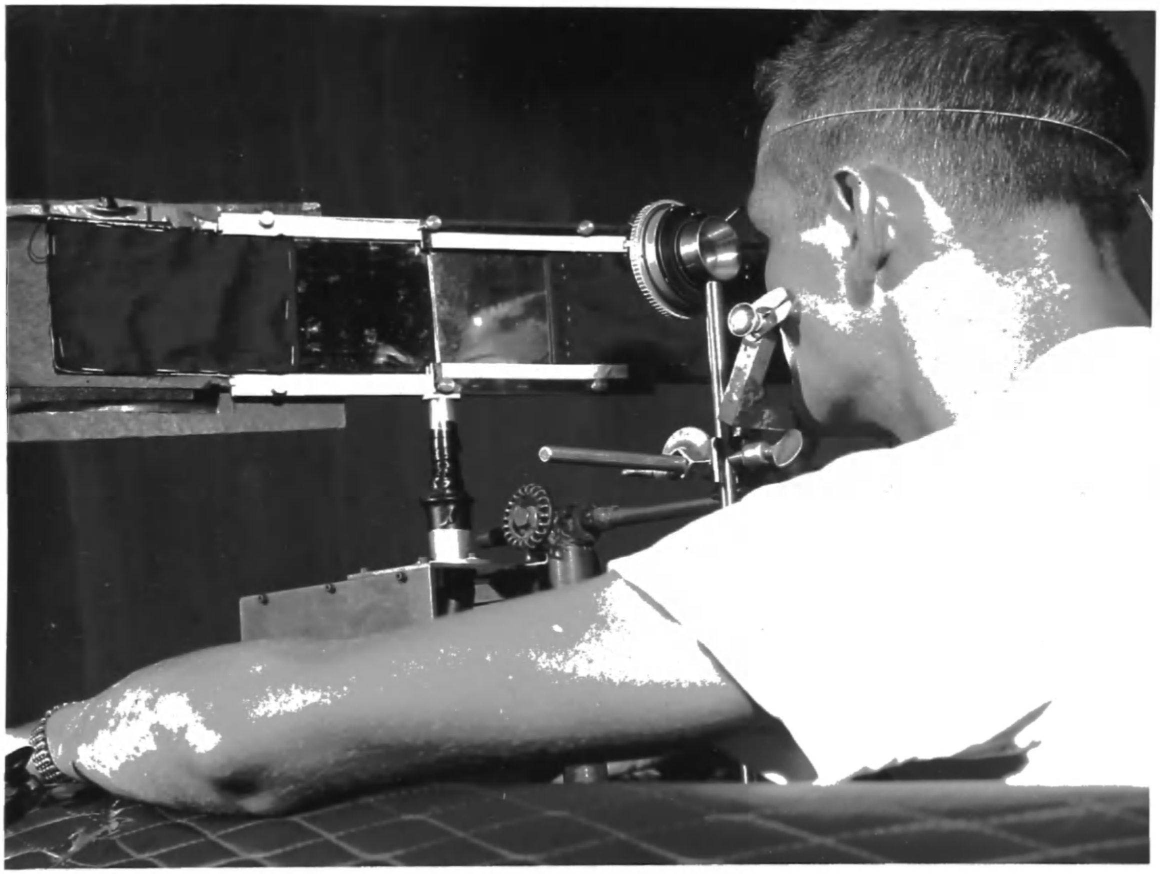

Fig. 7.

Photograph showing relation between
mirror and shutter used in static determinations.

this latter instance. The rings themselves under all conditions were the same but the change in distance from subject to target resulted in altering the subtended visual angle at the subject's eye.

Results

The present investigation was divided substantially into two parts. Part one consisted in determining some of the effects of rotating an individual, at constant angular velocities, on the ability to resolve a visual target. Part two dealt with the examination of the effects of different levels of target illumination on the visual acuity at each of the angular velocities employed.

The results of part one are indicated in Figure 8 plotted in the conventional manner with the reciprocal of the visual acuity in minutes of arc plotted on the ordinate and the angular velocity in degrees per second plotted on the abcissa. The same results are shown in Figure 9 in which the visual acuity in minutes of arc is plotted directly against the angular velocity of test object in degrees per second. It should be noted here that one minute of arc is equal to a visual acuity of 20/20 in standard Snellen notation, and that five minutes of arc is equivalent to 20/100, etc. Each of the points plotted on Figure 8 and 9 represent the mean value of six subjects. The numerical values of these plots may be seen in Table 2.

It is apparent from Figure 8 that, at all levels of illumination visual acuity deteriorates to some extent as the angular velocity of the test object increases. Figure 10 shows that the visual acuity is also adversely affected by a decrease in the level of chart illumination, which is here expressed in foot-candles plotted on a logarithmic scale with the visual acuity

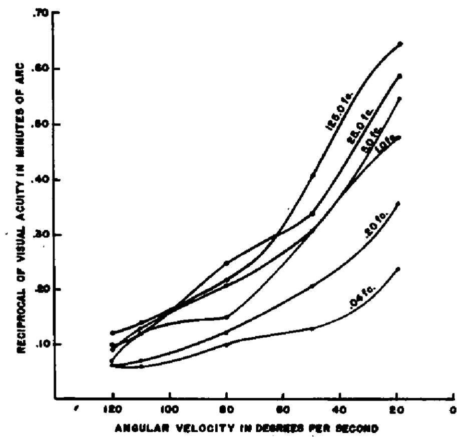

Fig. 8.

The effect of increased angular velocity of rotation on visual acuity at each of six levels of illumination.

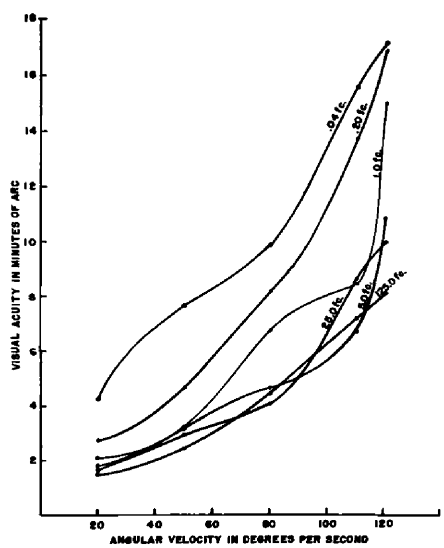

Fig. 9.

The effect of increased angular velocity of rotation on visual acuity expressed in minutes of arc, at each of six levels of illumination.

TABLE 2

THE MEAN VISUAL ACUITY THRESHOLDS OF SIX SUBJECTS COMBINED EXPRESSED IN MINUTES OF ARC AND THEIR RECIPROCALS

Chart Illumination in Footcandles	Static .2 sec		Static .5 sec		20°/sec		50°/sec		80°/sec		110°/sec		120°/sec	
	'Arc	Recip.	'Arc	Recip.	'Arc	Recip.	'Arc	Recip.	'Arc	Recip.	'Arc	Recip.	'Arc	Recip.
.04	8.53	.12	2.51	.40	4.25	.24	7.67	.13	9.95	.10	15.66	.06	17.26	.06
.20	6.59	15	1.59	.63	2.76	.36	4.66	.21	8.22	.12	13.79	.07	16.97	.06
1.00	4.95	.20	1.19	.84	2.10	.48	3.25	.31	6.81	.15	8.55	.12	15.08	.07
5.00	4.00	.25	.99	1.01	1.82	.55	3.19	.31	4.73	.21	7.82	.13	10.93	.09
25.00	4.85	.20	.98	1.02	1.69	.59	2.98	.34	4.09	.25	8.66	.12	10.00	.10
125.00	3.20	.31	.91	1.10	1.54	.65	2.44	.41	4.53	.22	7.22	.14	8.17	.12

Angular Velocity of the Test Object

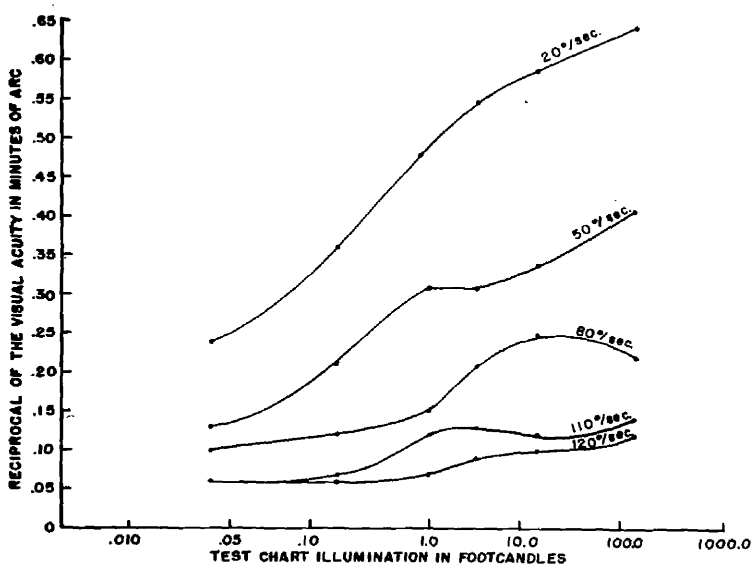

Fig. 10.

The effect of increased test chart illumination on visual acuity at each of five angular velocities of test object.

plotted on the ordinate in terms of reciprocal in minutes of arc.

An analysis of Figure 8 reveals that the threshold values determined at the various levels of test chart illumination are not affected in the same manner as the angular velocity of the test object is increased. In order to determine whether there were significant differences between the six levels of illumination as the angular velocity increased, a chi-square, based on the method of ranks, as described by Friedman (10), was calculated for each of the five angular velocities, and also for the two series of observations taken while the subject remained stationary. The resulting chi-square values are shown in Table 3. It is seen here that there were significant differences between the levels of illumination at each of the five angular velocities and for the two static series.

TABLE 3

THE VALUES OF CHI-SQUARE BETWEEN THE THRESHOLDS OBTAINED AT THE SIX LEVELS OF TEST CHART ILLUMINATION FOR EACH OF FIVE ANGULAR VELOCITIES AND TWO STATIC SERIES*

Angular Velocity	Chi-Square
Static .2 sec. exposure	23.61
Static .5 sec. exposure	26.22
20°/sec	21.85
50°/sec	17.85
80°/sec	15.28
110°/sec	18.32
120°/sec	23.20

*To be significant at the .01 level of confidence the required chi-square is 15.086 with five degrees of freedom.

Figure 10 reveals that as the level of illumination increases, the differences between the thresholds obtained at the five angular velocities utilized do not remain constant. So as to determine whether there were significant differences present between angular velocities as the illumination was altered, a chi-square, of the same type described above, was computed for each of the six levels of illumination. The resulting chi-square values are shown in Table 4. It is seen here that there are significant differences between the angular velocities at all six levels of test chart illumination.

TABLE 4

THE VALUES OF CHI-SQUARE BETWEEN THE THRESHOLDS OBTAINED AT THE FIVE ANGULAR VELOCITIES FOR EACH OF SIX LEVELS OF TEST CHART ILLUMINATION*

Level of Illumination	*Chi*-Square
.04	21.93
.20	21.93
1.0	21.00
5.0	20.33
25.0	15.93
125.0	19.00

*To be significant at the .01 level of confidence the required chi-square is 13.277 with four degrees of freedom.

As stated above the effect of altering the test chart illumination on visual acuity is not the same throughout the range of angular velocities tested. In other words there is an interaction present between the two variables angular velocity and illumination. A chi-square, for testing interaction using the method of ranking (10) was computed and found to be 41.50 which is significant, with twenty degrees of freedom, at the .003 level of confidence.

The analysis of the data thus far described has been performed with the aid of non-parametric statistical methods for the following reasons. The data had previously been tested and found to be distributed in an abnormal fashion. The thresholds taken at the lower angular velocities were found to be positively skewed and those at the higher velocities were negatively skewed.

In order to determine the presence or absence of homogeneity of variance, Bartlett's test, as described by Lindquist (21) was performed on the data obtained at an illumination level of five footcandles between the five angular velocities. The resulting chi-square, with four degrees of freedom, was 75.37 which was significant at less than the .001 level of confidence. This lack of homogeneity of variance coupled with the abnormality of frequency distribution invalidated the use of the usual parametric statistical procedures.

The semi-empirical equation $Y = a + bx^3$ was found by Ludvigh and Miller (27) to describe reasonably well their results obtained when the visual acuity of a group of subjects was tested over a range of angular velocities by means of a rotating mirror with the observer remaining stationary. The illumination used by these workers was twenty-five footcandles throughout. In this equation $\underline{Y}$ is the visual acuity expressed in minutes of arc, $\underline{x}$ is the angular velocity of test object measured in degrees per second and $\underline{a}$ and $\underline{b}$ are parameters which were determined by curve fitting using the method of moments. The $\underline{a}$ parameter is chiefly attributable to static acuity and the expression $Y = a + bx^3$ reduces to $\underline{Y} = \underline{a}$ when the angular velocity is zero. Good acuity therefore is indicated by a small $\underline{a}$ parameter. The value of $\underline{Y}$ is determined chiefly by the *b*x^3 term at higher angular velocities and a small *b* parameter indicates a relatively small amount of deterioration of visual acuity with increased velocities of the test object. Table 5 presents the values of the *a* and *b* parameters of the equation $Y = a + bx^3$, for each of the six levels of test chart illumination, when the thresholds of all six subjects are combined. These parameters were computed on the basis of the five angular velocities 20°/sec, 50°/sec, 80°/sec, 110°/sec and 120°/sec. The thresholds obtained with the subject remaining stationary were not included in the calculations. It will be noticed here that as the test chart illumination increases the values of both the *a* and *b* parameters decrease. This demonstrates that not only does the ability to resolve visual targets improve with higher illumination but that also the amount of deterioration of visual acuity resulting from increased angular velocity also decreases as is evidenced by the lower *b* coefficients.

TABLE 5

THE VALUES OF THE *a* AND *b* PARAMETERS FOR THE EQUATION $Y = a + bx^3$ FOR EACH OF SIX LEVELS OF ILLUMINATION WHEN THE RESULTS OF SIX SUBJECTS ARE COMBINED

Level of Illumination	*a* Value	*b* Value
.04	5.732	$7.058 \cdot 10^{-6}$
.20	3.417	$7.911 \cdot 10^{-6}$
1.0	2.360	$6.476 \cdot 10^{-6}$
5.0	2.135	$4.810 \cdot 10^{-6}$
25.0	1.936	$4.789 \cdot 10^{-6}$
125.0	1.981	$3.779 \cdot 10^{-6}$

So as to determine the goodness of fit of the equation $Y = a + bx^3$ relative to the empirical data obtained in this experiment, the equation was fitted to the observed points at each of the six levels of illumination employed. In order to examine the possibility that an equation of a higher order might better describe the obtained data, a second equation $Y = a + bx^4$ was also fitted to the observed points. In this equation the *a* and *b* parameters and the *x* and *y* terms represent the same function as in the equation previously described. The values of the *a* and *b* parameters, for the six levels of illumination, computed on the basis of the equation $Y = a + bx^4$ are shown in Table 6. It may be seen here that the value of the *a* parameter is consistently larger and the values of the *b* parameters consistently smaller than the corresponding values in the equation $Y = a + bx^3$. However they are both affected in a similar manner as the illumination is increased. The values of chi-square, indicating the amount of discrepancy between observed and computed points, for both of the equations discussed above are shown in Table 7. It is seen here that in no case is the chi-square between observed and computed values found to be significant. This indicates that both equations are satisfactory fits with the equation $Y = a + bx^3$ being slightly better.

The data thus far has been analyzed in terms of the six subjects, which participated in the experiments, taken as a group. Although the subjects used were of approximately the same age and all possessed static visual acuity of 20/20 or better uncorrected, the data indicated that there were substantial differences in their abilities to resolve a moving target. In order to examine these differences, the data of two subjects were compared at both .04 and 125.0 footcandles of test chart illumination. These data are shown in Table 8 and are presented graphically in Figures 11 and 12. It

TABLE 6

THE VALUES OF THE a AND b PARAMETERS FOR THE EQUATION $Y = a + bx^4$ FOR EACH OF SIX LEVELS OF ILLUMINATION WHEN THE RESULTS OF SIX SUBJECTS ARE COMBINED

Level of Illumination	a Value	b Value
.04	6.399	$.057 \cdot 10^{-6}$
.20	5.806	$.064 \cdot 10^{-6}$
1.0	2.888	$.053 \cdot 10^{-6}$
5.0	2.535	$.039 \cdot 10^{-6}$
25.0	2.347	$.039 \cdot 10^{-6}$
125.0	2.336	$.030 \cdot 10^{-6}$

TABLE 7

THE VALUES OF CHI-SQUARE INDICATING THE AMOUNT OF DISCREPANCY BETWEEN OBSERVED AND COMPUTED POINTS OF THE EQUATIONS $Y = a + bx^3$ AND $Y = a + bx^4$ AT EACH OF SIX LEVELS OF ILLUMINATION*

Level of Illumination	chi-square of $Y = a + bx^3$	chi-square of $Y = a + bx^4$
.04	.664	1.129
.20	.241	2.378
1.0	.978	1.374
5.0	.223	.408
25.0	.155	.312
125.0	.225	.582

*To be significant at the .05 level of confidence the required chi-square is 7.815 with three degrees of freedom.

TABLE 8

THE VALUES OF THE a AND b PARAMETERS OF THE EQUATION $Y = a + bx^3$ AND THE THRESHOLDS* OF TWO SUBJECTS FOR FIVE ANGULAR VELOCITIES AT EACH OF TWO LEVELS OF TARGET ILLUMINATION

	Level of Target Illumination in Footcandles			
	.04		125.00	
Angular Velocity	Sub. A	Sub. B	Sub. A	Sub. B
20	3.50	2.44	1.10	1.56
50	5.62	12.61	1.57	3.16
80	8.10	15.02	1.85	4.69
110	8.98	21.81	2.20	20.08
120	12.34	25.99	4.51	20.69
a Value	4.60	7.32	1.10	.95
b Value	$4.19 \cdot 10^{-6}$	$11.14 \cdot 10^{-6}$	$1.55 \cdot 10^{-6}$	$12.27 \cdot 10^{-6}$

*The threshold values presented above are expressed in minutes of arc. (One minute of arc being equal to 20/20, five minutes of arc equaling 20/100, etc.)

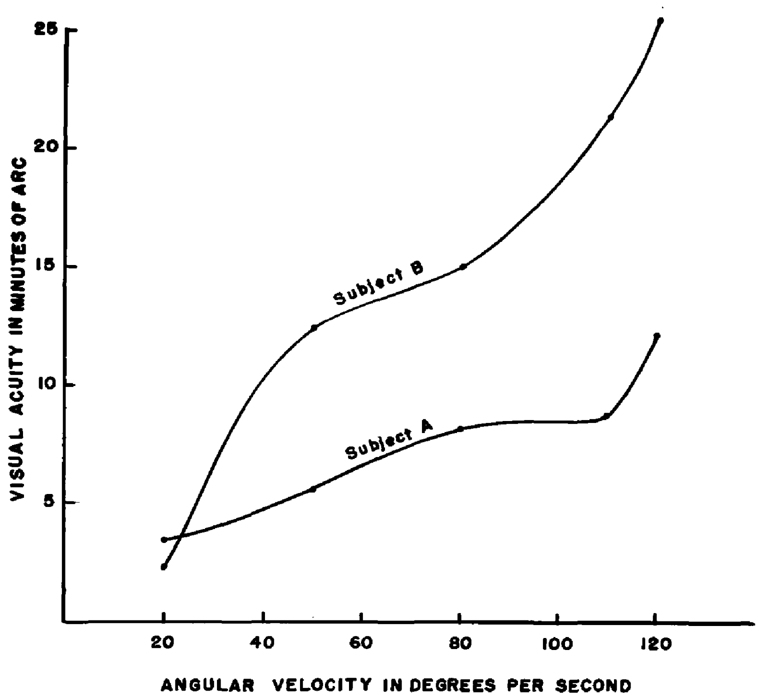

Fig. 11.

Comparison of the thresholds of two subjects tested with a target illumination of .04 footcandles.

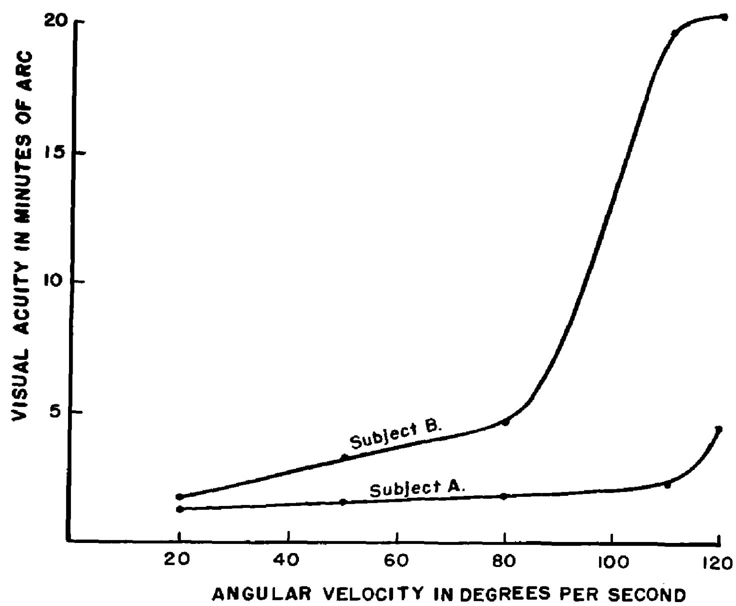

Fig. 12.

Comparison of the thresholds of two subjects tested with a target illumination of 125.00 footcandles.

is seen here that both subjects have similar threshold values at 20°/sec angular velocity for both .04 and 125.00 footcandles of illumination. However the visual acuity of subject B deteriorates to a much greater extent than does that of subject A with increased angular velocity at both levels of illumination. This marked difference in effect, of increased angular velocity on visual acuity is shown clearly in Table 8 when the values of the $\underline{b}$ parameters of the two subjects are compared. The value of the $\underline{b}$ parameter for subject B is 2.66 times as large at .04 footcandles and 7.92 times as large at 125 footcandles of illumination than that of subject A. It should be pointed out that for .04 footcandles although subject B is slightly better than subject A at 20°/sec angular velocity his $\underline{a}$ parameter is actually higher. This is due to the extremely rapid acceleration of deterioration as may be seen in Figure 11. Thus it is shown that very large differences in ability to resolve moving targets exist among individuals having substantially similar static visual acuities.

Discussion

It was shown in Figures 8 and 9 (page 25) that visual acuity deteriorates consistently and significantly as the angular velocity of the test object increases from 0°/sec to 120°/sec. These results agree substantially with those found by earlier investigators who examined the problem of ocular pursuit.

Blackburn (4) investigated the range of angular velocities over which movement of objects could be seen. The objects moved in a horizontal plane around an imaginary center between the eyes and subtended a visual angle of about two minutes. He concluded, from these experiments, that movement of objects of this size first becomes perceptible at an angular velocity of $.0007^{\circ}$/sec. At 25°/sec the object was barely visible and it disappeared completely when the velocity reached 50°/sec. These results are corroborated by those found in the present investigation. It may be seen in Figure 9 (page 25) that at 25°/sec the average threshold of the six subjects combined is 1.6 minutes of arc even under the most favorable conditions of illumination. At 50°/sec the lowest average threshold obtained was 2.5 minutes of arc. Thus one could predict that an object having an angular subtense of two minutes would barely be seen at 25°/sec and would not be visible at 50°/sec.

Ludvigh (24), using Landolt rings as test objects, conducted an investigation to determine the effect of increased angular velocity of test object on visual acuity. He found that at an angular velocity of 75^{o}/sec the acuity had deteriorated to 38% of the acuity obtained at 0^{o}/sec. By the time a velocity of 110^{o}/sec was reached the acuity had dropped to 28% of the value at 0^{o}/sec. In the present investigation the acuity at 80^{o}/sec was found to be 24% of the acuity at 0^{o}/sec when an exposure time of five tenths of a second was used with twenty-five footcandles of target illumination. The corresponding value at 110^{o}/sec was found to be 11%. It is thus seen that the acuity deteriorated to a greater extent in the present study. This difference of results may be attributed to the fact that in Ludvigh's study the target was moved whereas in the present study the subject was rotated. Another possible cause of the poorer acuities found by this author could be the method of presenting the stimulus. The break in the ring was placed into any one of eight positions in present investigation. If only four positions were utilized by Ludvigh, the resulting threshold values may have been lowered as a result of the greater likelihood of guessing correctly.

It has been pointed out in the introduction that visual acuity has been shown by Ludvigh to deteriorate more rapidly, with increased velocity of target, when the pursuit is circular than when it is horizontal and linear (25). In Ludvigh's study the effect on visual acuity of both angular velocity and the number of target revolutions per minute were investigated. It was found that at a given angular velocity, the deterioration of acuity was much less than when there were fewer revolutions per minute. At an angular velocity of 62^{o}/sec using a four diopter prism the visual acuity was reduced to 20/200. When a twelve diopter prism, which requires fewer revolutions per minute to produce the same velocity, was used the acuity was only reduced to 20/40. He suggests on the basis of these results that the rapid decrease in acuity, found during ocular pursuit in a circular path, may be due to both the increased angular velocity of the test object and to the inability of the subject to adjust the relative innervation of the various ocular muscles satisfactorily.

The experimental conditions in the study conducted by Ludvigh and Miller (27) were similar to those of the present investigation. However in the former study twenty-five foot-candles of target illumination was the only intensity used. A second difference between the two studies was that in the former the observer remained stationary and the object was made to move by means of a mirror rotating in a horizontal plane as opposed to the observer himself being rotated in the present study. A comparison of their results with those of the present investigation may be seen in Table 9. Also on Table 9 may be found a brief summary of results determined by other investigators. The results chosen from the present study for comparison are those obtained at a target illumination level of twenty-five foot-candles. It can be seen that the only substantial difference in threshold values found between this study and that of Ludvigh and Miller was obtained at an angular velocity of 110°/sec. This difference of mean thresholds was tested and found to be insignificant. It would seem then that visual acuity is affected in approximately the same manner, with increased angular velocity of the test object in a horizontal plane, regardless of whether the target is moved relative to the observer or the observer moved relative to the target.

It is interesting to note that the results found by various authors which are presented in Table 9 seem to agree fairly well with one another. The difficulty one encounters when comparing the results of a given visual function taken under different experimental conditions has long been a problem and has been considered quite extensively by earlier investigators (35), (18), (3), (31). In spite of the diverse methods of experimentation used by the authors cited in Table 9 it appears that these authors would agree with the statement that the ability of the eye to successfully follow a moving target is considerably retarded by the time an angular velocity of approximately 50°/sec is reached. It may also be seen that the decrement of visual acuity proceeds very rapidly at higher velocities.

The question of why visual acuity deteriorates with increased angular velocity of the test object is not as easy to answer as it would first appear. One explanation might be that the eye has difficulty in keeping up with the target. Adler (1) has pointed out that voluntary movements of the eye can attain speeds as high as 500°/sec for large movements and that the average speed for small movements may be taken as between 100°/sec and 200°/sec. Inasmuch as the highest velocity used in the present investigation was 120°/sec it does not seem likely that the decrement in visual acuity with increased angular velocity was due to the inability of the eye to attain sufficient speed.

It was shown earlier that ocular pursuit does not simply

TABLE 9

COMPARISON OF THE FINDINGS OF DIFFERENT AUTHORS REGARDING OCULAR PURSUIT AT VARIOUS ANGULAR VELOCITIES

Angular Velocity	Author	Findings
$.14^{\circ}$/sec	Blackburn	Object subtending 2' arc easily visible
8°/sec	Travis and Dodge	Adequacy of ocular pursuit is 95%
10°/sec	Langmuir	Visual angle necessary to see botfly is .96' arc
20°/sec	Miller	Mean acuity is 1.69' arc (observer moving)
	Ludvigh and Miller	Mean acuity is 2.17' arc (observer moving)
25°/sec	Blackburn	Object subtending 2' arc is barely visible
30°/sec	Westheimer	Beginning of saccadic pursuit movements
50°/sec	Miller	Mean acuity is 2.98' arc (observer moving)
"	Ludvigh and Miller	Mean acuity is 2.97' arc (target moving)
	Blackburn	Object subtending 2' arc is invisible
"	Langmuir	Visual angle necessary to see botfly is 4.8' arc
52°/sec	Travis and Dodge	Adequacy of ocular pursuit is 10%
62°/sec	Ludvigh	Acuity with rotary pursuit, 4 prism is 10' arc
"	Ludvigh	Acuity with rotary pursuit, 12 prism is 2' arc

"TABLE 9-Continued."

75°/sec	Ludvigh	Visual acuity deteriorated by 62%
80°/sec	Miller	Visual acuity deteriorated by 76%
"	Ludvigh and Miller	Mean acuity is 4.10' arc (target moving)
"	Miller	Mean acuity is 4.09' arc (observer moving)
110°/sec	Ludvigh	Visual acuity deteriorated by 72%
"	Miller	Visual acuity deteriorated by 89%
"	Ludvigh and Miller	Mean acuity is 6.80' arc (target moving)
"	Miller	Mean acuity is 8.66' arc (observer moving)

consist of a single smooth tracking motion of the eye (7), (38). It has also been demonstrated by Westheimer (38) that the number of saccadic movements of the eye during pursuit increases as the velocity of the target increases. It might be possible then that the decrement in visual acuity with increased angular velocity of the test object is a result of the saccadic movements of the eye causing the image of the target to be displaced from the foveal region. Many investigations have been conducted in an effort to measure indirect or peripheral visual acuity, one of the earliest being that of Purkinje (34). Several techniques have since been used to determine indirect visual acuity but perhaps the study most applicable here is one which was conducted by Ludvigh (22). Using Snellen test-letters as test objects he found that at two degrees distant from the fovea the acuity was reduced only from 20/20 to 20/30. In order to reduce the visual acuity to 20/70 it was found that the test objects must be displaced by as much as ten degrees from the fovea. In the present investigation the image of the target travels over a total of about thirteen degrees. Assuming that the eye made no attempt at all to follow the target and merely fixated the point at which it first appeared, the acuity would only be reduced to a little more than 20/75 as a result of peripheral displacement. The reduction of acuity as a result of extrafoveal displacement would possibly be even less in the present study when one considers that Landolt rings are perhaps a simpler test object to resolve than the more complex Snellen test-letters. Inasmuch as there were acuities obtained which were considerably poorer than 20/75, it would appear that the decrement of visual acuity found to exist with increased angular velocity of test object cannot be solely attributable to the target being in an extrafoveal position.

A question which might be asked with regard to ocular pursuit is; can the eye react to perceived movement fast enough to begin tracking the target before it disappears? Dodge (6) and Ludvigh (26) have found that the eye can respond to movement of an object in the visual field within two tenths of a second after it first becomes visible. The exposure time of the target in the present investigation was four tenths of a second at all angular velocities used which according to the authors just cited, would allow ample time for pursuit to begin.

We have now seen that the eye is capable of moving sufficiently fast to pursue the targets employed here. We have likewise seen that the eye has time enough to begin pursuit of the targets. Also it has been shown that the extrafoveal position of the test objects cannot account for the large decrement of acuity with increased velocity. Why then does visual acuity deteriorate so markedly when the angular velocity of the test object is increased? As was discussed earlier it has been shown that ocular pursuit consists of a series of saccadic movements and is not simply a single smooth sweep. These saccadic movements have been shown to increase in number as the velocity of the target increases (38). Inasmuch as the target is moving continuously and the eye is moving in a succession of jerks, it would seem to follow that the image of the test object on the retina would be blurred. A blurred image reduces the intensity contrast between figure and ground which would subsequently interfere with the resolving power of the retina. It would appear then that one way to compensate for the loss of contrast would be to increase the intensity of illumination of the test object.

Figure 9 (page 25) shows the effect on visual acuity of increasing the level of test chart illumination at each of five angular velocities. As would be expected there is some improvement in acuity at all velocities as the level of illumination increases. It was demonstrated in Table 3 (page 28) that there were significant differences between the levels of target illumination at each of the five angular velocities employed. It should be noted however that there is considerably less improvement with increased illumination at the higher angular velocities. This result at first glance would seem to be somewhat paradoxical. In our previous discussion it was concluded that as a result of a greater number of saccadic eye movements at higher angular velocities the intensity gradient of retinal illumination was decreased which resulted in a reduction of visual acuity. It would seem to follow then that an increase in the illumination of the test objects would be of greater benefit at high angular velocities than at low. This is, as we have just seen, not the case.

It was shown in Figure 8 (page 25) that with sufficient illumination there is relatively no loss of visual acuity at an angular velocity of 20°/sec which would indicate that ocular pursuit is fairly adequate at this speed. As the speed of the test object increases however, the pursuit becomes less and less effective. By the time an angular velocity of 120°/sec is reached the pursuit is so inaccurate as to overcompensate any substantial improvement which would ordinarily be afforded by increased illumination.

It may be seen in Table 2 (page 26) that with five tenths of a second exposure time the static acuity values are somewhat smaller than those found at 20°/sec. This demonstrates that even speeds as low as this adversely affect visual acuity to some extent.

The high static values found in Table 2 with two tenths of a second exposure time may be attributable to the rapid shift in accommodation required or to the lack of a pre-fixation point or to the rapid change in brightness from shutter to target.

The higher values are most likely to be due to the combined effect of the three factors. These factors are not as serious a problem when the exposure time is lengthened to five tenths of a second as the results indicate.

It was pointed out earlier that previous investigators have shown that when visual acuity is measured using a stationary target, the improvement is negligible for levels of illumination above one footcandle (16), (29), (9). This finding is further supported in a report by Pratt and Dimmick (33) in which it was found that approximately 91% of the improvement in visual acuity under optimal conditions occurred by the time one footcandle of illumination was reached. Figure 10 (page 27) shows that this relationship does not hold true when the test object is moving. Particularly at the lower angular velocities it may be seen that there is considerable improvement at levels above one footcandle. This finding is further supported by Ludvigh (25). He found that visual acuity during rotary pursuit was still improving at levels of illumination of over 200 footcandles when the angular velocity of the target was 90°/sec. The improvement at 80°/sec in Figure 10 is seen to actually decrease between 25 and 125 footcandles. This reversal is probably due to an experimental artifact and if it may be disregarded, it appears reasonable that increases of illumination well over a level of 100 footcandles may be beneficial especially at the lower angular velocities.

In Table 8 (page 34), it was demonstrated that there were marked differences in the ability to visually track and resolve a moving target, between two individuals possessing substantially equal static acuities. The reasons for these differences are not immediately apparent. The visual functions of the two subjects compared, particularly with regard to visual acuity, were found to be equal. The experimental conditions were the same and the subjects were of approximately equal age. It is not possible to say whether such individual differences are attributable to a mechanism located in the sensory pathways, the cortical centers, the motor pathways, or in the receptor organ itself. They may even be due to more general psychological characteristics such as set, attitude motivation, etc. The only satisfaction in this regard we may draw at the present time is to recognize that such differences do exist and to apply this knowledge in practical situations where it is found useful.

As has been indicated previously, the investigation of visual acuity during ocular pursuit is a relatively unexplored field of experimentation. This means that there are numerous factors involved which warrant future study. Some of the fields for possible future research are listed below.

1. The effects of varying degrees of anoxemia.
2. The ability of the eye to pursue a constantly accelerating target.
3. The effects of varying the exposure time of the target.
4. The effects of vestibular stimulation resulting from an acceleration of the observer.
5. The effects of using targets of various colors.

6. The determination of the characteristic eye movements at various angular velocities either photographically or optically.

7. The relationship between acuity obtained in a controlled experiment and certain practical situations such as are found in different areas of sports or in certain facets of aviation.

8. Examination of the possible applications in the clinic, as for example the ability to pursue moving targets could be used as a means of provoking latent defects in the extraocular muscles.

It is evident then that the present investigation has only scratched the surface of a problem which has wide practical and theoretical implications.

Summary

The present investigation was an attempt to determine the effect, on visual acuity, of rotating an observer at various constant, angular velocities with the test object remaining in a fixed position. In addition to this the effect of varying the intensity of target illumination on visual acuity was examined at each of five angular velocities.

A review of the literature was made and it was found that two or three attempts had previously been made to determine visual acuity when the test object moved relative to the observer but that no effort had been made to measure it while the observer himself was moving. It was also found that no attempt had been made to measure visual acuity while systematically varying the illumination of the target over a range of angular velocities of ocular pursuit.

Six subjects were used in the experiments, all of which possessed static visual acuity of 20/20 or better uncorrected.

The apparatus employed was a modified link trainer which could be rotated in a horizontal plane at speeds ranging from zero to twenty-six revolutions per minute. The object was viewed monocularly by means of a front surface mirror mounted on the link directly in front of the subject's head. The test objects used were Landolt rings and the exposure time was controlled by means of appropriate masking on the mirror. The method of constant

stimuli was used and the thresholds were obtained by using a forced-choice among spatial intervals technique. Five angular velocities were utilized ranging from 20^{o}/sec to 120^{o}/sec. The visual acuity was determined at each velocity under six levels of test chart illumination which ranged from .04 to 125.0 footcandles.

The results showed that visual acuity deteriorated consistently and significantly as the relative angular velocity of the test object increased. Some possible reasons for this deterioration were discussed and it was suggested that as a result of imperfect pursuit movements of the eye, the gradient of retinal illumination was reduced and it was this loss of contrast which lead to the observed decrement of visual acuity.

The results were compared with those of earlier investigations in which visual acuity was determined during ocular pursuit with the observer remaining stationary. It was concluded that visual acuity deteriorates in a similar manner with increases in the relative angular velocity of the test object regardless of whether it is the target or the observer which moves. The manner in which visual acuity deteriorated with increased angular velocity was similar at each of the levels of test chart illumination employed. It was demonstrated however that increases in illumination were more beneficial for visual acuity at the lower angular velocities than at the high, and that the obtained differences were significant at all angular velocities tested.

It was pointed out that previous studies showed that when the intensity of target illumination exceeded one footcandle further increases resulted in only negligible improvement in visual acuity when the targets were stationary. The present investigation demonstrated that acuity during ocular pursuit was benefited by a substantial amount when the illumination was increased beyond a level of 100 footcandles. These findings were found to be in agreement with those of Ludvigh (25).

It was found that when visual acuity was plotted against angular velocity the resulting curves were satisfactorily described by the semi-empirical equation $Y = a + bx^3$, where Y is the visual acuity expressed in minutes of arc, x is the angular velocity of the test object expressed in degrees per second and the a and b coefficients are parameters describing the manner in which visual acuity deteriorates with increased angular velocity.

It was pointed out that there are large differences in the ability to resolve moving targets existing among individuals having substantially the same static visual acuity.

The general results of this investigation were compared with the results obtained by several previous workers. It was shown that when considering the wide variety of experimental procedures which were employed, the results of the studies cited were in substantial agreement with those determined in the present study. These investigations when viewed totally seem to indicate that by the time an angular velocity of 50°/sec is reached the ability of the eye to adequately track a moving target is seriously impaired. It is pointed out however that this impairment of ocular pursuit begins at lower velocities and is a gradual deterioration.

Finally some possibilities for future investigation of problems involving ocular pursuit were mentioned.

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