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DYNAMIC VISUAL ACUITY IN AN APPLIED SETTING

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. NAVAL AIR STATION PENSACOLA, FLORIDA

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U.S. NAVAL AVIATION MEDICAL CENTER
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JOINT PROJECT

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DYNAMIC VISUAL ACUITY IN AN APPLIED SETTING

Report By

James E. Goodson, LTJG,MSC,USNR
and
James W. Miller,Ph.D.

Approved By

Captain Ashton Graybiel, MC,USN
Director of Research

Released By

Captain Langdon C. Newman, MC,USN
Commanding Officer

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SUMMARY PAGE

THE PROBLEM

The purpose of the present study was to determine the relationships between performance in the laboratory and in the air with regard to the visual pursuit of moving targets.

FINDINGS

Visual acuity deteriorates in the air with increased target speeds in much the same manner as it does in the laboratory when similar targets (Landolt C's) are used. The rate of deterioration in acuity, when using two targets, seems to take a linear form over the range of speeds used as opposed to the curvilinear form taken when one target is used. Performance of the visual tracking task was affected both by the deceleration and by the change in configuration of the targets. The effect appears to be beneficial. Physiological factors peculiar to the flight conditions either did not affect performance, or else acted in a consistent manner. Anxiety toward flight, as measured by proneness to become air sick, did not have an effect on performance of the task. All three methods used for testing dynamic acuity discriminated among subjects significantly at all speeds. While there was considerable learning in the one target method, no learning took place when the more complex target was used. It was pointed out however that learning might have taken place with the complex targets had more practice been given.

INTRODUCTION

The recent advances in speeds of operational aircraft and the development of high-speed, visual-contact missions have caused an increasing emphasis to be placed upon the visual problems of the aviator. One of these problems involves the ability to resolve the critical detail of moving targets. The term "dynamic visual acuity" may be defined as the manner in which one's visual acuity deteriorates as a function of increasing target speeds. Ludvigh and Miller found that this deterioration occurs independently of static acuity when target speeds exceed 20 degrees per second (3). Since appreciable deterioration seldom occurs at speeds less than 30 degrees per second, the aviator who flies at medium to high altitudes is not concerned with the problem. However, the aviator of today may be called on to navigate visually while flying a high speed, low altitude type mission, during which he may be confronted with angular velocities upwards of 110 degrees per second. The question arises, then, as to whether the knowledge gained from our laboratory studies will enable us to select or train pilots more efficiently to carry out such missions.

Three reasons why the laboratory results may not be applicable here are: Only constant velocities have thus far been used in the laboratory studies, whereas nearly all the visual tracking performed by the aviator will be with either accelerating or decelerating velocities; there is a vast array of environmental differences between the laboratory and plane settings, for instance, buffetting, vibration, varying atmosphere conditions, and anxiety toward flight; and, the targets used in the laboratory, at least in Pensacola, have been extremely simple ones (single Landolt C's), whereas the visual targets to be defined by the aviator are considerably more complex.

The purpose of the present study was to determine the relationship between performance in the laboratory and in the air with regard to the visual pursuit of moving targets.

PROCEDURE

SUBJECTS

Fifteen male ex-candidates for naval aviation training who had either dropped or been dropped from the program were used as subjects.* All had 20/20 or better static acuity as measured by the Snellen method.

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*None of these subjects left the flight program for reasons connected with vision.

METHOD

The aircraft used in the present study was a Navy AD-5 (attack bomber). All experimental flights were made over a practice landing field which is 4,000 feet square and has perpendicular center lines running north-south and east-west. Arrangements were made so that this area was restricted to all other aircraft for altitudes up to 1200 feet for the duration of the experiment. An appropriate metal view box (see Figure 1) was mounted on the port, rear canopy ledge, just aft of the trailing edge of the wing. This apparatus was designed so that the box could be easily adjusted to any desired vertical angle. A level and protractor were attached to provide a means of setting the box at 45° with the vertical regardless of the attitude the aircraft had to assume in order to maintain a straight and level path. In the lateral plane the box was fixed at 90° with the longitudinal axis of the aircraft. The exposure time of the targets was held constant at 0.4 seconds by inserting masking plates into slots provided across the front (outboard) end of the box. A head rest was attached to the box in such a position that the subject could comfortably sight down the right, inside edge with his right eye. The box itself was 2.75 inches high, 6.75 inches wide, and 5.25 inches deep (inside dimensions).

The targets were Landolt C's which were slanted at a 45° angle. One target stand was placed on the north-south center line of the field, 50 feet south of its perpendicular line; a second stand was placed 24.3 feet south of the first. This arrangement allowed the subject to view the targets as one complex target with two critical details rather than two simple targets. The east-west center line served as a preparatory stimulus, as the path of the plane was from north to south. The targets were positioned on the stands by an assistant with whom the experimenter, in the plane, was able to communicate by radio. The flat black rings were painted on heavy white cardboard having a reflectance factor of 85 per cent. Twelve sizes of Landolt C's were used.

The minimum weather conditions for experimental flights were 5,000 feet ceiling and 8 miles visibility. The conditions above this minimum, of course, caused variations in the illumination. Miller (5) has shown that dynamic visual acuity varies greatly with variation in illumination. However, his results indicate that any differential effect illumination might have occurs at levels substantially below those in the present study.

All subjects were first tested in the air and then in the laboratory. They were instructed as to the general purpose of the study prior to arrival at the plane. As a precaution against airsickness, all subjects were required to have breakfast on the morning of the flight.

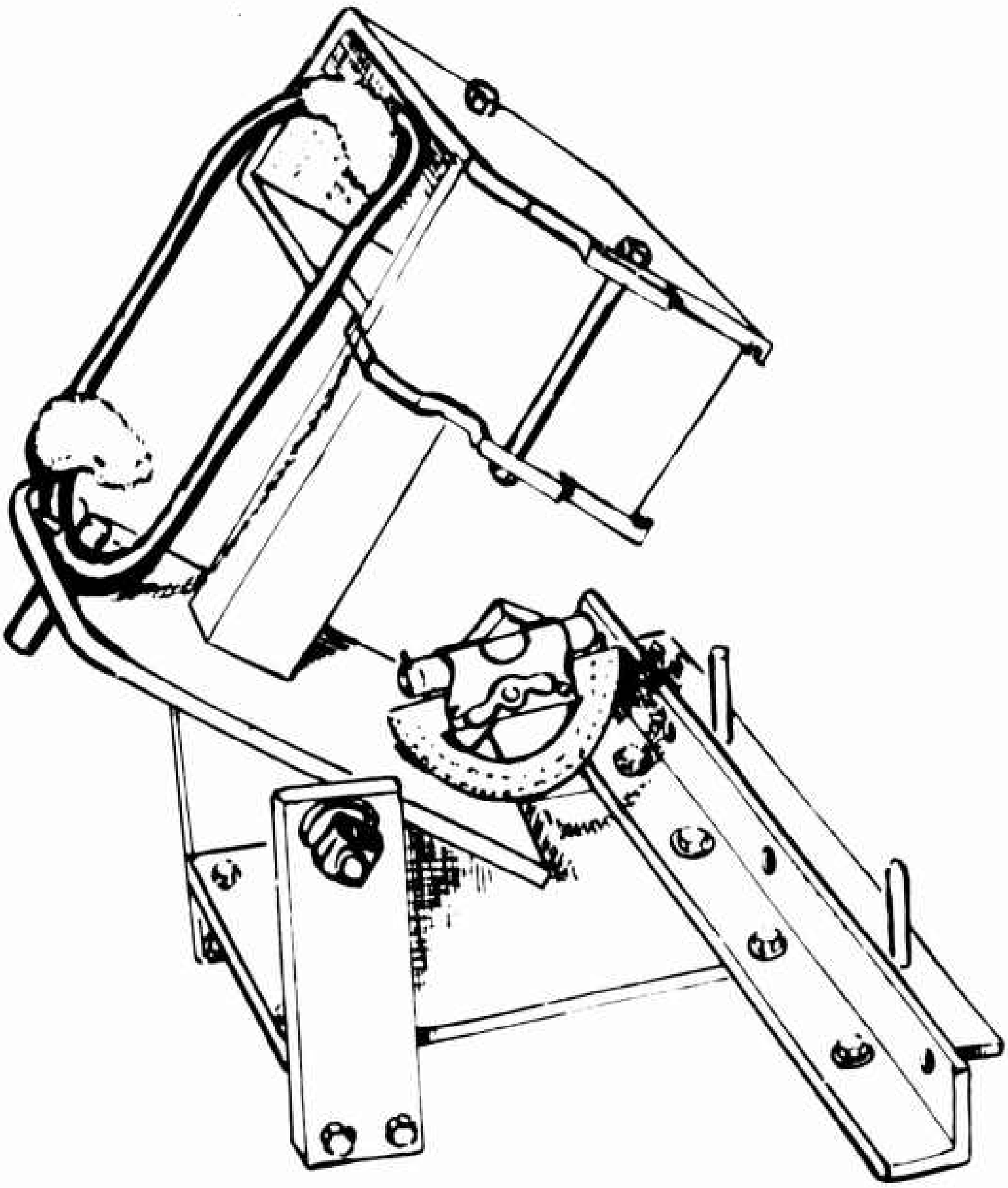

FIGURE I

IN AIR VIEWING APPARATUS

The subject was seated in the aircraft facing out and shown how to observe the target. He also was warned to turn and face forward all the time except during the period over the field in order to minimize the possibility of airsickness.* He was given the masking plates and told how to change them when the altitude and speed of the plane were changed. Finally, he was instructed as to emergency procedures, proper use of radio gear, burp bag, et cetera.

Ten minutes after take-off (about 0900) the experimental flight pattern was entered at the field. The flight path ran parallel to the north-south center line at a 45° angle with the east-west line. The first run was an introductory one at 200 feet altitude and 170 knots.# Then, instructions concerning target size and position were given to the assistant on the field, and the experimental runs were begun.

The assistant had two matched sets of twelve targets. The targets could be set with the opening of the C in either of four positions (up, down, left, or right); the position of one target was not necessarily the same as that of the other. The subject's task was to report the position of each C. All thresholds taken from the air employed two targets at a time of identical size. If, on a given pass, the position of the opening of both Landolt C's was stated correctly, the next smaller size was presented on the following pass. If, on the other hand, either one or both of the targets was missed, the next larger size was subsequently presented. A threshold was considered to be the interpolated value between the size target identified correctly on both stands and the size missed on either one or both stands. If one target was missed, the threshold was half way between the two sizes; if both targets were missed, it was three-quarters up from the missed target size. Five such thresholds were obtained in the air at each of three angular velocities, 20, 69, and 90°/sec. This procedure required an average of thirty passes per subject or approximately two hours.

Because the trailing edge of the wing extends so far back, the subject would not have been able to look forward even had the apparatus allowed it; hence only decelerating speeds were used, i.e., the target was tracked from a position 90° off the plane's

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*It was found in work preliminary to this study that sickness was facilitated in those who remained facing out. For similar reasons, patches were not worn over the left eye; however, subjects were instructed to close their left eye.

#References to speed and altitudes are, of course, true measures, since indicated measures would be meaningless. However, these have probable errors amounting approximately to altitude $\pm$ 5 feet and speed $\pm$ 3 knots.

longitudinal axis, back. As the plane moves away from the targets, two obvious, but important processes begin. The relative angular velocity decelerates, and the angular size of the targets becomes smaller. For this reason, it is difficult to know just what speeds and sizes of targets to designate as those at which the target was actually resolved. It will be recalled that the total exposure time was 0.4 seconds. Since the reaction time of the eye when beginning a tracking movement is about 0.2 seconds (1), it can be assumed that the target was not seen clearly during the first half of the exposure time. In an effort to minimize the possible error introduced, the midpoint of the second half of the exposure time (0.3 seconds) was chosen as the time at which the targets were resolved. Consequently, all angular velocities and target sizes were computed on the basis of the conditions existing at this instant. Figure 2 illustrates that the angular relationships with respect to the targets changed as a function of the position of the aircraft. The computed changes in angular relationships over the full exposure time are presented in Table I, using one representative target size.

Table I

Angular Changes During Exposure Time

Altitude	Linear Velocity	Elapsed Exposure Time	Angular Velocity	Target Size (Minutes)	Separation of Targets
105 ft.	346/ft/sec	0.0 sec	134°/sec	5.45	9° 19.8'
		0.2 sec	110°/sec	4.52	8° 11.1'
		0.3 sec	90°/sec	3.56	6° 43.0'
		0.4 sec	71°/sec	3.00	5° 26.8'
148 ft.	297 ft/sec	0.0 sec	81°/sec	3.83	6° 39.0'
		0.2 sec	75°/sec	3.28	6° 18.4'
		0.3 sec	69°/sec	3.16	5° 50.5'
		0.4 sec	61°/sec	2.92	5° 16.1'
442 ft.	220 ft/sec	0.0 sec	20°/sec	1.28	2° 13.6'
		0.2 sec	20°/sec	1.27	2° 13.2'
		0.3 sec	20°/sec	1.26	2° 12.5'
		0.4 sec	20°/sec	1.26	2° 12.4'

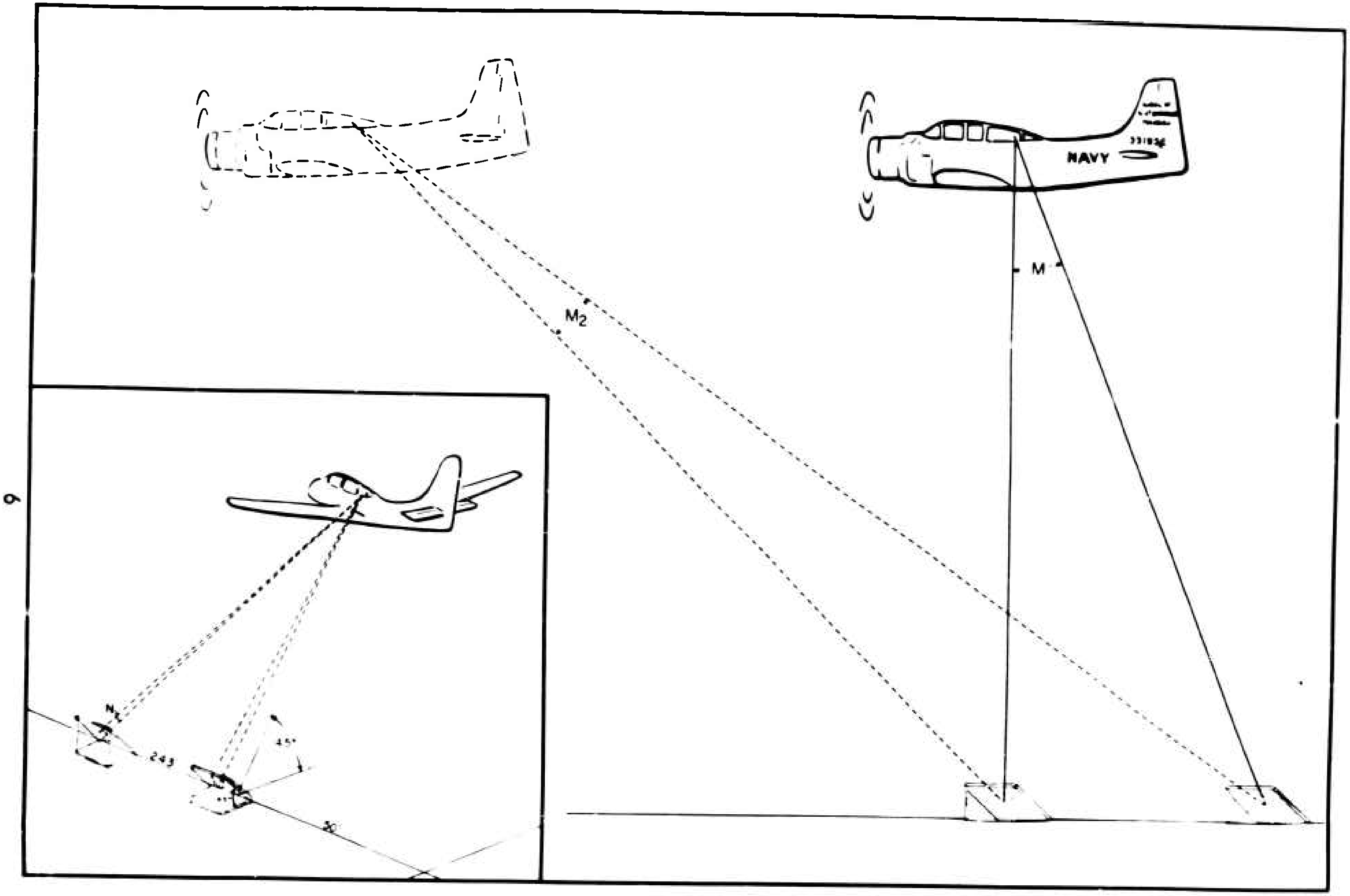

FIGURE 2

A SCHEMA SHOWING POSITIONS OF AIRCRAFT RELATIVE TO TARGETS

In the air, the target sizes not only change with deceleration, but they change differentially according to whether they are positioned vertically or horizontally.*This difference is, of course, maximal at the higher speeds (lower altitudes), and very slight at the lowest speed. A chi-square statistic was computed to test the difference between proportionate incorrect responses for vertically versus horizontally positioned targets at the highest angular velocity, and this difference was found to be far from significant.

After the determination of the thresholds in the air, a series of thresholds was obtained on the ground for the same subjects. The laboratory experiments were conducted either on the same day as those in the air or the day following. In the laboratory, the static acuity was determined using the Snellen chart. Following this, the dynamic acuity was determined at five angular velocities (20, 50, 75, 95, and 110°/sec) using only one target at a time. The experimental procedure for this method has been described previously (4). Then, using the same five angular velocities, thresholds were determined using two targets. In this instance the angular separation of the two targets was 4 degrees and 25 minutes. The testing distance was in both instances 4 meters. The apparatus utilized to move the targets was a rotating mirror, and, again, exposure time was 0.4 seconds.

RESULTS AND DISCUSSION

Figure 3 presents curves of mean threshold scores obtained for the three methods. The curve for the one target method is similar to the curves obtained by Ludvigh and Miller using a much larger sample (4). This curve takes the form $Y = a + bx^3$ in which $\underline{Y}$ is the visual acuity in minutes of arc, $\underline{x}$ is the angular velocity in degrees per second, and $\underline{a}$ and $\underline{b}$ are parameters determined by the method of least squares. However, it can be seen that the data for the two target methods take a linear form ($Y = a + bx$). Thus, it is demonstrated that the deterioration of acuity occurs more rapidly at the lower velocities and less rapidly at the higher velocities with the two target methods than with the one target method. This probably is because the major factor here is the complexity of the target rather than the speed. The rate of deterioration for two targets, however, seems to remain constant, whereas it begins to increase markedly at the higher speeds when only one target is used. Since, in the laboratory, we assume that the greatest, if not the only difference between the one target and the two target methods is the complexity of the targets, we would expect this difference in rate of deterioration to be reflected in the proportionate number of incorrect responses for first versus second detail in the two target method. Table II presents chi-square tests for differences between the number of incorrect responses to the first and second detail. These differences were found to be

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*The target sizes given in Table I refer only to vertically positioned targets.

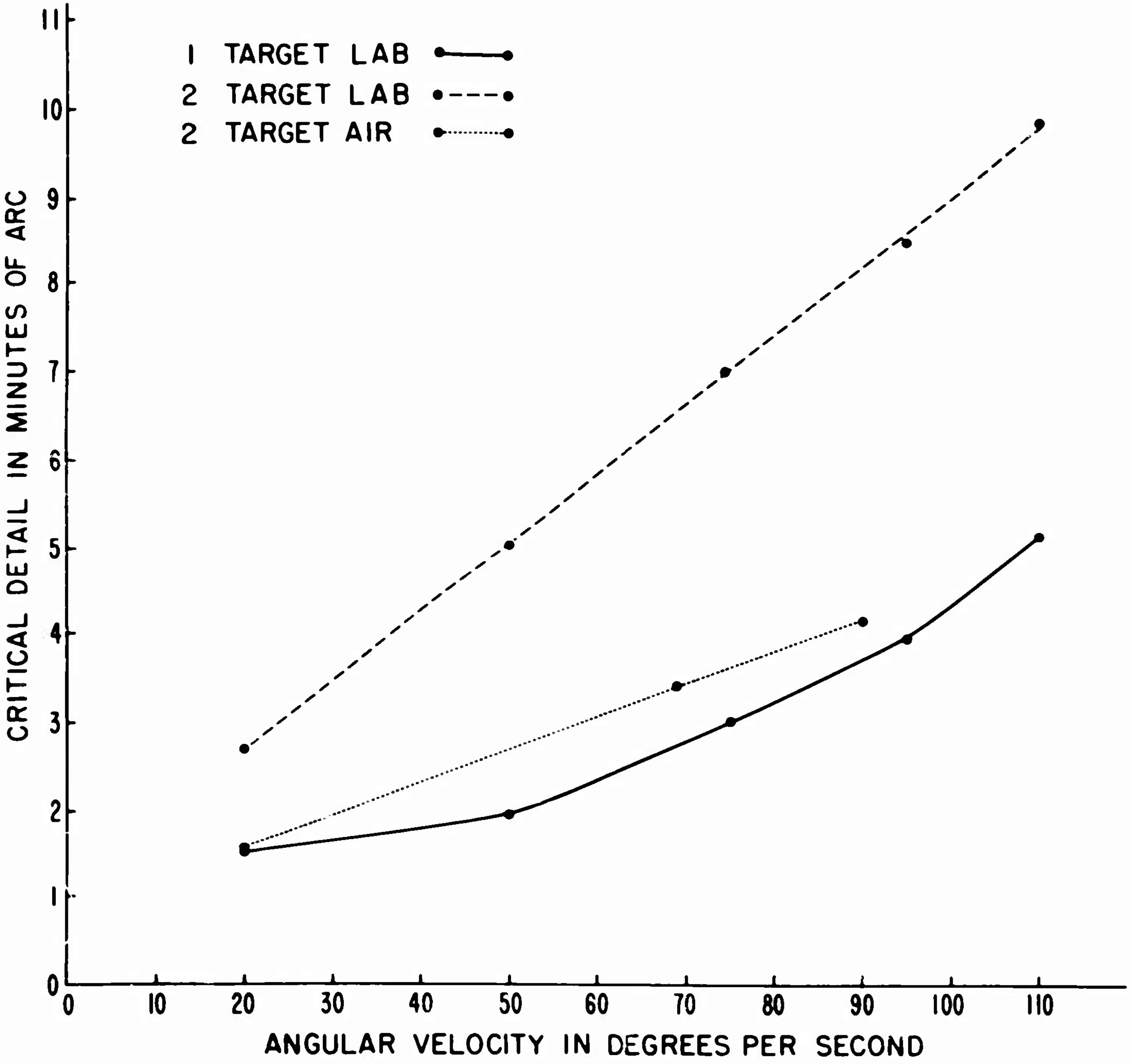

FIGURE 3

MEAN THRESHOLDS FOR 3 METHODS OF TESTING DYNAMIC VISUAL ACUITY insignificant for the in-air method; however, they followed the anticipated pattern for the two target laboratory data. For the 20,50, and 75 degree per second conditions the accuracy for the first detail was greater than for the second above the .01 level of significance with a trend toward increasing as the speeds increased. Then, at 95 degrees per second, the significance dropped to the .05 level, and, at 110 degrees per second, the difference was not significant. Although details of the complex targets are separated by a constant angular distance for all speeds, the temporal distance becomes less as the speeds increase. It may be , then, that although the speed becomes a crucial hindrance in both methods at about 75 degrees per second, it also becomes beneficial when two details are used in that it brings them temporally closer together. This is not to say that acuity begins to get better; rather that it continues to get worse at a constant rate as opposed to the increasing rate in the case of the one target method.

Table II

Chi-Square Tests for Differences in Incorrect Responses on Second vs First Target

	20°/sec	50°/sec	75°/sec	95°/sec	110°/sec	Total
2 Targets Lab	15.70***	18.05***	25.20***	6.79**	1.17	5.43**
2 Targets Air	2.57		.47	.41		2.74*

*** .01 level of significance
** .05 level of significance
* .10 level of significance

Product-moment correlations were computed between all speeds in all methods. The resulting matrix is presented in Table III. None of the speeds in the in-air method correlated significantly with any speeds in the other methods. The one target laboratory method seemed to be significantly related to the two target laboratory methods at the lower three speeds, but not at the higher two. The reliability coefficients (in parentheses) were computed using the Hoyt analysis of variance method (2). These coefficients indicate that although there are factors operating in the air which seem to be absent in the laboratory, they are highly reliable. These factors may be contributed by one or a combination of the elements peculiar to the flying situation. In considering possible contributing factors, however, we should remember that the mean threshold curve for the two target air method shows considerably better acuities in general as well as a smaller rate of deterioration than does the two target laboratory method. While we must not expect to compare the results between air and laboratory methods in absolute terms, it would still seem that the influential factors unique to the air method serve in a helpful, rather than a detrimental role. Deceleration is likely the greatest source of variance unique to the in-air method.

In considering the role of anxiety toward flight in dynamic acuity, we must draw heavily upon two assumptions: that air sickness is strongly related to this anxiety, and that vomitting is an equitable criterion of this sickness. Three subjects met this criterion. A Mann-Whitney U test (6) showed the differences between the sick and not sick groups to be insignificant.

Analyses of variance were computed for subjects versus runs on each speed in each method (Table IV). These indicated that all conditions discriminated at the .001 level of significance among subjects. While learning took place at the higher three speeds in the one target method, there was no learning in either of the two target methods. However, subjects might have learned on the two target methods had they been given more practice.

Even though the data collected in the air in the present study were based on the perception and recognition of two Landolt C's, it must be remembered that this constitutes a simple configuration. In this instance the critical detail involved was easily defined as the size of the opening in the C's. However, as the object of search or recognition becomes more complex, it becomes increasingly difficult to define the visual requirements. Ludvigh determined the visual acuity necessary to recognize a human face. In this unpublished study the subject wore a patch over one eye, and a strong fogging lense was placed in front of the other eye. The strength of the fogging lense was gradually reduced until the subject could barely identify the faces of familiar girls. The visual acuity of the subject was then determined, using a standard eye chart, with the subject looking through that fogging lense. In this manner it was possible to determine the acuity needed to recognize the faces. This technique could well be used to determine the visual acuity necessary for recognition of other complex configurations. In planning a high speed, low level type mission, for example, photographs might be taken of areas resembling check points to be used on the mission, and the technique described above used to determine the acuity needed for identification. If it were known that the check points on a particular mission required a given acuity for recognition, one could hardly expect the pilot to navigate successfully this mission when his dynamic acuity is less than that required.

Table III

Product-Moment Correlations Between Conditions

		1 Target Lab - Method 1 L					2 Target Lab - Method 2 L					2 Targets Air - Method 2 A		
		20°/sec	50°/sec	75°/sec	95°/sec	110°/sec	20°/sec	50°/sec	75°/sec	95°/sec	110°/sec	20°/sec	75°/sec	95°/sec
1 L	20°/sec	(.90)	.67**	.64**	.68**	.68**	.73**	.46	.52*	.31	.46	.16	.02	.38
	50°/sec		(.93)	.92**	.90**	.89**	.65**	.46	.66**	.31	.56*	.10	.14	.36
	75°/sec			(.92)	.97**	.93**	.65**	.44	.64**	.13	.49	.24	.18	.37
	95°/sec				(.95)	.93**	.67**	.51*	.69**	.15	.47	.26	.15	.47
	110°/sec					(.96)	.72**	.59*	.68**	.17	.54*	.20	.03	.40
2 L	20°/sec						(.85)	.46	.51*	.44	.59*	.20	.01	.41
	50°/sec							(.76)	.74**	.39	.44	.43	.23	.33
	75°/sec								(.88)	.54*	.62**	.28	.21	.21
	95°/sec									(.87)	.54*	.21	-.04	.02
	110°/sec										(.79)	.00	-.22	.07
2 A	20°/sec											(.99)	.59*	.60*
	75°/sec												(.93)	.46
	95°/sec													(.95)

** .01 level of significance
* .05 level of significance

Table IV

F-Ratios for Subject X Run Analysis

		20°/sec	50°/sec	75°/sec	95°/sec	110°/sec
1 Target Lab	Between Subjects	9.57**	14.02**	15.10**	18.34**	26.69**
	Between Runs	.37	.79	12.10**	11.10**	5.22*
2 Targets Lab	Between Subjects	6.35**	4.10**	8.11**	7.97**	4.82**
	Between Runs	2.20	1.03	.75	1.06	.72
2 Targets Air	Between Subjects	61.45**		14.79**	19.98**	
	Between Runs	.35		1.90	1.32	

** .001 level of significance
* .01 level of significance

In summary, then, we would make the following points:

1. Visual acuity deteriorates in the air with increased target speeds in much the same manner as it does in the laboratory when similar targets are used.

2. The rate of deterioration in acuity, when using two targets, seems to take a linear form over the range of speeds used as opposed to the curvilinear form taken when one target is used.

3. Deceleration of target speeds has a marked effect on performance of a visual tracking task because of both the change in speeds and the resulting change in configuration of the target. The effect appears to be beneficial.

4. Physiological factors peculiar to the flight conditions either did not affect performance, or else acted in a consistent manner.

5. Anxiety toward flight, as measured by proneness to become air sick, did not have an effect on performance of the task.

6. All three methods used for testing dynamic acuity discriminated among subjects significantly at all speeds.

7. While there was considerable learning in the one target method, no learning took place when the more complex target was used.

REFERENCES

1. Adler, F. H., Physiology of the Eye, Clinical Application. St. Louis: C. V. Mosby Co., 1950, p. 394.

2. Hoyt, C., Test reliability estimated by analysis of variance. Psychomet., 6: 153-160, 1941.

3. Ludvigh, E. J., and Miller, J. W., A study of dynamic visual acuity. Joint Project NM 17 01 99 Subtask 2, Report No. 1, Pensacola, Fla.: Kresge Eye Institute and Naval School of Aviation Medicine, 1953.

4. Ludvigh, E. J., and Miller, J. W., Study of visual acuity during the ocular pursuit of moving test objects: I. Introduction. Jr. Opt. Soc. Amer., 48: 799-802, 1958.

5. Miller, J. W., Study of visual acuity during the ocular pursuit of moving test objects: II. Effects of direction of movement, relative movement, and illumination. Jr. Opt. Soc. Amer., 48: 803-808, 1958.

6. Mann, H. B., and Whitney, D. R., On a test of whether one of two random variables is statistically larger than the other. Annals Math. Stat., 18: 50-60, 1947.