EFFECTS OF IMAGE DISTANCE AND SEAT INCLINATION ON THE LINE-OF-SIGHT ANGLE

by

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(ABSTRACT)

The line-of-sight angle (LOSA) was investigated for a simple tracking task. The distance from the eyes of the subject to the image was varied through the use of optical lenses. The subject was seated in a chair with 5 different back angles: 90 degrees, 111.6 degrees, 135 degrees, 158.5 degrees, and 177.1 degrees. No significant difference in the selection of LOSA was found between image distances of .5 meters, 1 meter, 2 meters, and infinity. The subjects' selection of LOSA was affected by the change in seat inclination angles.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I: INTRODUCTION

PURPOSE

Simply observing the side of a worker at a desk or a pilot at the controls shows that usually both the head and the eyes are rotated downward from the horizon. This combined angle of rotation is known as the line of sight angle (LOSA). Quantifying the amount of rotation is important when considering the placement of instrumentation and images for optimal viewing. When considering helmet mounted displays (HMD), the head rotation is unimportant since the helmet and displays move with the head; only eye rotation needs to be considered.

In her dissertation, Hill (1988) recommends not a single LOSA, but a range of angles that change with viewing distance and seat position. To make a recommendation for the HMDs, further research is needed to better define these angles. This experiment expands on Hill's work and attempts to define the relationship between chair back angle and image distance and LOSA.

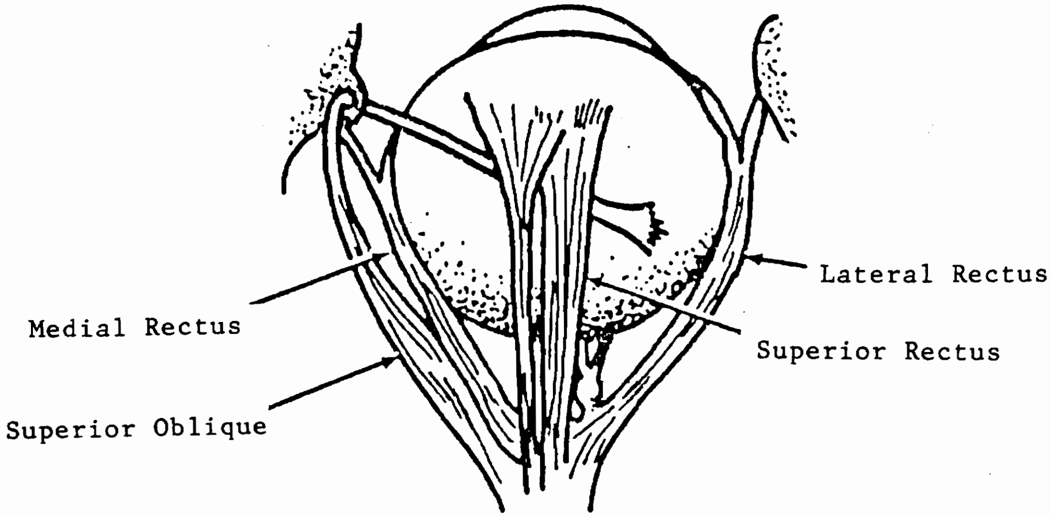
REVIEW OF LITERATURE

Ocular Muscles

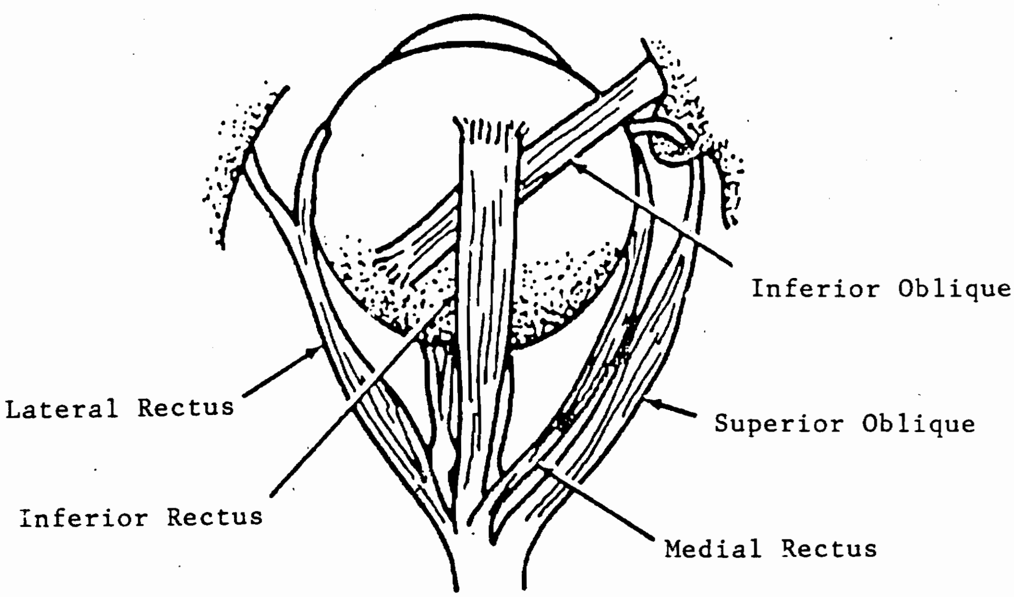
Six extra-ocular striated muscles are attached to the outside of the orbit controlling its movements. These muscles the medial (internal) and lateral (external) recti, superior and inferior recti, and superior and inferior oblique muscles (see figure 1).

The largest of the extra-occular muscles is the medial rectus muscle which, when paired with the lateral rectus muscle, provides adduction and abduction (yaw) of the eyes. When the eye is pitched downward, these two muscles act to further rotate the globe in addition to providing horizontal movements. Likewise, when the eye is pitched upwards these muscles act to further rotate the globe upwards.

The superior and inferior recti muscles are primarily responsible for eye rotations in the sagittal plane (pitch). Due to their angled line of action (23 to 25 degrees from the vertical plane through the line of sight when the eyes are in the straightforward position), they also provide some secondary torsional movements (roll).



View from above



View from below

FIGURE 1

Extra-Occular Muscles for the Right Eye

Whereas the four recti muscles originate in a common ring-shaped tendon at the apex of the orbit (annulus of Zinn), the oblique muscles effectively originate at the anterior medial corners of the orbit. When the eye is in a straightforward position, the obliques have a line of action of about 55 degrees with respect to the line of sight. As a result, the oblique muscles primarily provide torsional movement. However, when the globe is rotated horizontally, the oblique muscles control secondary pitch and yaw movements (Alpern, 1962; Carpenter, 1977).

The current study is concerned with pitch movements of the eye; therefore the primary muscles involved are the superior and inferior recti muscles. However, the remaining two muscles groups also contribute to the vertical movement.

Line of Sight

The line-of-sight angle (LOSA) is the angle at the eye between a line drawn from the eye to the center of an object and the horizontal plane. A positive angle denotes a line of sight above the horizon and a negative angle denotes a line of sight below the horizon. Hill and Kroemer (1986) defined LOSAF as the angle between the Frankfurt Plane and the line of sight. The Frankfurt Plane is established by passing lines through the lowest points of the left and right orbits (eye sockets) and the right tragion (approximately the ear hole). This reference moves with the head, and allows measurements to be taken regardless of head or chair position.

Range of Motion

MIL-STD-1472D states that a "normal" line of sight for an upright worker is -15 degrees from the horizon. Further, the motion of the eye in the sagittal plane ranges from 40 degrees above the normal line to 20 degrees below the normal line. Switching to the horizon as a reference, the resulting occular range of motion is +25 degrees to -35 degrees from the horizon (see Figure 2).

Ripple (1952) found that the near and far point of vision varied as the eye pitched upward and downward. Studying only monocular vision, accommodation increased as the subjects looked below the horizon and decreased as the subjects looked above the horizon

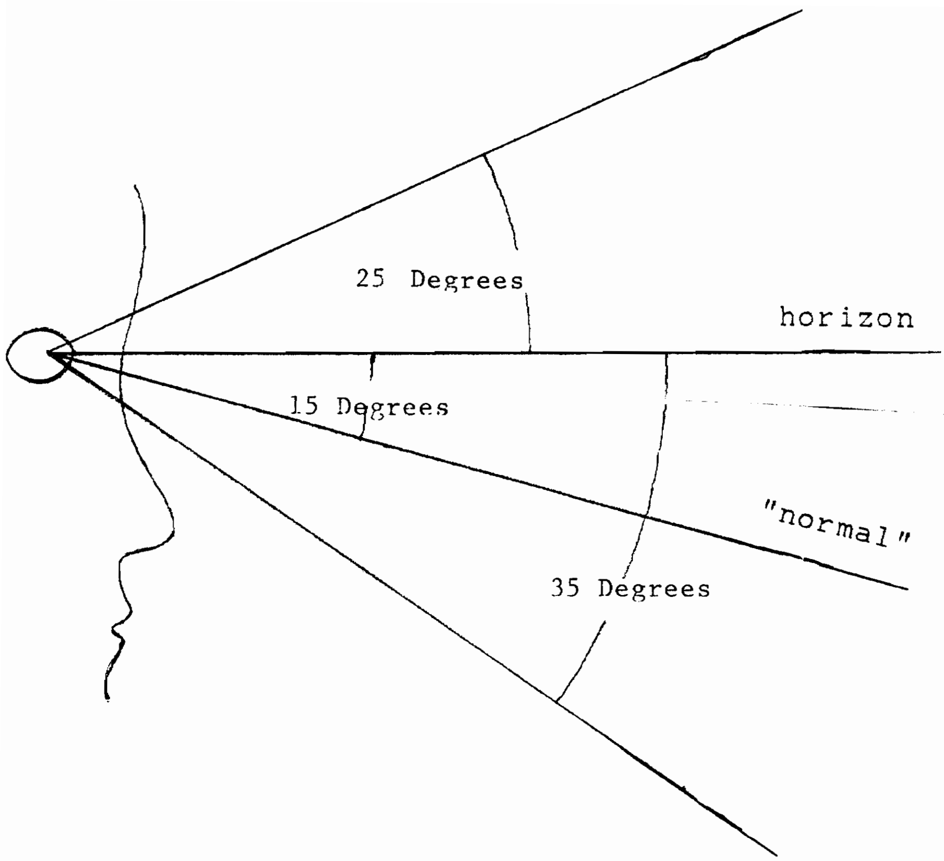


FIGURE 2

Line-of-Sight Angle

(9.42 diopters at 20 degrees above the horizon and 12.42 diopters at 40 degrees below the horizon). The same phenomenon was found with far vision; however, the change in accommodation was not as noticeable (1.50 diopters beyond infinity at 20 degrees above the horizon and .45 diopters before infinity at 40 degrees below the horizon).

Line of Sight Determination

Depending on the type of work and experimental set-up, estimations of line of sight range from 6 degrees to 65 degrees below the horizon for an upright seated worker (Konz, 1990; Povlotsky and Dubrovsky, 1988). Head rotation accounts for a portion of the angle and the remainder is due to eye rotation. Although the experimental part of this study is only concerned with eye rotation, the following discussion includes studies which examine both factors.

Eye Rotation

Hill and Kroemer (1986) examined the effects of 4 different head positions, 2 visual tasks, and 2 target distances on the LOSA (Kroemer and Hill, 1986). They found significant differences in the preferred LOSA due to head position and image distance. The angle flattened as the task display panel was moved from .5 meters to 1 meter (-37.6 degrees to -30.2 degrees, respectively). The smallest mean declination (-28.6) occurred when the subject was upright, and the largest declination (-40.3) occurred when the subject was supine. Since the angles were determined in relation to the head (Frankfurt Plane), these LOSAs were caused solely by eye rotation.

In her dissertation, Hill (1988) compared the LOSAs for 2 groups of women with mean ages of 20.2 and 44.8 years. The older group preferred a mean LOSA of -19.3 degrees over both seat angles, while the younger group preferred a mean LOSA of -13.3 degrees over both seat angles relative to the Frankfurt plane. The mean angle decreased as the backrest reclined (from 98 to 112 degrees). Table 1 provides a summary of Hill's and Kroemer's principal work.

Head and Eye Rotation

The following references all use the horizontal

TABLE 1

Summary of Research by Hill and Kroemer

IMAGE DISTANCE	BACK ANGLES 90	98	105	112	130	180
.5m	-32.8 HK		-38.1 HK		-36.4 HK	-43.3 HK
1m	-24.4 HK	-17.2 H	-31.0 HK	-15.4 H	-27.8 HK	-37.4 HK

HK: Hill and Kroemer, 1986
H: Hill, 1988

plane to determine the LOSA instead of the Frankfurt plane. Since the use of horizon does not rely on anatomical landmarks, the angle includes both eye rotation and head rotation.

Lehmann and Stier (1961) recommend a mean LOSA of -38 degrees (+/-6.3 standard deviations) from the horizon with the head tilted between -8 and -22 degrees (eyes rotated -14 to -30 degrees). These angles were determined by observing seated workers as they viewed architectural drawings. These values are close to the results of Hill's and Kroemer's experiment.

In a review of current literature, Stewart (1979) recommends a line of sight -35 to -40 degrees from the horizon for VDT use. Normal head slump and slightly downward gaze were included in this recommendation.

Chaffin (1973) found that tilting the head more than -30 degrees "greatly increases" neck extensor fatigue rates for young healthy females. However, over a 6 hour period, a head angle of -15 degrees produced no EMG changes or discomfort. No attempt was made in these experiments to examine eye rotation.

Grandjean, Hunting, and Nishiyama (1984) found that VDT operators preferred viewing angles that were between -4 degrees to -14 degrees.

Ruhmann (1984) assessed posture and subjective evaluations of workers seated at adjustable VDT work-stations. He reports the "normal line of sight" to be -25 to -35 degrees below the horizon.

CHAPTER II: METHODS

Subjects

Since the specific purpose of the present study was to gain information to be used in the design of helmet mounted displays to be worn by male fighter pilots, 10 male subjects were used. Their ages ranged from 19 to 25 years, with the mean age being 21.3 years. To ensure that they had Snellen 20/20 near and far vision, all subjects were tested prior to the experiment on the Bausch and Lomb Orthorater. Subjects were also questioned to screen for diabetes or other medical problems that could affect eyesight.

The subjects' sitting eye height ranged from 71.8 cm to 83.9 cm with a mean of 78.8 cm. This corresponds to a range of 1st percentile to 82nd percentile, with the mean sitting eye height at approximately the 25th percentile for 1967 USAF flight personnel (NASA, 1978).

Apparatus

Chamber. The experiments were conducted in a specially built chamber. The ceiling and front surface of the chamber were curved with a radius of curvature of 1.75 meters. To remove external visual cues (e.g. horizontal lines and corners), the curved surface was textured with plaster and painted white. Light pens were mounted at the center of the curvature on the wall to the subject's left. To the subject's right, a window was cut in the wall and a transparent grid marking the center of the chamber's curvature was placed over the opening and used in positioning the subject. During the experiment, the chamber was dark except for 2 red lights (25 watts) used by the experimenter to collect and record subject data. For safety, a fluorescent light in the chamber was turned on whenever the subject was required to enter or leave the chamber.

Chair. A barber-type chair was modified for use in this experiment. The head rest was removed and replaced with a single metal bar to which the helmet could be attached. The range of the chair back was extended so that it pivoted from 90 degrees (upright) to almost 180 degrees (supine). The chair could be positioned at 90, 111.6, 135, 158.5, and 177.1 degrees. To keep the eyes at the same height in the experimental chamber, 4 wooden platforms were built to be placed beneath the chair when the back angle was changed. The platforms were 17.5, 12.5, 4, and 2 inches high (see Figure 3). In addition to the platforms, the chair could be raised or lowered approximately 6 inches using its built-in hydraulic lift feature.

Light pens and movement tracking system. Two light pens were mounted on a pivoting platform on the chamber wall at the center of curvature. One light, acting as the target, was controlled by a step motor that moved the light horizontally by seemingly random increments. The second light was controlled by the subject through a push-pull cable connected to the controls. The filaments in the lightbulbs were arrow-shaped. Both lights were mounted on a platform that could rotate through 360 degrees. This rotation could be controlled by the experimenter in setting the pre-

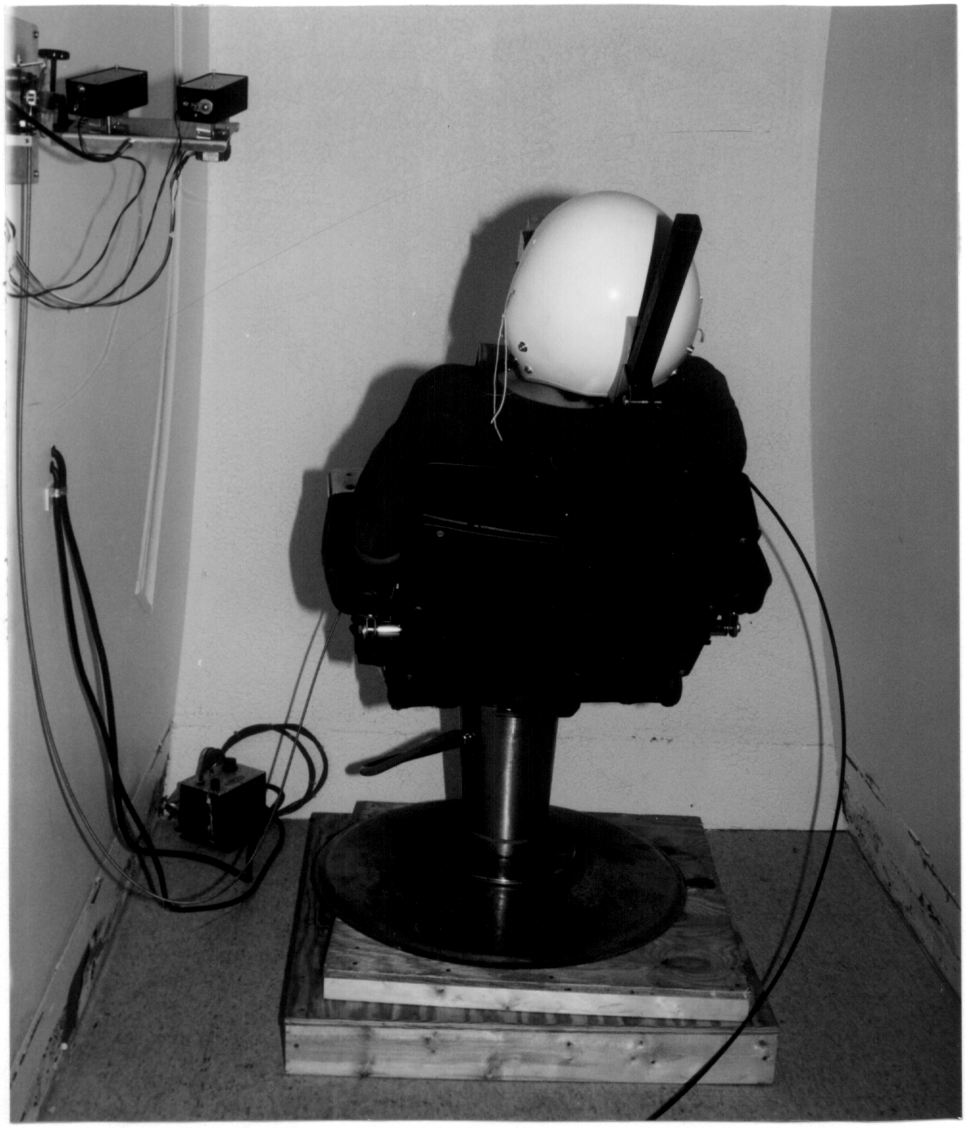


FIGURE 3

LOSA Test Chamber

set image location or by the subject in positioning the lights to the preferred LOSA. A protractor was attached to the platform so that the experimenter could read the selected LOSA (see Figure 4).

The light pen angle and tracking task were controlled by the subject. The subject set the angle of the light pen platform by either pushing or pulling a T-handle attached to a push-pull cable. To keep the platform from slipping during the tracking task, the T-handle could be locked into place by turning the handle clockwise. To unlock, the T-handle was turned counter-clockwise. The horizontal tracking movement was controlled by moving a joystick back and forth. The joystick, like the T-handle, was connected to the light pen by a push-pull cable.

Helmet and lens system. An Air Force pilot's helmet was modified to hold the lenses. The front visor was removed and replaced with metal mounts to hold the lenses. A bracket was fastened to the back of the helmet to attach the helmet to the metal bar on the headrest of the chair thereby holding the head in place (see Figure 5).

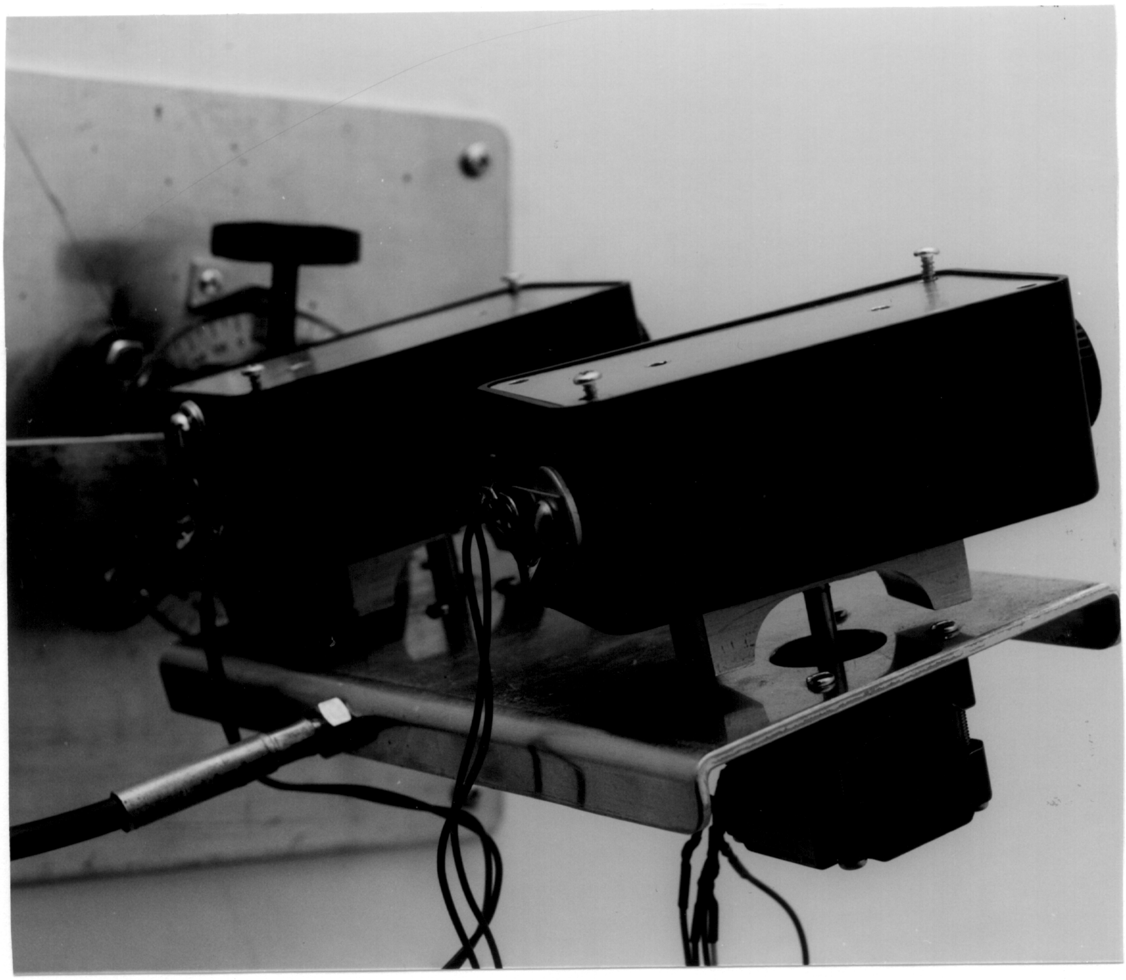


FIGURE 4

Light Pen Equipment

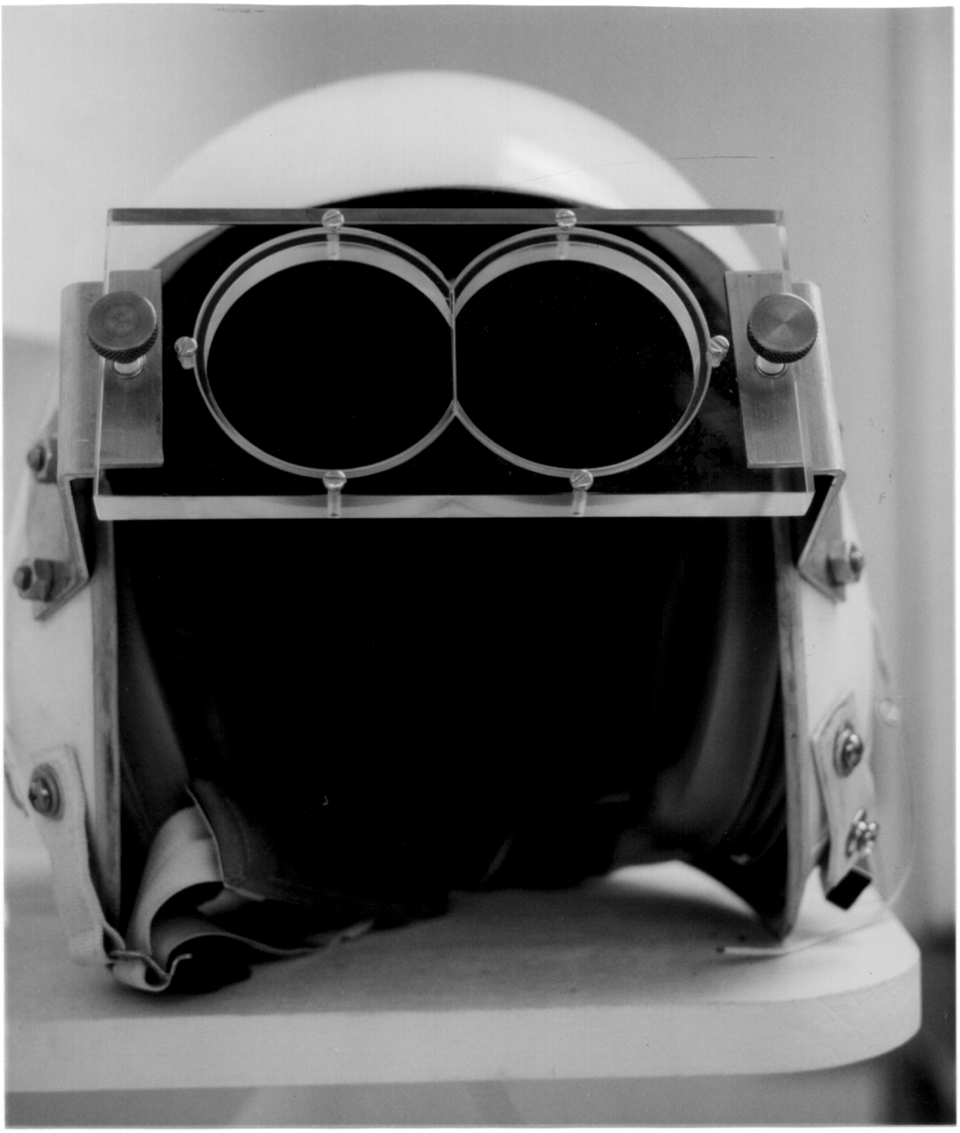


FIGURE 5

Helmet and Lens for LOSA Experiment

Pairs of lenses were mounted in a plexiglass frame. The lenses were 6.5 cm in height and 6.0 cm in width, allowing the eyes a pitch of approximately 60 degrees. Two of the lenses were planar-convex and ground to focal lengths of 1.75 and 14.29 meters. The remaining 2 pairs of lenses were planar-concave and were ground to focal lengths of -2.33 and -.699 meters. These lenses provided real image distances of infinity, 2 meters, 1 meter, and .5 meters respectively. See Appendix A for the optics equations.

Due to expense and difficulty in developing and grinding lenses that had the same subtended angle, it was decided that the subtended angle could be allowed to vary. Magnification of the image was approximately .29, .57, 1.14, and 11 times for the .5 meter, 1 meter, 2 meter, and infinite lenses respectively.

Procedure

Task. The subject was asked to perform two tasks. First, he was to set the light pens at a level that was preferable and comfortable for his eyes. Second, after the LOSA was selected, he was to track the moving light with the light that he controlled.

The subject was asked to keep the controllable light arrow aligned with the moving target. During each session, the subject performed these tasks 32 times.

Experimental Design

Independent variable. Only one independent variable was of interest in this experiment; that was the line-of-sight angle (LOSA).

Dependent variables. Four independent variables were controlled: chair position, image distance, preset image location, and trial.

The chair position variable had five levels: 90 degrees (upright), 111.6 degrees, 135 degrees, 158.5 degrees, and 177.1 degrees (supine).

The arrows from the light pens were projected as real images onto the curved chamber ceiling and wall. The images were viewed through planar-convex and planar-concave lenses so that they appeared to the subject at four distances: 0.5 meters, 1 meter, 2 meters, and infinite distance from the eyes.

Before the subject was allowed to adjust the lights to a position that he preferred, the lights were set to one of four "preset" locations. The locations were spread throughout 45 degrees at 10 degrees above, 5 degrees below, 20 degrees below, and 35 degrees below the Frankfurt plane of the subject.

Every combination of the independent variables was repeated once. This repetition allowed each subject's variability to be tested. The second trial followed immediately after the first and repeated the same ordering of variables.

<u>Ordering.</u> The chair position variable was blocked by days and was arranged in a partial Latin square design. Subjects were assigned to either the first week or the second week of testing. The order of treatments was held constant between the weeks. Within chair position, all image distances were presented. Their order was randomly assigned. Within image distance the preset image location order was also randomly assigned. This method of assignment is commonly known as a split-split plot design (Cochran and Cox, 1957) and was used in place of a full factorial due to difficulty in changing the experimental set-up. The image distance and preset image location

treatments were replicated once within each chair position (see Figure 6).

Protocol

Prior to the subjects' arrival, the chair was positioned at the proper height by using wooden platforms. The light pens were set to the initial preset image location and the controls were checked to make sure they were working properly.

On the first day, the subjects' eyesight was tested using the Orthorater to ensure 20/20 Snellen near and far acuity. The subjects were then given the consent form and instructions to read and sign (see Appendix B). The subjects' age and sitting eye height were recorded.

To begin the experiment, the subject put on the helmet and sat in the chair. The chair back was then pivoted to the testing position. The experimenter made sure the eyes were at the center of curvature by aligning the eyes and a mark on the transparent grid in the chamber wall. Fine height adjustments were made by lowering or raising the chair by employing its hydraulic lift feature. The helmet was fastened to

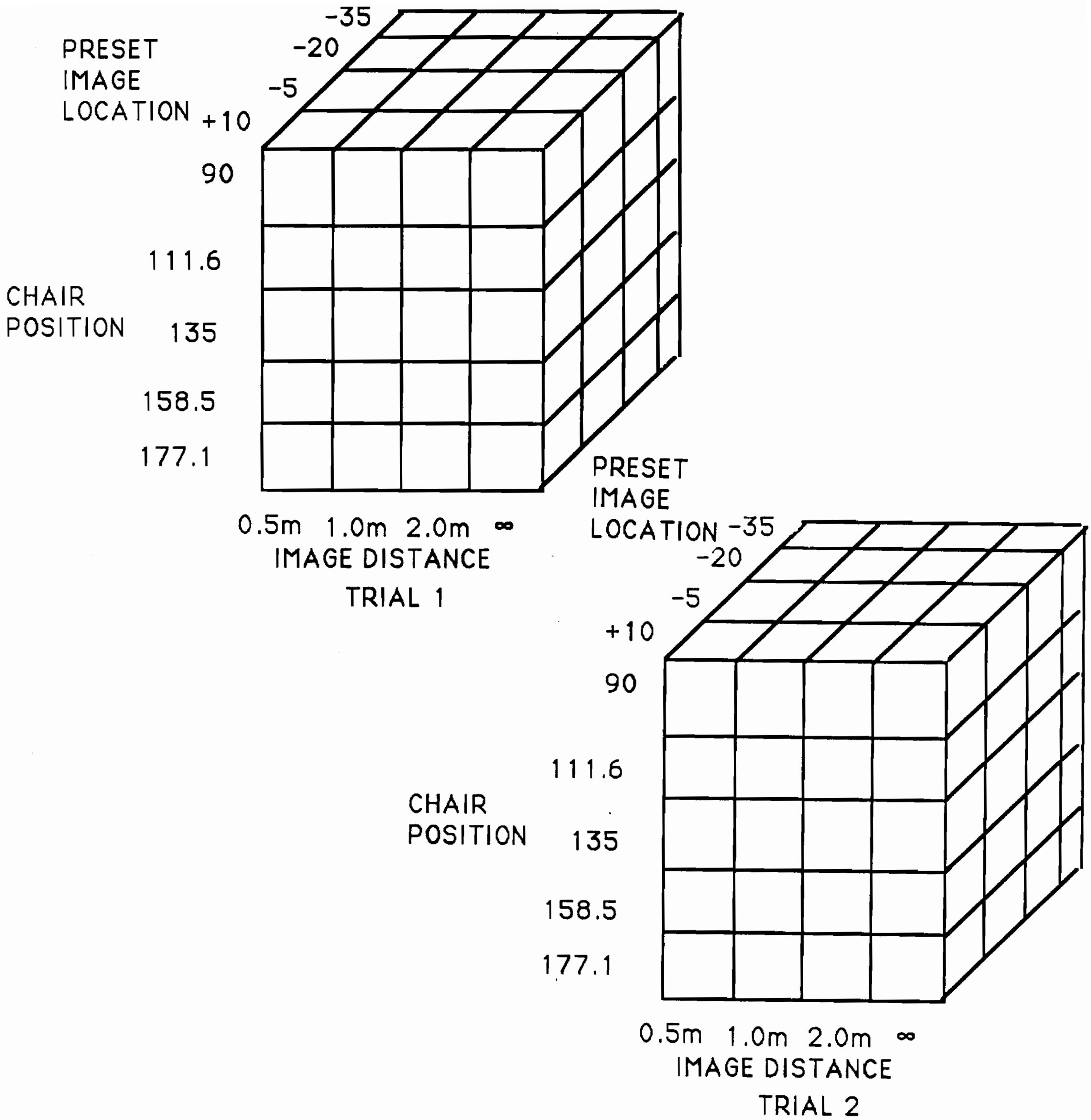


FIGURE 6

Experimental Design

the chair back. The first pair of lenses was attached to the helmet and the experimenter checked to make sure the subject's eyes were centered behind the lenses. The lights in the lab and chamber were turned off leaving a red light over the protractor connected to the light pen platform and the red light over the table where the experimenter recorded the data.

The controls were given to the subject, who was then reminded to adjust the lights to where they were "preferable and comfortable for the eyes" and then to track the moving light. The subject loosened the T-handle on the controls and either pushed or pulled the handle to set the light arrows to the preferred LOSA. After the subject was satisfied with the position of the lights, he tightened the T-handle to lock it in position. The experimenter then turned on the tracking task apparatus.

While the subject was tracking the moving light, the experimenter read the angle of the preferred LOSA with respect to the perpendicular of the chair back from the protractor attached to the light pen platform. In the upright chair position, this measurement corresponds with previous studies in which the LOSAs were measured with respect to the horizon. The LOSA was recorded in a notebook; the data were entered in the computer for analysis at a later time. The experimenter then turned off the tracking task mechanism and allowed the subject to relax. The light pens were set to the next preset image location and the subject began the process of adjusting the lights again. This procedure was followed for all four preset image locations and then the lenses were exchanged. In each session, the four lens pairs were used twice each with four preset image locations for 32 data points per session. (See Appendix C for the experimental schedule.)

When the subject finished the last tracking task, the lenses were removed from the helmet and the chamber lights were turned on. The helmet was loosened from the chair and the subject was allowed to sit up. The subject then removed the helmet and left the chair. The session took approximately 45 minutes.

CHAPTER III: RESULTS

ANOVA

The main effects of chair back position, image distance, preset image location and selected interactions were examined using an analysis of variance (ANOVA) procedure on SAS. Results of this analysis are summarized in Table 2. Higher order interactions were pooled to form the error terms. Chair back position and preset image location had significant effects on LOSA, while image distance and simple interactions among these measures were not found to be significant effects. The week, day within week, and subject factors also were found to have significant effect on LOSA. Effects of chair back position and preset image location are briefly discussed below.

Chair Position

According to a post-hoc Tukey analysis, the LOSA of the 90 degree chair back position was significantly different from all others except the LOSA associated

TABLE 2

ANOVA Summary Table

Source	df	MS	F	p
Week (WK)	1	3296.2	7.29	.0116
Day/WK	8	1061.1	2.35	.0453
Subject/WK	8	1963.2	4.34	.0017
Chair position (CP)	4	7363.6	16.29	.0001
Error 1	28	452.2	-	-
Image distance (ID)	3	20.3	1.23	.2997
CP * ID	12	21.6	1.31	.2184
Error 2	135	16.5	-	-
Preset image location (PL)	3	3072.5	70.92	.0001
ID * PL	9	10.4	0.24	.9886
CP * PL	12	29.6	0.68	.7688
PL * CP * ID	36	5.5	0.13	1.000
Error 3	540	43.3	-	-
Trial Error	800			
Total	1599			

with the 158.5 degree chair back positions (alpha = 0.05). The 111.6, 135, and 177.1 degree positions resulted in statistically the same LOSA, as did the 158.5 and 177.1 degree chair positions (see table 3). The means for the chair positions are shown in table 4 and graphically presented in figure 7. The mean LOSA varied from -0.5 degrees (chair back upright) to -11.94 degrees with no systematic effect of chair back angle apparent

Preset Image Location

A Tukey analysis was also preformed on the preset image location variable. Across all chair back positions the mean LOSAs were -4.04 degrees, -6.13 degrees, -8.95 degrees, and -10.18 degrees for preset locations of 10 degrees above, 5 degrees below, 20 degrees below, and 35 degrees below the subjects' Frankfurt Plane, respectively (see table 5 and figure 8). The effects on LOSA of the first 2 preset locations were not significantly different from each other; the same was true of the last 2 preset locations (see table 6).

TABLE 3

Tukey Table for Chair Position

	-0.46	-5.05	-7.59	-11.60	-11.94
-0.46			***	***	***
-5.05				***	***
-7.59					
-11.60					
-11.94					

*** Statistically different at alpha = .05
Minimum significant difference = 4.90

TABLE 4

LOSA means for Chair Position

CHAIR POSITION	LOSA MEANS	GROUPINGS		
90 Degrees	-0.5 Degrees	*		
158.5 Degrees	-5.0 Degrees	*	*	
177.1 Degrees	-7.6 Degrees		*	*
135 Degrees	-11.6 Degrees			*
111.6 Degrees	-11.9 Degrees			*

* Statistically the same LOSA

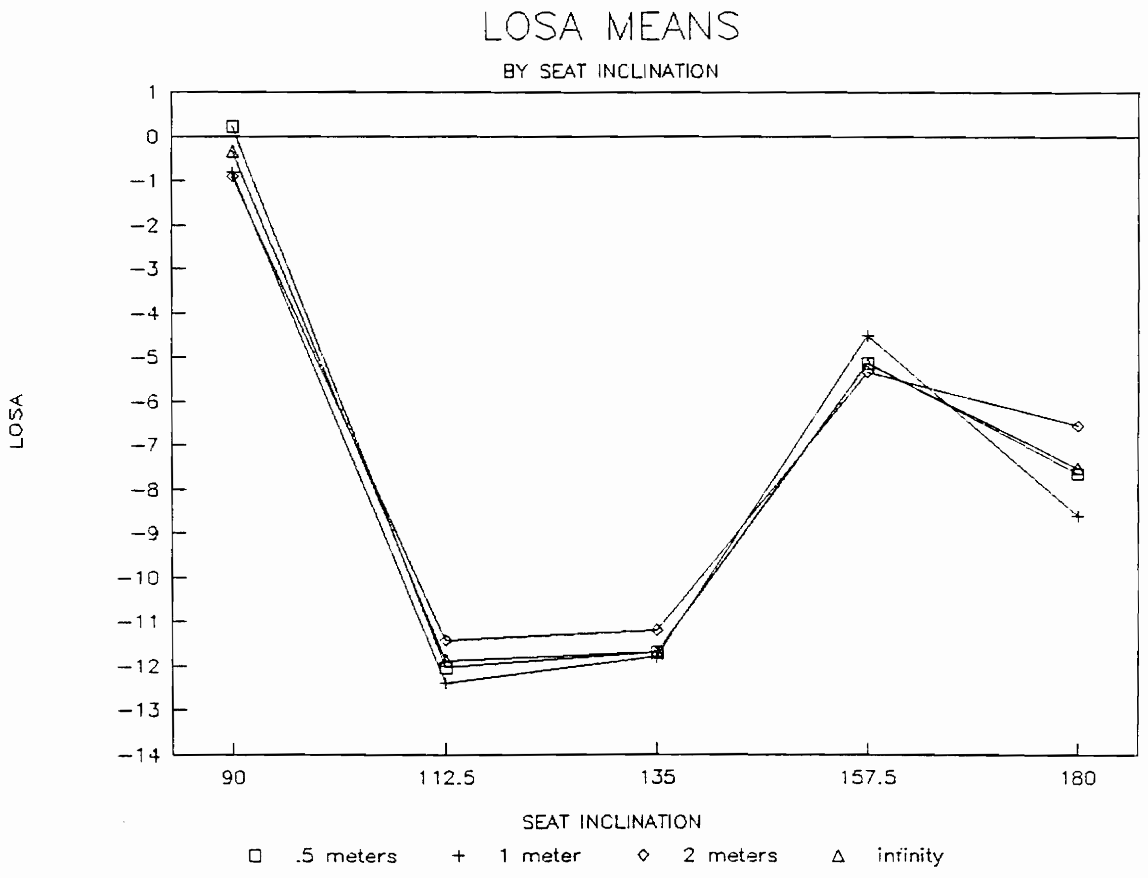


FIGURE 7

Graph of LOSAs by Seat Inclination

TABLE 5

LOSA means for Preset Image Locations

PRESET IMAGE LOCATIONS #	LOSA MEANS	GROUPINGS	
10 Degrees Above	-4.0 Degrees	*	
5 Degrees Below	-6.1 Degrees	*	
20 Degrees Below	-8.9 Degrees		*
35 Degrees Below	-10.2 Degrees		*

* Statistically the same LOSA
\# In reference to the subject's Frankfurt Plane

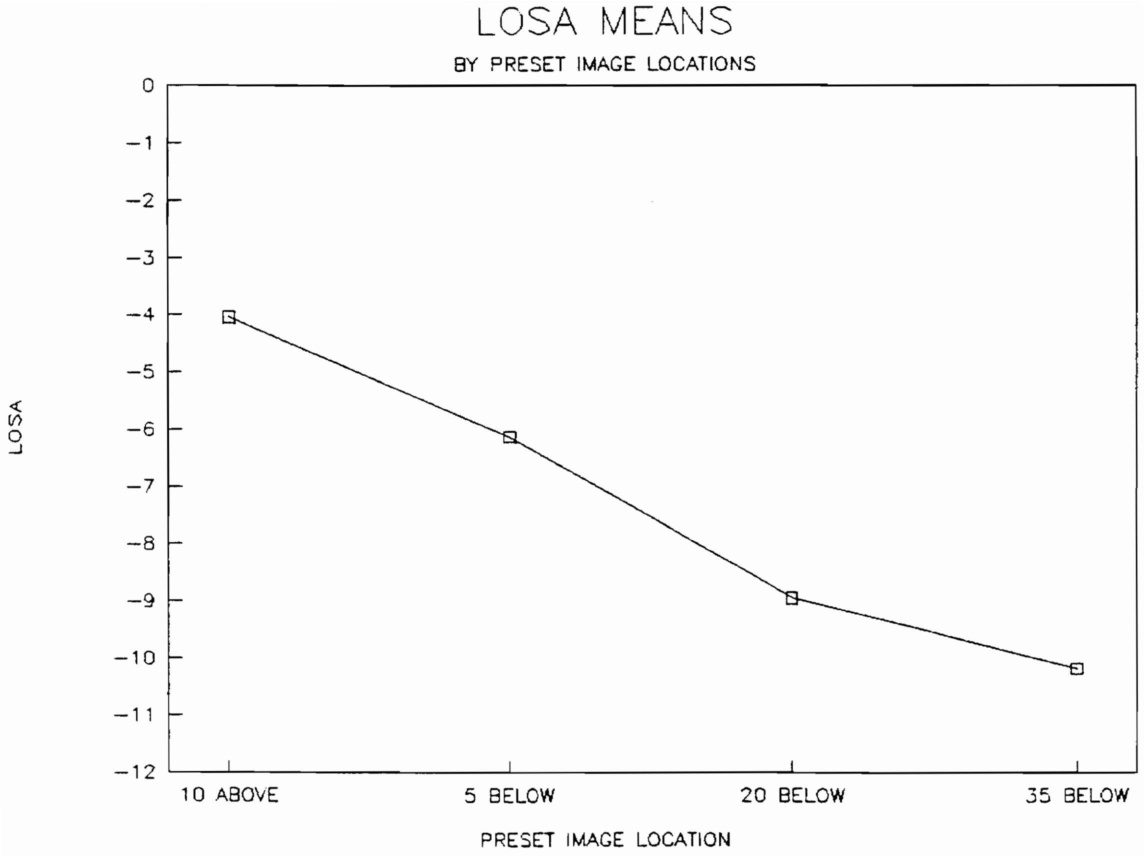


FIGURE 8

Graph of LOSAs by Preset Image Location

TABLE 6

Tukey Table for Preset Image Location

	-4.04	-6.13	-8.95	-10.18
-4.04			***	***
-6.13			***	***
-8.95				
-10.18				

*** Statistically different
Minimum significant difference = 2.28

CHAPTER IV: CONCLUSIONS AND DISCUSSIONS

Image Distance

Image distance did not have a significant effect on LOSA selection (at alpha = .05 and sigma = 1 and at 1/2, the power of test >> .99). This differs from the findings of Hill and Kroemer (1986). In that study, a paper display was positioned 0.5 and 1.0 meter from the eyes. In the current experiment, a real image was seen through lenses placed in front of the eyes. In the 1986 study, the subjects might have perceived the change in distance when the display was moved. However, the subject may not have noted the distance change with the lenses in the current experiment.

Another possible explanation for the differing results is that the tasks in the two experiments were very different. In the 1986 study, Landolt Rings and a proofreading task were used. Both tasks required the subject to focus intently on the CRT screen. In this experiment, the tracking task required less intensive focusing. In other words, the subject could complete the task with blurred vision. The occular muscles were not forced to bring the arrows into focus.

Some of the subjects did mention that when the lenses were exchanged the lights seemed to move closer or further away. This observation assures that the lenses did work for at least some of the subjects and that the distance change could be perceived.

It can be concluded that for this simple tracking task the image distance does not contribute to the selection of LOSA. However, on more complicated visual tasks, image distance might be a factor that needs to be considered.

Another explanation for the differing results could be that the subtended angle remained constant in Hills experiment but was allowed to vary in the current experiment. The magnification associated with the change in the subtended angle could have affected the subjects' perception of image distance. However, it is possible that the changes in magnification would only serve to accentuate the changes in image distance. Further research is needed to resolve this issue.

Day, Week, and Subject Variables

The day factor was expected to be significant since day acted as a blocking factor for chair position. The statistical significance of week and subject factors can be explained by individual preference differences in subjects. In examining the individual results, subjects 1 and 10 showed large deviations from the remainder of subjects particularly on the chair back angle of 158.5 degrees.

Trial (Errors within condition)

The exact replication of all variable combinations not only added to the amount of data collected, but allowed individual subject's variation to be examined. If a large variance occurred within the error term comprised solely of this replication, then the results could be suspect. It would have shown that the subjects, given the same experimental set-up did not select the same LOSAs. However, the ratio of the error term (df=800) to the final ANOVA error term (Day * Subject * Chair position * image distance * preset image location / week df=540) was 0.45 which is not significant at alpha =0.01 for a F-test. Therefore, the subjects did select approximately the same LOSAs when presented with an identical set-up.

Since the trial error was not significant, the two error terms could have been pooled to create a single error term with 1340 degrees of freedom. This was unnecessary, since any significant effects found using 540 degrees of freedom would also be found with 1340 degrees of freedom. The model with 540 degrees of freedom was more conservative and therefore was used.

Preset Image Location

Preset image location was found to have been a significant influence on the selection of LOSA. As stated by Hill (1988), starting position of the monitor used in her task was not a significant factor; however, her group comprised of the older subjects did select LOSA differently dependent on the initial placement of the display panel. Hill did not report the power of the test; therefore, the type II error is unknown for the starting position variable.

This effect shown in this study has two possible explanations. First, the mechanical connection between the T-handle and the light pen platform was stiff and difficult to use. This may have influenced the subject to make less adjustment in the level of lights then he would had the controls been easier to use. To alleviate the problem, the cable was oiled each day. Additionally, the subject was reminded that the experimenter could adjust the level of the platform if the subject did not feel he could do it. A second plausible explanation is that a range of angles is acceptable to some subjects instead of a single LOSA and they moved the lights only until they were within this range. Whether the lights were placed above or below their accepted range would have affected their selection of LOSA.

Chair Back Position

As expected, the chair back position variable had a statistically significant effect on the preferred LOSA. Since the head position was held constant in relation to the body and the chair back, only the occular muscles were affected as the chair back was pivoted. The superior and inferior recti muscles are the primary muscles affected by the sagittal movement required in selecting LOSA. The change in the direction of the gravitational pull due to changes in the chair back angle was likely to affect the occular muscles. However, since this experiment concentrated on the extrinsic effect of the muscles, more research is needed before the exact effect can be determined.

Kroemer and Hill (1986) found that the LOSA angle generally flattened as the chair back was pivoted from upright to supine. In the current experiment, such a trend was not as apparent; rather, the LOSAs formed a U-shaped curve when plotted by chair position. The greatest mean angle occurred at a back angle of 111.6 degrees and the smallest angle occurred at 90 degrees. Possible explanations for the contrary results are the different experimental set-ups and the use of lenses instead of a moveable display panel. The U-shaped curve of LOSA by chair position was fairly consistent for all subjects (see figures 9 and 10). Further research, particularly concerning the contributions of the extra-occular muscles, is needed to explain this phenomenon.

For all chair positions the LOSAs found by Hill (1988) and Kroemer and Hill (1986) are larger than the

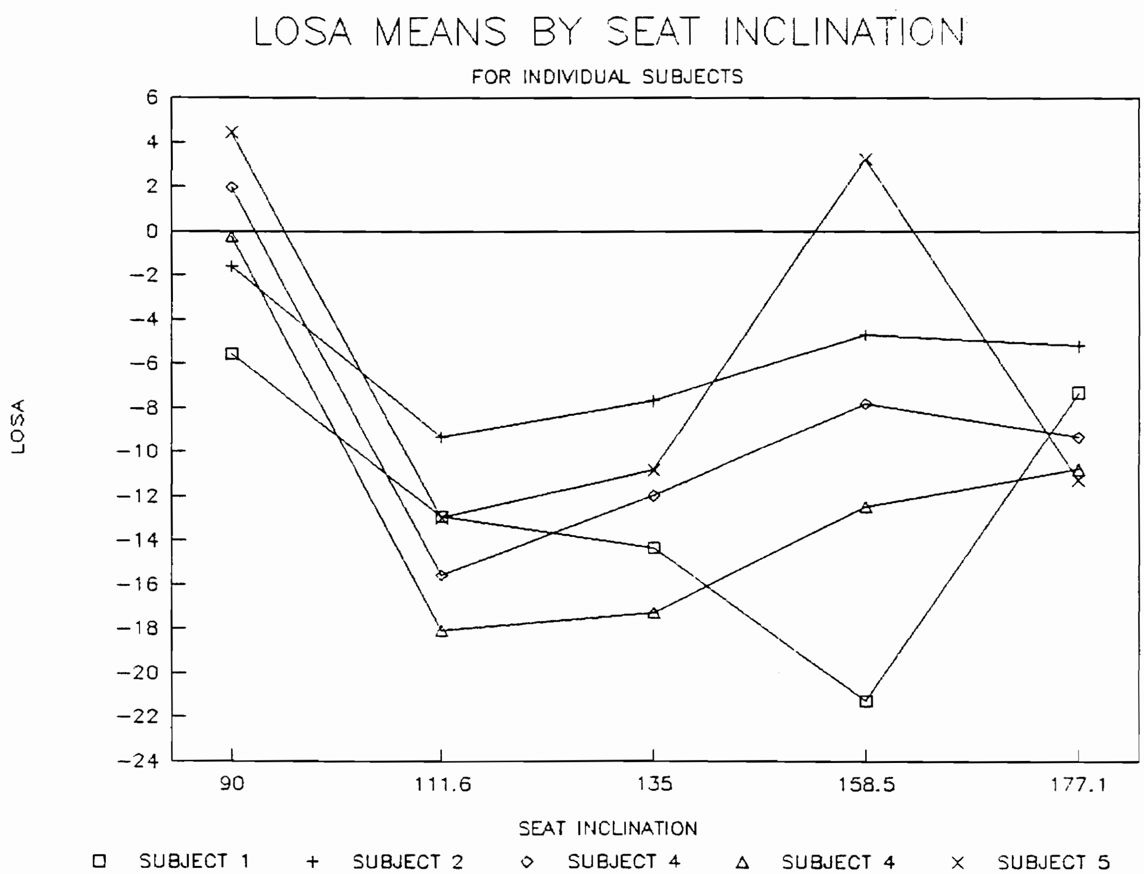


FIGURE 9

Graph of Week 1 Subjects' LOSA by Chair Position

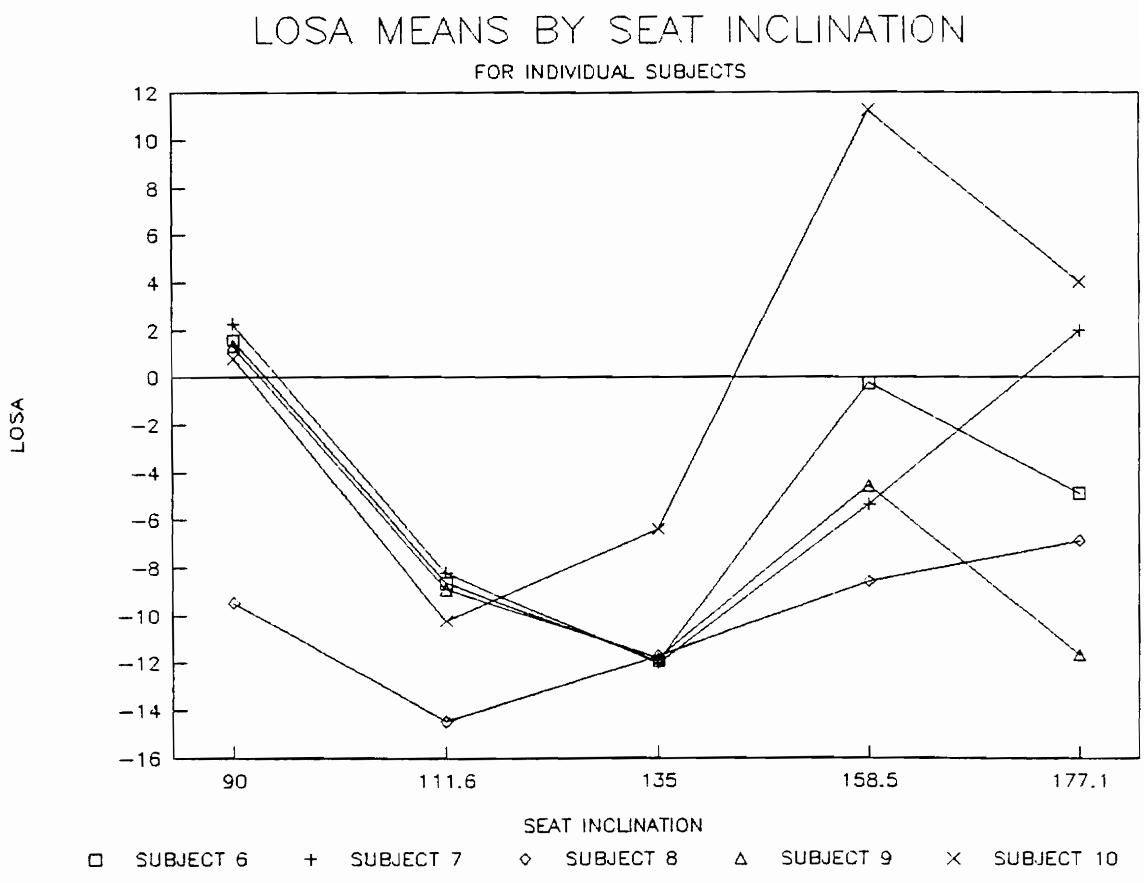


FIGURE 10

Graph of Week 2 Subjects' LOSA by Chair Position

LOSAs found in the current experiment. The previous experiments recorded LOSA with respect to the subject's Frankfurt plane; when the head is upright, the Frankfurt Plane coincides with the horizon. So at the 90 degree chair position, the current study, previous studies by Hill and Kroemer, and studies using the horizon as a reference can easily be compared (see table 7). The mean angle found in this experiment is flatter (closer to the horizon) than all other reported angles. As previously discussed, this could be due to the task or the use of lenses instead of physical images.

RECOMMENDATIONS FOR FURTHER WORK

To better understand the effect that gravity has on the selection of LOSA, studies of the activities of the occular muscles are needed. Since chair position has a significant effect on the preferred LOSA, it is logical to assume that gravity or any acceleration vector plays some role in the selection of the preferred LOSA.

Since it is unclear whether the use of optical lenses or the selection of the experimental task

TABLE 7

Comparison of Previous and Current Studies' Results

CHAIR BACK OR HEAD ANGLE	HILL*	HILL AND KROEMER*	MCMULLIN**
90		-28.6	-0.5
98	-17.2	-34.5	
105			
111.6			-11.9
112	-15.4		
130		-32.1	
135			-11.6
158.5			-5.0
177.1			-7.6
180		-40.3	

* Measured against the Frankfurt Plane
** Measured against the perpendicular of the chair back angle

explains the differences between this study and the previous work (Hill, 1988; Hill and Kroemer, 1986), further research is indicated. A more intricate visual task requiring that the eyes focus clearly should be used. Though theoretically the lenses should have altered the image distance, a question remains whether or not they are effective and accurate in providing data for helmet mounted displays.

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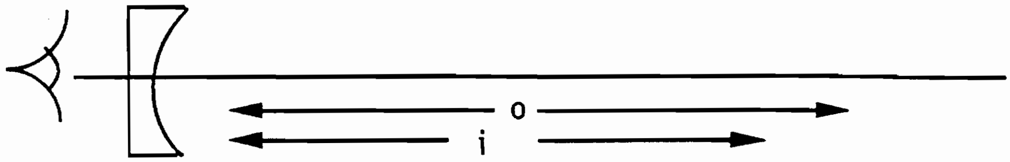
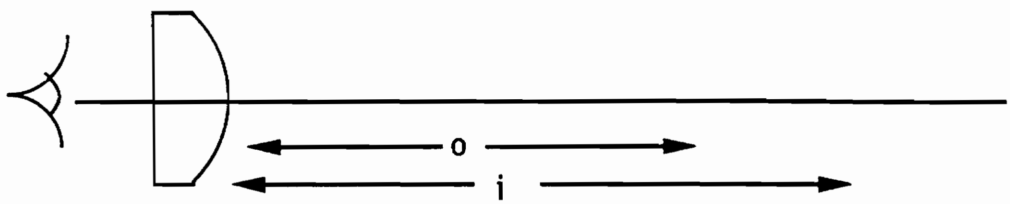
APPENDIX A

OPTICAL EQUATIONS





$$\frac{1}{i} + \frac{1}{o} = \frac{1}{f} \qquad \frac{r}{n-1} = fl$$

i = image distance
o = object distance
fl= focal length

r = radius of curvature
n = index of refraction

i=-0.5	o=1.75	fl=-0.70	r=-0.36
i=-1	o=1.75	fl=-2.33	r=-1.20
i=-2	o=1.75	fl=14.00	r= 7.24
i=infinity	o=1.75	fl=1.75	r= 0.90

Negative image distance since the image is on the same side as the object.

APPENDIX B

INSTRUCTIONS AND CONSENT FORM

CONSENT FORM

I, ____________________________ am participating in this research study because I want to. The decision to participate is completely voluntary on my part. No one has coerced or intimidated me to participate.

The experimenter has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are described in the attached "EXPERIMENT INSTRUCTIONS," which I have initialled.

I recognize the research team as Dianne McMullin (231-4882); and Dr. K.H.E. Kroemer, Principal Investigator (231-5677).

I understand that they will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the experimenter for this study may terminate my participation in this study if he or she feels this to be in my best interest. I may be required to undergo certain further examinations, if they are necessary for my health or well being.

I do not have diabetes or any disorder affecting the eyes, any disorders of my cardiovascular system, of my spinal column (particularly the neck), or any other disorders or deficiencies which make it inadvisable for me to participate in this experiment. I am not currently wearing contacts or any type of eye correction device.

I understand that in the case of physical injury no medical treatment or compensation are offered under the research program, or by VA Tech-VPI.

I understand that I shall receive payment in the amount of $5 per hour. However, I further understand that if I withdraw from the experiment before it is completed, I will be paid only for the time I actually spent performing in the experiment.

I understand that the results of my efforts will be recorded and that I may be photographed, filmed, or audio/videotaped. I consent to the use of this information for scientific or training purposes, and I understand that any records of my participation in this study may be disclosed only according to federal law, including the Federal Privacy Act, and its implementing regulations. This means that personal information will not be released to an unauthorized third party without my permission.

I understand that if I have any further questions about my rights as a participant, I may contact Dr. Ernest R. Stout, Chairman of the Institutional Review Board at VPI&SU, at 231-5281.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE UNDER THE CONDITIONS DESCRIBED ABOVE.

______________________________ Signature

____________________ Date

______________________________ Printed Name

____________________ Phone Number

____

______________________________ Address

EXPERIMENT INSTRUCTIONS

The purpose of this study is to gather information about the effect the chair back angle and the distance of an image has on the angle of the preferred line of sight angle. You will be expected to participate for five days (Monday-Friday) for approximately one hour each day. (Please contact the experimenter as soon as possible if you think you might miss an appointed session.)

In each session you will wear a helmet which is attached to the chair to keep your head still. At any time if you need to remove the helmet, unsnap the chin strap and slide your head out of the helmet. You will be asked to sit in a chair that will be adjusted from an upright position to a fully reclined position depending on the day. After you are comfortable, a pair of lenses, similar to eyeglasses, will be placed in front of your eyes.

To begin the task, turn the T-handle on the control board counterclockwise and either push or pull the handle to place the two light dots in a preferred, comfortable position. After the light dots are positioned where you prefer, turn the T-handle clockwise to lock in the position. Now use the lever on the back of the controls to track the moving light dot. This sequence will be repeated many times. Your job is to keep the light dot you control on top of the first randomly moving light dot.

If you have any questions, feel free to ask them now or at any time.

____
Initials

APPENDIX C

EXPERIMENTAL SCHEDULE

EXPERIMENTAL SCHEDULE

SUBJECT	MON	TUES	WED	THUR	FRI
	90	158.5	111.6	177.1	135
1 and 6	.5:3124	.5:1423	2:1243	.5:2413	2:3214
	1:4123	I:3214	I:4231	2:4132	I:2431
	I:1423	1:3124	1:4231	1:3241	.5:3124
	2:4132	2:1234	.5:4321	I:1324	1:2431
	158.5	90	135	111.6	177.1
2 and 7	2:3412	I:3214	I:1324	2:1243	I:1432
	.5:1243	2:1243	1:2341	.5:2341	1:4312
	I:1432	1:4123	.5:1243	I:2413	2:2413
	1:1423	.5:4123	2:1234	1:4132	.5:1234
	135	111.6	177.1	158.5	90
3 and 8	I:3124	.5:3412	1:2314	2:4231	1:3124
	2:2314	2:3142	I:4213	1:4231	.5:3412
	1:3412	I:4231	.5:2431	I:1423	2:3142
	.5:4321	1:2341	2:1243	.5:1342	I:2413
	111.6	177.1	90	135	158.5
4 and 9	I:4312	.5:3241	I:3241	1:1324	I:3124
	.5:3412	2:1432	1:2413	2:2431	.5:1324
	2:1243	I:3421	2:4132	I:1432	2:4231
	1:4321	1:2431	.5:1432	.5:3214	1:1324
	177.1	135	158.5	90	111.6
5 and 10	1:4213	.5:4321	.5:2431	.5:4132	2:4132
	2:3241	2:4321	I:1342	I:3412	1:2431
	.5:4231	I:4213	1:1243	1:4231	.5:4132
	I:3142	1:3214	2:2413	2:4231	I:3142

IMAGE DISTANCES
 I: INFINITY
.5: .5 METERS
 1: 1 METER
 2: 2 METERS

PRESET IMAGE LOCATIONS
 1: 10 DEGRESS ABOVE FRANKFURT PLANE
 2: 5 DEGREES BELOW FRANKFURT PLANE
 3: 20 DEGREES BELOW FRANKFURT PLANE
 4: 35 DEGREES BELOW FRANKFURT PLANE

VITA

Dianne Lynn McMullin was born on July 29, 1964. She completed her B.S. degree in Industrial Engineering at Iowa State Univerisity in December of 1986.

During undergraduate work, she was a cooperative education student at Yellow Freight System, Inc. After graduation, she worked as a management services analyst at American Mutual Life. She was involved in white collar productivity and task analysis and improvement.

In the fall of 1988, she started masters level work in human factors at Virginia Polytechnic Institute and State University. She was a teaching assistant in engineering economy and a research assistant in the industrial ergonomics lab.

Her future plans include doctoral work at the University of Nebraska in industrial ergonomics.

Dianne L McMullin