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GLARE RECOVERY OF A TWO DIMENSIONAL TRACKING TASK WITH RESPECT TO VARIOUS COLORS

DARCOM INTERN TRAINING CENTER

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GLARE RECOVERY OF A TWO DIMENSIONAL TRACKING TASK WITH RESPECT TO VARIOUS COLORS

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Final Report

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) significantly better than white, red, or orange-red filtered light when a glare was imposed.

FOREWORD

The research discussed in this report was accomplished as part of the Maintainability Engineering Program conducted jointly by DARCOM Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Army.

This report has been reviewed and is approved for release. For further information on this project contact Dr. Ronald C. Higgins, Chief of Maintenance Effectiveness, Red River Army Depot, Texarkana, Texas.

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For the Commander

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James L. Arnett, Director
Intern Training Center

ABSTRACT

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This report describes the results of research intended to determine the effect of variation in color on a two dimensional tracking task with superimposed glare flashes. The EAI 680 Analog Computer was the primary function generator with the EAI 600 Pacer digital computer performing control functions and data analysis. Tests on five subjects under four colors indicates that the blue filtered light was significantly better than white, red, or orange-red filtered light when a glare was imposed.

ACKNOWLEDGEMENTS

For serving as the chairman of my committee and offering many helpful suggestions, I extend my appreciation to Dr. R. S. Morris. For serving as members of my committee, I wish to thank Dr. J. M. Covan and Dr. W. L. Johnston. Gratitude is extended to Dr. R. W. Ferguson for his assistance in the experimental portion of this project. I would especially like to thank my fiance Kathy for the typing and editing of this work.

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CHAPTER I

STATEMENT OF PROBLEM

Since man first began to fly at night for any great distances, the incandescent red filtered lamp has been used to light the aircraft instruments. Until only recently has the method of aircraft instrument lighting changed any appreciable amount. Most aircraft now use an electroluminescent lamp for the various secondary information displays, while the incandescent red filtered lamp is used for the primary instrument lighting system.

The electroluminescent sheets are excellent for use in various displays, however, they have the primary disadvantages of being susceptible to moisture and ineffective at high levels of ambient light. This was found by H. N. Renolds (17) in his study of electroluminescent lighting. The incandescent lamps, however, are still used as the primary instrument lighting system. These systems provide no redundancy; when an incandescent lamp fails completely. Whereas an electroluminescent lamp fails with gradually diminishing intensity. Also, the incandescent lamp will only provide a non-uniform lighting distribution across the face of the instrument, thus leaving dark areas in which a portion of the information vital to the pilot may be displayed.

An example of both incandescent lighting and of electroluminescent lighting systems can be seen in display shown in figure 1. The panel shown is a standard aircraft instrument panel used on a current U.S. Army aircraft.*
In some cases, a combination of both incandescent and electroluminescent systems are used. An example of the combined system is illustrated by the camera pulse control (see figure 1, number 24), in which the background lettering is illuminated by an electroluminescent lamp, and the pulse control button contains an incandescent lamp. As an example of a pure electroluminescent display see item number 19 on figure 1. The lighting of the primary instrumentation is by the red filtered lamps which are housed inside the lens caps of the light receptacles. These lens caps only allow light to be emitted in a small arc across the instrument face. An example of this type of illumination can be seen at the top two corners of the airspeed indicator (figure 1, number 26).

Though these two methods of lighting aircraft instruments have been in use for a period of time, little work

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* This figure was taken from the Gruman OV-1C Mohawk operators manual.

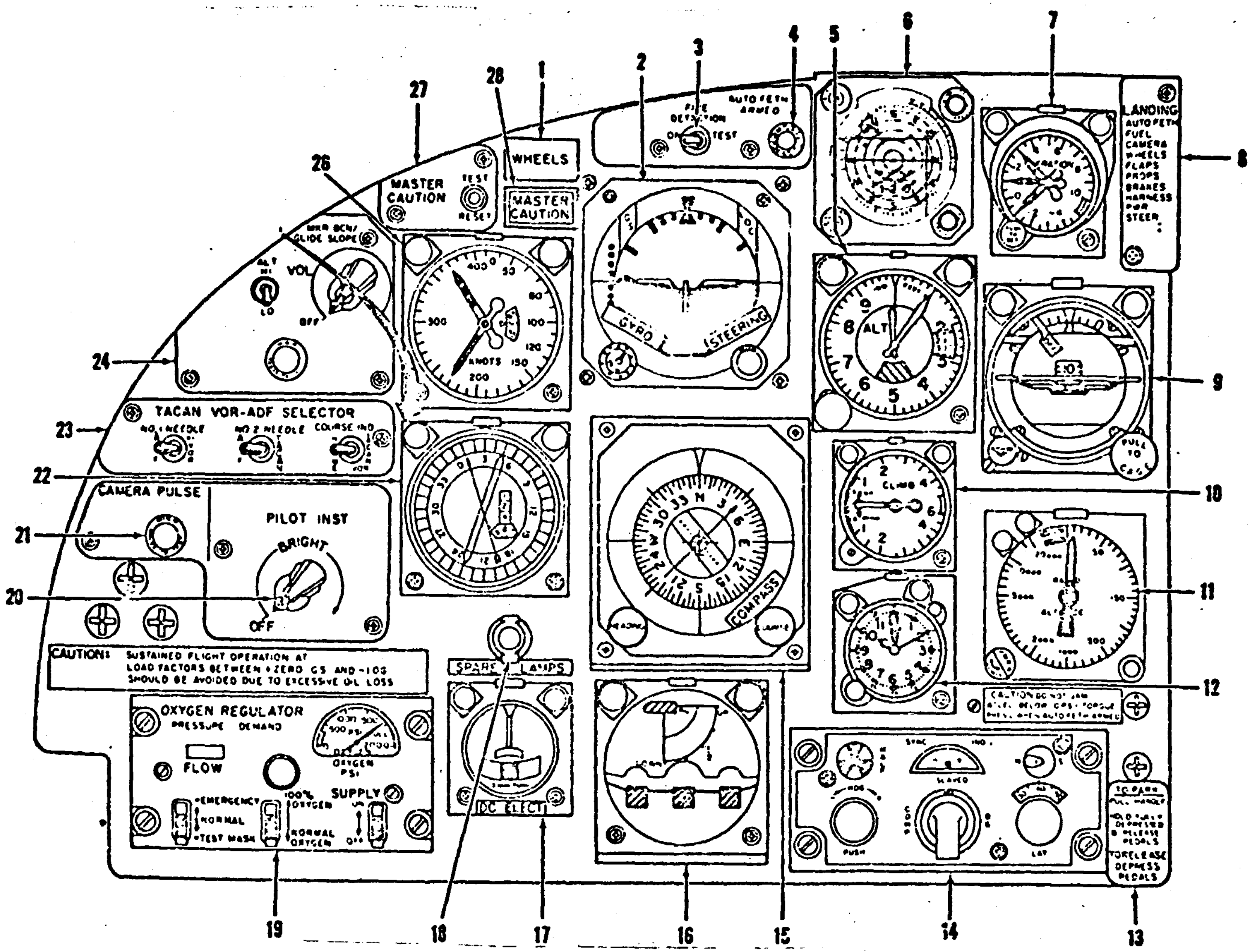

Figure 1. Pilot's Instrument Panel.

has been done on glare recovery with respect to the electroluminescent panels, or with either electroluminescent or incandescent lighting colors.

OBJECTIVES OF RESEARCH

The object of this research is to determine if the color of the instrument lighting system will affect the ability of a human to recover from a short duration glare and perform a two dimensional tracking task. The effect of the lighting color on the ability of a human to perform the tracking task can be divided into two separate areas of interest. These two areas are to determine if the effect of the instrument color 1) will correlate in some manner with the level or error produced between the reactions of the subject and the applied signal stimulus, and 2) the time required for the subject to return to his preglare level of accuracy.

It is with this basic, underlying idea that the equipment was developed and the experiment designed and conducted. The remainder of this paper will discuss the literature that was reviewed, the experimental design, the equipment that was developed, and the results of the experiment.

CHAPTER II

REVIEW OF PERTINENT LITERATURE

The Eye

The human eye is a small spherical body capable of transforming visual images, which have passed through the lens (shown in figure 2, number 19) and are projected on the rear of the retina, into impulses of energy. The impulses of energy are then passed along the nerves to the brain. The human eye itself is only about 24 mm in diameter and can be divided into seven separate areas. These seven areas are the cornea, the anterior chamber, the lens, the vitreous chamber, the retina, the optic nerve, and the fovia.

The cornea is the small portion of the eye which is transparent and which focuses the light image on the lens. The light image must then pass through the anterior chamber in order to reach the lens system. Contained in the anterior chamber is a transparent liquid fluid called the Aqueous Humor. The Aqueous Humor is thought by several persons to supply a portion of the oxygen to the cornea (13). The remainder of the oxygen to the cornea is supplied by the contact of the surrounding air. The Aqueous Humor is produced in the vitreous chamber, and is circulated to the

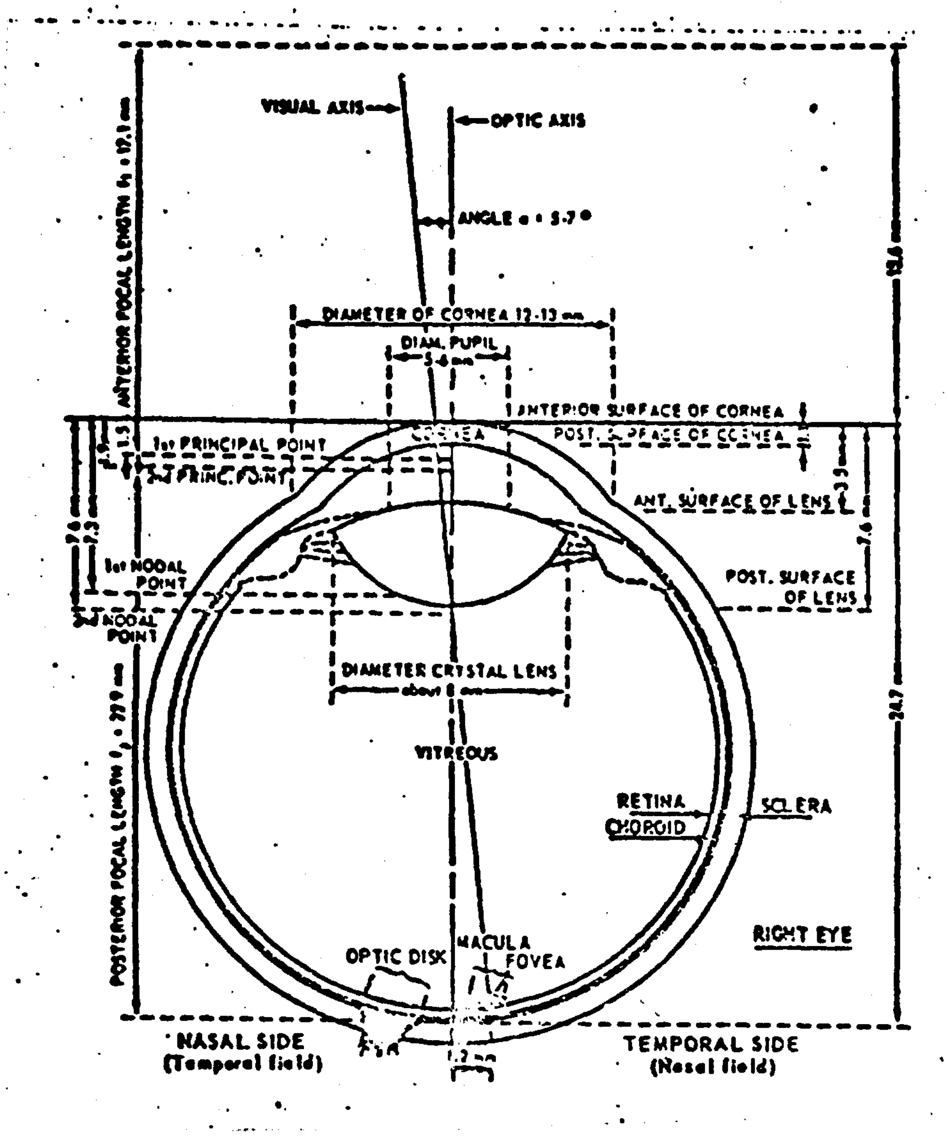

Figure 2. The human Eye.
(NASA, 1964).

anterior chamber through the lens supportive structure. The excess fluid in the anterior chamber is drained through a canal into the vascular system of the outside case of the eye. The exterior case of the eye is called the sclera.

The lens system of the eye is composed of a small, transparent, yellowish tinged crystalline material of complex bio-chemical structure. Yellowing of the lens will continue with age, and thus increase the light absorbtion and scattering by the lens. This yellowing causes a loss of visual acuity with age (12,18). Over the front of the lens is a heavily pigmented membrane which can contract or dilate to allow various amounts of light to enter the vitreous chamber. The lens is focused by slight variations in its shape accomplished by contractions of the ligaments which suspend the lens in the eye.

The retina, or the inner lining of the rear wall of the eye (as shown in figure 3, number 19), contains the rods and cones which are connected to the nerves. This allows the light images to be changed to neurological impulses. The retina is covered with a brown pigment, which reduces the internal optical scattering of the light and acts as a support for the rod and cone receptors in the eye. Figure 4 illustrates the variation in the horizontal distribution of the rods and cones across the eye. Table 1 gives the numerical population of the rods and cones in

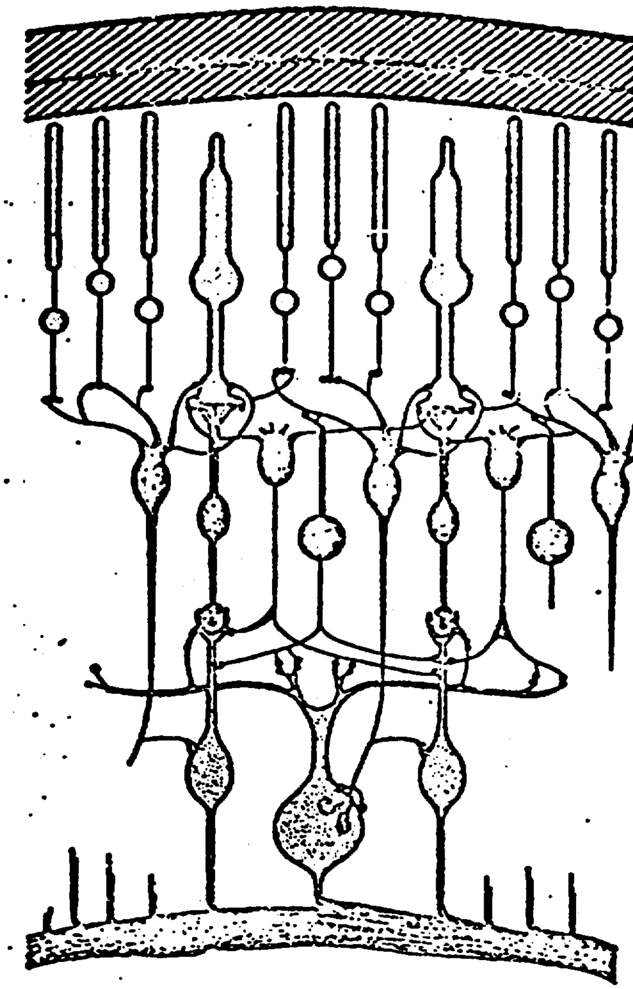

Figure 3. Plan of the Retina.
(NASA, 1964).

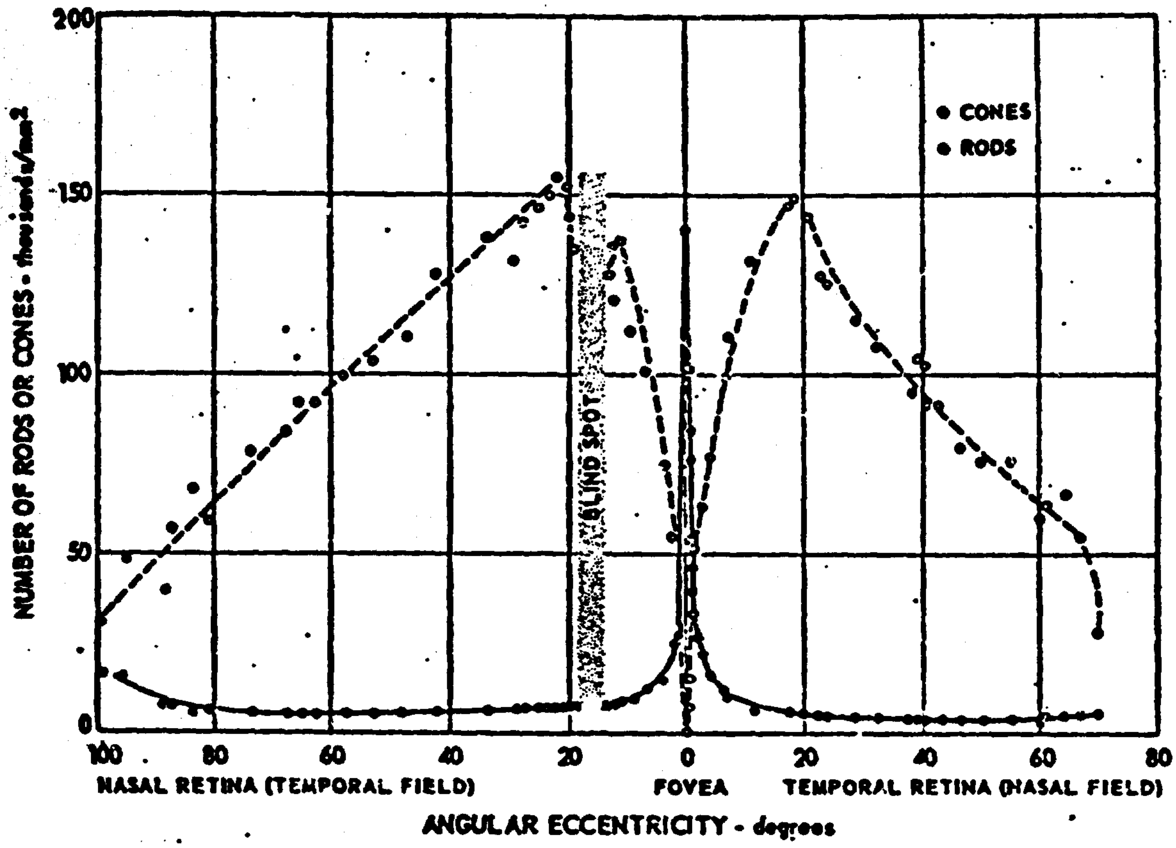

Figure 4. Centeral and Peripheral Vision. (NASA, 1964).

Angular Eccentricity	Population Rods/sq mm	Cones/ sq mm
degrees	thousands	
0.00	0	136.
0.25	0	84.4
0.50	7.22	57.5
1.00	34.2	41.3
5.00	88.	19.4
6.00	105.	12.1
10.00	118.	9.13
12.00	125.	7.64
12.50	126.	7.63
20.00	158.	7.08
30.00	140.	6.52
40.00	132.	5.95
50.00	108.	5.79
70.00	80.4	5.47
90.00	57.7	6.84

Table 1. Rod and Cone Populations. (NASA, 1964).

terms of angular eccentricity across the eye.

The basic, and most important, differences of the rods and cones are their susceptibility to variations in light wavelength and intensity. Hardesty and Projector (7), in their studies of cone to rod ratios, and Lazo (10), in his studies, found results which were quite similar. Figure 5 shows that the relative spectral luminous efficiency curves for scotopic (dark adapted) rod vision, and photopic cone vision vary only slightly. It should, however, be noted that these curves have the peaks normalized, and they show the relative sensitivity to radiant energy of different wavelengths. They do not give a value of the absolute difference in the sensitivity between the rods and the cones. This graph demonstrates the situation that Hardesty and Projector (7) studied, which is called the Purkinje Effect. The Purkinje Effect states that the spectral sensitivity of the dark adapted rods is greater for lower wavelengths of illumination that are the cones.

The actual composition of the chemical action which takes place in the rods and cones is quite complex. Basically as stated by Guyton (6), light enters the eye and strikes the receptors. At this time a photochemical change takes place. In this chemical change the rhodopsin changes to what is called lumi-rhodopsin, which then decomposes to a state called meta-rhodopsin. The meta-rhodopsin then

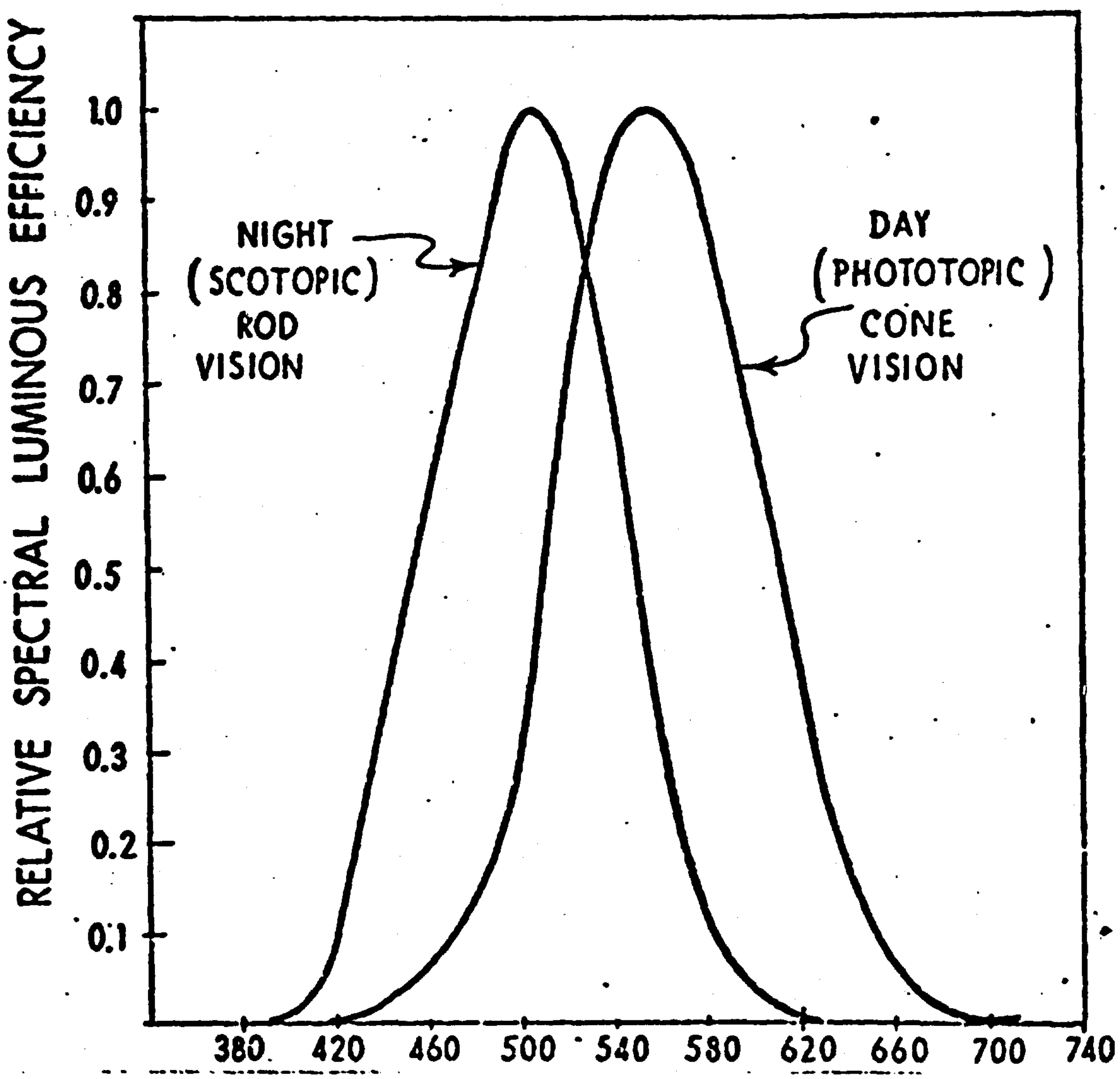

Figure 5. Night and Day Vision Efficiency.
(Naval Ship Laboratory, 1969).

decomposes to sctopsin, and then to retinene. When the retinene seperates from the scotopsin it is partially ionized, thus causing an electrical charge to be transmitted along the nerves to the brain. The time required for the complete chemical reaction to take place is called the flicker fusion and will only last about 0.1 second. An approach using a method similar to the flicker fusion was used for various experiments involving optimum flash rates by Markowitz (11), and by Goodwin and Smith (4).

Webb (19) states that in the optic nerve region there are no rods or cones present. This is the area of the eye in which the nerve endings go from the rear nasal side of the eye to the brain. More commonly, this region is called the blind spot. Its actual position is about 15 degrees to the nasal side of the center of the eye, and about 1.5 degrees below the horizontal meridian of the eye. The region is sometimes called the fovea.

The final and last portion of the eye that will be discussed is the macula lutea. In this region the largest number of cones are grouped together forming the major portion of the day light sensitivity of the eye. As seen from the distribution of the rods and cones in figure 4, page 9, this region is devoid of rods, which supply the scotopic vision when the luminescence level drops below .001 milli-lamberts (ml). When the luminescence level drops below the .001 ml level, this region becomes non reactive. Therefore, in order to see an object at night, it is necessary to look to the side of the object. This is stated by the U.S. Air Force (15) in several of their military courses. The night vision, as shown by figure 4, page 9, is greatly enhanced by looking approximately 20 degrees to the side of the object.

Interior Lighting Systems

Although aircraft instruments today are primarily lighted by red incandescent filtered lamps there is now a large group of people who believe that white instrument lighting should be used. This belief is due in general to the commercial and military high performance aircraft in which most of the flying that is done is solely under instruments. The only exception, it seems, to this rule is that of the slow flying fixed wing aircraft and the helicopter. In these cases the visual detection of other aircraft, ground obstructions, and of unlighted airfield night landings makes it necessary for the pilot to use his maximum scotopic or night vision.

In reports by Grether (5) and in a report by Jolly and Planet (9), it was pointed out that some U.S. Air Force aircraft during World War II were equiped with an ultraviolet lighting system. In this system the markings of the instruments were in a florescent coloring.

This allowed the aircraft cockpit to be continuously dark. The ultraviolet method however had several drawbacks 1) the instruments which were not treated with the florescence seemed to disappear, 2) pilots often reported the phenomenon of the instruments appearing to float in a black void, 3) pilot eye strain and headaches and 4) fogging of the pilots vision due to the ultraviolet light being reflected into the eyes. This method of instrument lighting was changed after World War II to that of primarly red light. However, as stated earlier in this report, red lighting usually results in an uneven distribution of lighting across the instrument face.

A point in favor of the white lighting system over the red system is discussed in reports by Greather and Renolds (5), by Lazo (10), and by Mercier and Whiteside (16) that visual acuity is greater with white lighted system, and will produce a more comfortable environment than will a red light system. Greather and Renolds found that by using a much lower filament temperature than was normally used that a white light system could be safely employed with only a slight increase in the dark adaption index for non-glare situations. In their report the dark adaption index was defined as the time required to adapt to a specified value of 90% of total dark adaption.

Another point which was discussed by Mercer and

Whiteside (16) was that in both civilian and in military aircraft the use of maximum dark adaption is less important at present due to the use of radar which can locate other aircraft long before the human eye is able to receive any image.

Color Temperatures

A consideration of the dark adaption index is also that of the color temperature. Figure 6 is taken from a report by Muick (14) and is a copy of the chromaticity diagram. This diagram shows the coordinates of the U.S. information color limits. In this diagram the color of the U.S. Air Force white light, which operates at approximately 2900° K, lies between the coordinates of (.420,.385) and (.460,.425). These two coordinates are that of the unfiltered white light and that of the blue filtered white light which Muick used in his study of aircraft instrument lighting systems.

In Greather and Renolds (5) report it was found that by testing the luminance levels in the mesopic range the red lighting increased the dark adaption threshold 48%, while the white lighting system increased the threshold 82%. It should also be noted that luminance levels are displayed on a log scale. The white lighting system used in this experiment used a military 28 volt system which was operated at a much lower voltage level than normal. The use of the

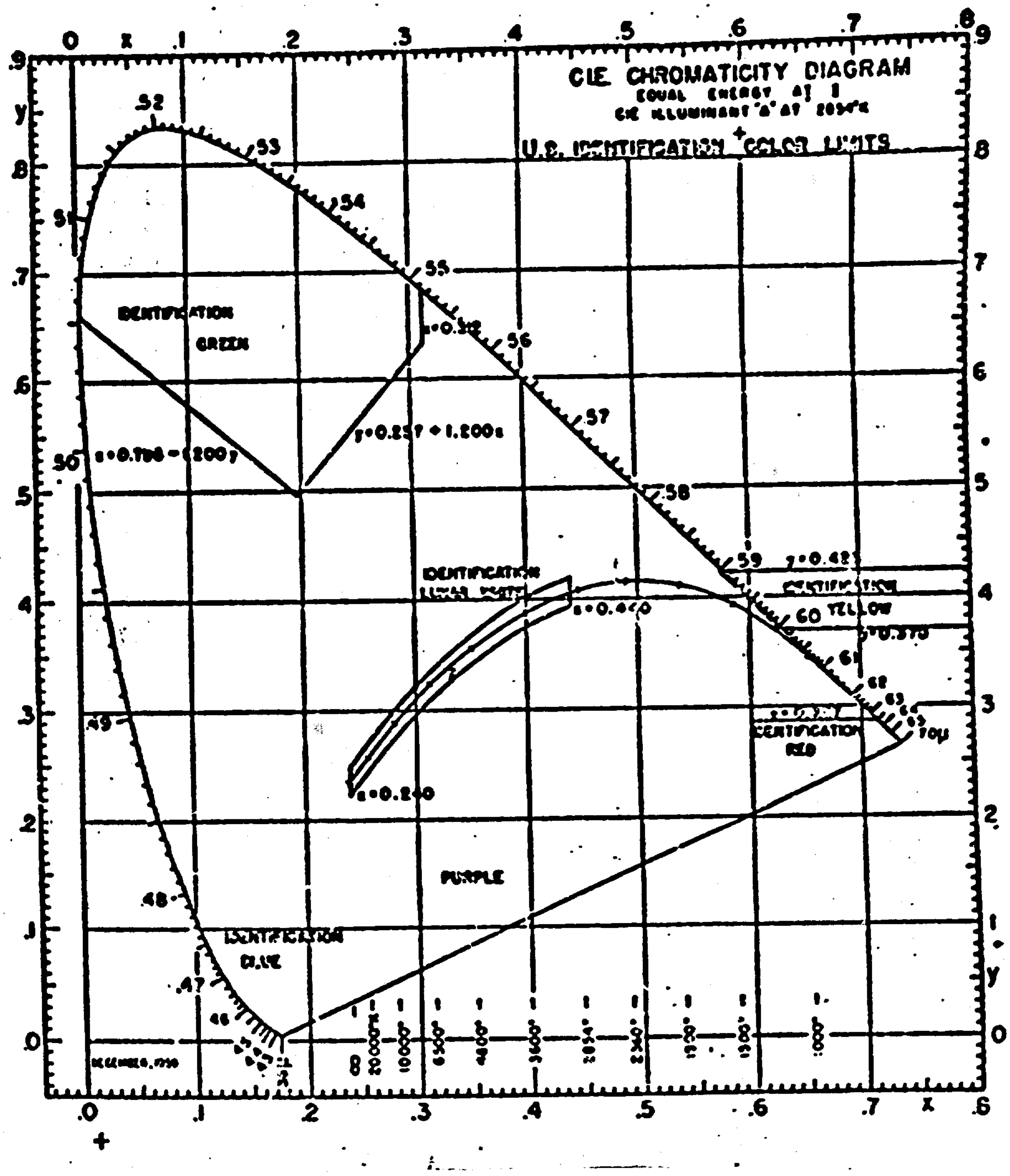

Figure 6. Chromaticity
Diagram.
(Muick, 1967).

lower voltage produced a color temperature which was below 1000° K. Similarly in the report by Lazo (10), it was found that the pure red light was better for the dark adaption index of the rods. Lazo also stated in his report that white light, which is produced by radiant energy from a tungsten filament includes all colors; while red light that is specified for aircraft use is in the range of light wavelengths above 600 nonometers, as shown in figure 7 (1). This would tend to explain the reason that an older instrument in which colors were fading seemed to produce a less uniform distribution of light across the instrument face. Under the narrow band red lighting system these variations in luminance are difficult for the rod receptors to discern due to the fact that the rod receptors are fairly insensitive to small variations in color. Similarly as the wavelength of the light increases to approximately 450 nonometer (7) the rods function is decreased and the cones become the primary visual receptors.

Glare and Glare Recovery

Glare is generally defined as a strong veiling light within the subjects field of vision. The actual amount of veiling produced depends basically on 1) the location of the light in the field of vision, 2) the intensity of the light observed at the eye, and 3) the ambient lighting conditions. As the glare illumination enters the eye the

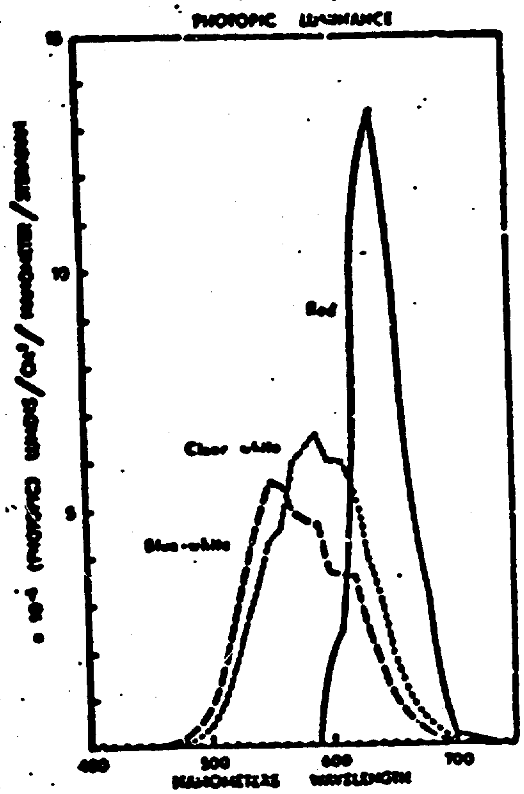

Figure 7. Light Energy
Distribution.
(Armstrong, 1961).

light will scatter according to a Raleigh distribution. The light focused on the retina will then cause the bleaching of the rods and cones and will begin the process described previously in this report on pages 14 and 15. The variations in glare recovery time when the ambient lighting conditions are high is easily explained due to the fact that under photopic or mesopic conditions there is less time required to allow the cones to regain their sensitivity to the variations in light. However in the case of the dark adapted subject, the amount of time to recover can vary.

There are basically two types of glare (or in the case of this study flash blindness) these being discomfort glare and disability glare. Disability glare can be defined as an excess amount of unwanted light entering the eye causing a partial loss of vision. Similarly discomfort glare can be defined as a larger amount of the unwanted light that enters the eye making adaption to any specific level difficult.

At present there are various methods of evaluating glare and glare recovery time. In the case of discomfort glare studies were done by Fry (3) and by Hopkinson(8) relating a glare index to various parameters of the glare. In the study by Hopkinson a modification was made of the Guth formula:

$$G = \frac{F(B_s)\ F(Q)}{F(B_b)\ F(B_i)\ F(\theta)} \qquad (2.1)$$

where

B_s is the source luminance

Q is the apparent size of the source

B_b is the adaption luminance

B_i is the luminance of the immediate surrondings of the source

θ is the angle between the direction of the source and the direction of viewing

G is the glare constant

These values of the different parameters of equation 2.1 are functions relating to the glare constant G. It should be noted that in this case the higher the value of G indicates a greater discomfort is encountered. Hopkinson found that the general population in his experiment was less sensitive to the glare than was an experienced team of observers.

In the study by Fry a modification of the Guth formula was also used. In this case the equation became:

$$M = H\left(\sum_{1}^{n} \frac{L^3 W}{P^3}\right) C_{(S)}^{1/C} \qquad (2.2)$$

where

M is the total glare,

S is a constant,

C is .283,

H is 6.38,

n is the number of luminances used in the room,

p is the position index,

W is the solid angle subtended by each glare source, and

L is the luminance of each glare source.

By the use of this formula Fry included to the Guth formula such things as the number and spacings of luminances, the lumen output of each lamp, the size and shape of the rooms, and the relative candlepower distribution of the lamps. In equation 2.2 the M can be correlated to the glare in the same way as that of the G of Hopkinsons relationship in equation 2.1.

A relation between the glare duration, intensity, and the glare recovery time was developed by Brown and reported in a dissertation by Morris (13) as

$$T = .2 + B \frac{2.7 - \log L}{(2.7 - \log L_o) \ \log L/L_o} \qquad (2.3)$$

where

L_o is the minimum illuminance need to detect the target by the dark adapted eye,

L is the illuminance of the target to be detected,

B is equal to $.022A^{.68}$, and

A is the energy of the flash in foot lambert seconds.

This emperical formula was developed from short duration and high intensity flashes. However it can be seen that as the value of $\frac{L}{L}$ (the target illuminance divided by the minimum illuminance needed to detect the target) approaches zero the value for the recovery time approaches .2.

In Frys (2) study of positive afterimage and measurements of light and dark adaption a conclusion is made that positive afterimages act like a small patch of veiling glare luminance and will affect the absolute threshold of the subjects vision. In his report Fry described the relationship of the primary and secondary reactions basically as shown in figure 8.

When light enters the eye a photosensitive element (S) is decomposed and becomes opsin (O) and retinene (R). The decomposition of the S will also form the substance M which then decomposes into substance N. The decomposition of the element S, Fry theorizes, will also become an element W. The element W is formed into another substance Z by part of the energy produced by the decomposition of S. This process of dwindling away gives off energy which decomposes M and generates nerve impulses. The rate of dwindling of Z in the dark adapted eye is, according to Fry,

$$\frac{dZ}{dT} = -K_5 Z \qquad (2.4)$$

where

K_5 is a constant

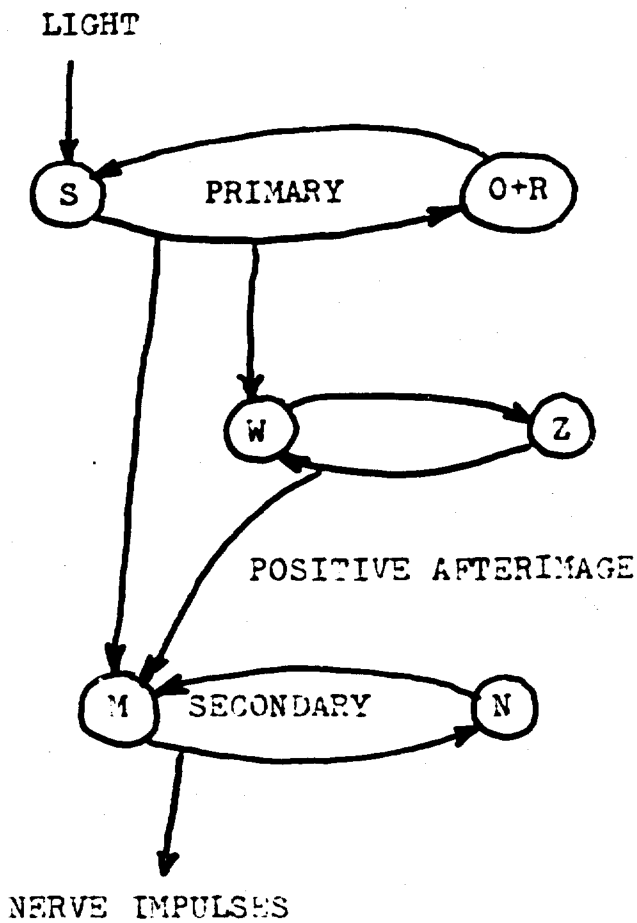

Figure 8. Chemical Chain.
(Fry, 1969).

Z is the rate of dwindling of substance M
In Fry's report, however, he states that in his experiments the positive afterimage has dwindled down to the measurement of about .01 troulands it will tend to disappear and then reappears as a negative afterimage. The negative afterimage will last at the most about eight minutes.

CHAPTER III

DESIGN OF THE EXPERIMENT

During the course of the experiment five subjects tested using five different color systems. Each of the subjects were tested using a Cathode Ray Oscilloscope having a green luminescence dot, with the color of the grid being varied by placing various filters over the screen. The test consisted of an unfiltered non dark-adapted control run, and the various filter colors of blue, white, red, orange-red, having a dark adaption period and a glare included. The subjects were run in accordance with the chart shown in figure 8. The subjects number is shown at the right and the run number along the top, with the color for that subject-run given inside the block.

Subject	Run				
	I	II	III	IV	V
001	U	OR	B	R	W
002	R	B	U	W	OR
003	OR	W	R	B	U
004	W	R	OR	U	B
005	B	U	W	OR	R

where

B is the blue filtered light

OR is the orange-red filtered light

W is the unfiltered light with a glare and dark adaption

U is the unfiltered light without a glare with no dark adaption

R is the red filtered light

Figure 9. Layout for the Run Colors.

The Experimental Apparatus

The subjects station includes the Cathode Ray Oscilloscope, control stick, buzzer, and the glare source. The subject is seated approximately 20 inches in front of the glare source, which is shown on top of the oscilloscope in figure 10. At the subjects right hand is the control stick which the subject can move to control the position of the dot on the oscilloscope screen. The buzzer which is controlled by the Analog computer will be set off when the dot is one unit of deviation off from the center of the grid. This is essentially a difference of potential of approximately 1.5 volts between the dots position and the zeroed position of the dot.

The oscilloscope which is essentially controlled by the Analog computer, displays a cross plot of two random varying voltages. The display of these two varying lines

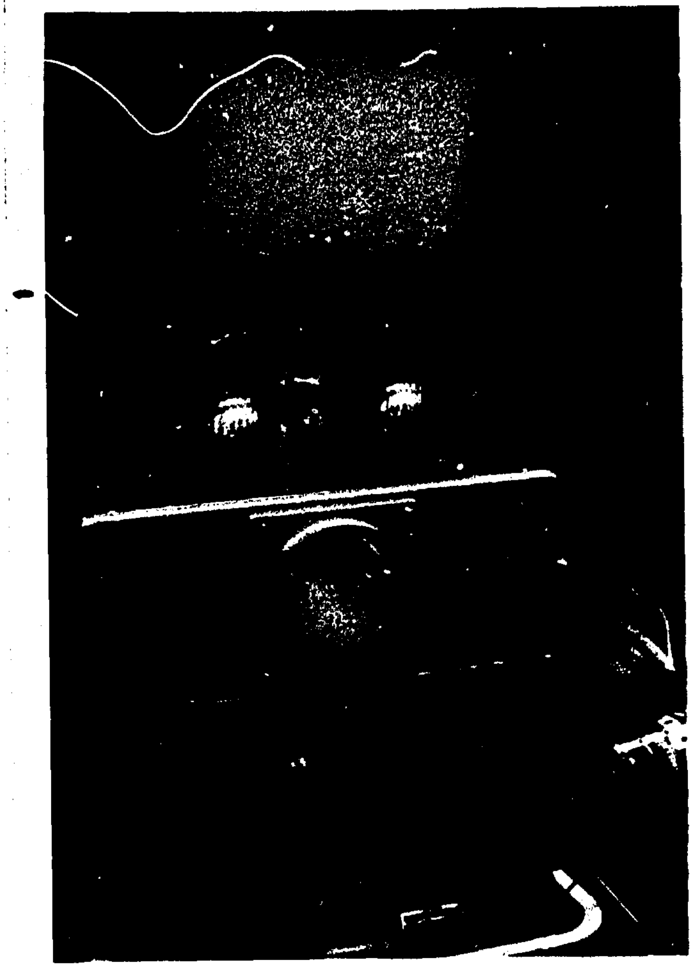

Figure 10. Subject's Position Oscilloscope and Glare Source.

results in a dot which will more randomly in both the vertical and the horizontal planes.

The glare source is an external circuit which is controlled only by the operator. When the operator places comparator button 104 high a timer will be energized allowing the headlamps to remain on for approximately five seconds. After the end of the five seconds the timer will turn off the headlamps and recycle for the next glare signal to be initiated by the operator.

The Analog Computer

The EAI 680 Analog Computer used in this study supplied the random number generators, integrators, the summers, and the time ramp generators. The Analog computer patching diagram shown in figure 11 provided most of the necessary trunk lines and hardware needed to perform the test runs. Two random varying number generators were used to form two random varying lines which when cross plotted formed the moving dot which the subject was to control. This dot was then displayed on the master control screen and on the subjects screen, as shown in figure 12. The moving dot can be seen in this figure just slightly above the center of the screen. The cross plotting of lines is controlled by the panel to the right and below the master control screen. The mode controls are located below the master control panel, as shown in figure 13. This provides the initial condition and operate modes for the Analog computer allowing the computer to run at the desired speed, to hold, or to perform the initial setup of the system. The push buttons and comparator control button are on the master control panel. To the right of the master control panel in figure 13 is the patch board in which the circuit of figure 11 is patched into the computer. This part of the

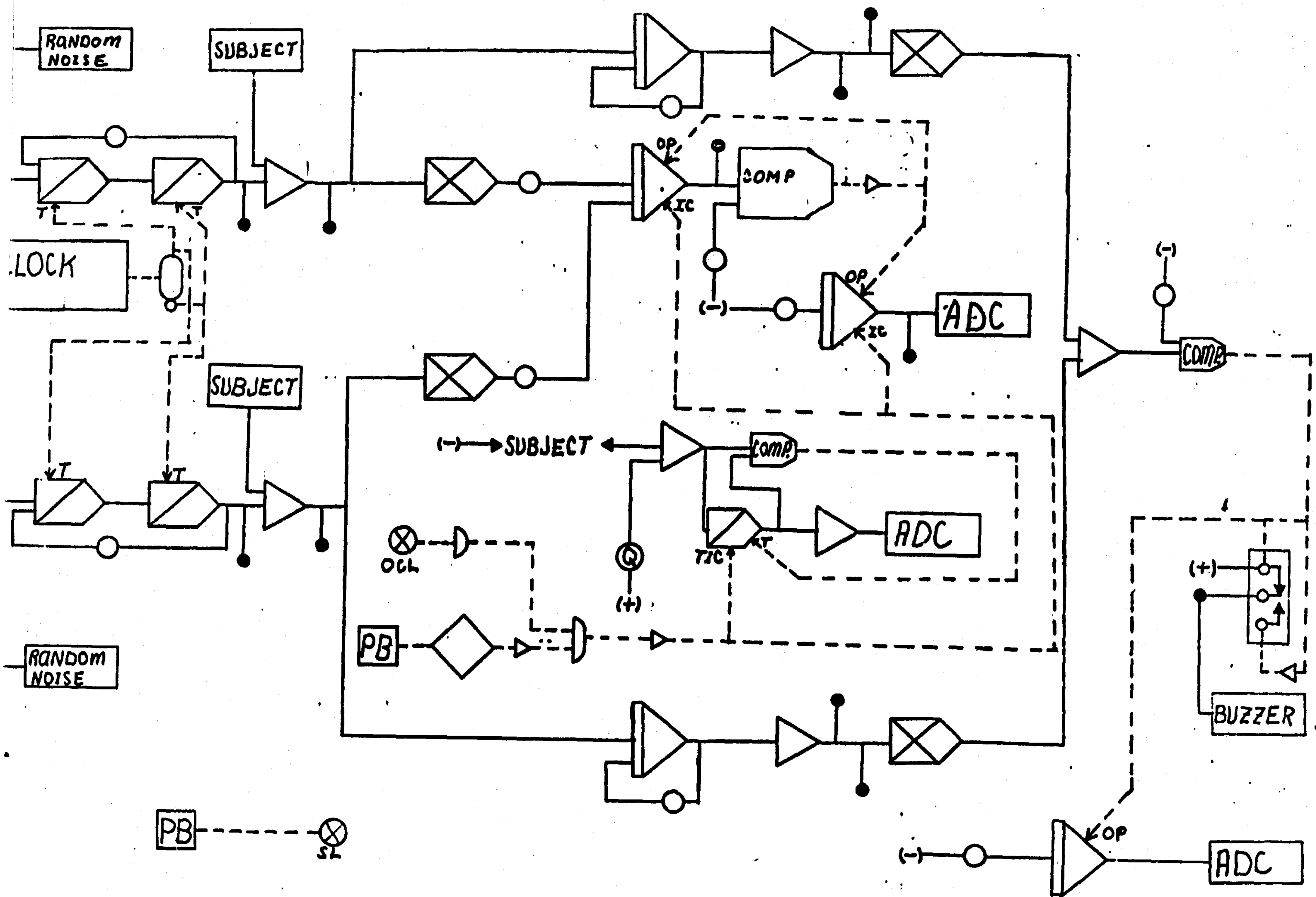

Figure 11. Analog Patching Diagram.

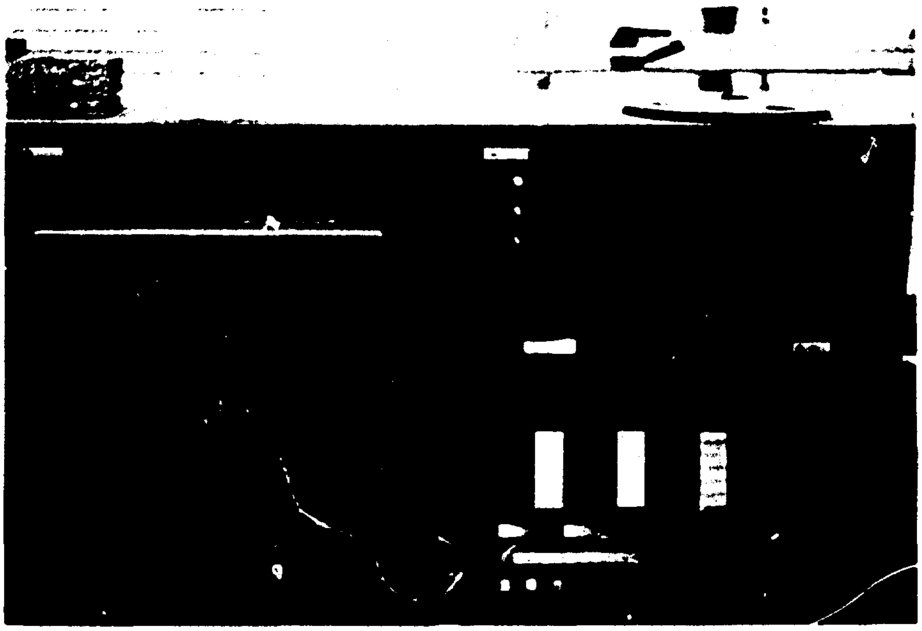

Figure 12. Master Control Screen and Crossplot Controls.

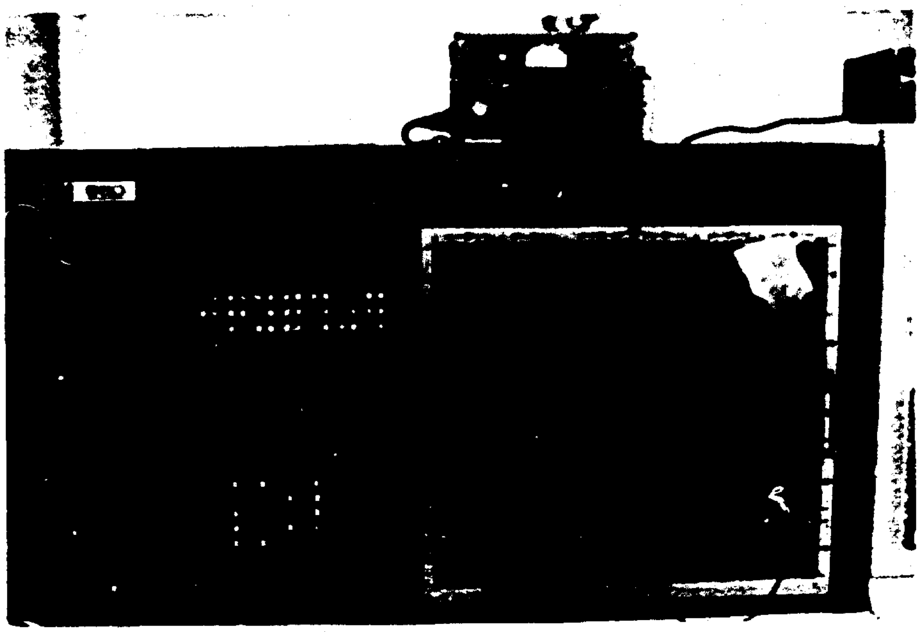

Figure 13. Master Control Panel and Patch Board.

master control panel also contains the logic circuits and the inputs for the trunk lines to the subjects station, as well as, the control and sense lines which go to the digital portion of the hybrid computer system.

The EAI 600 Pacer Computer

Included in Appendix III is the EAI Pacer program which controls the Analog computer through a special set of hybrid linkage routines. The program when called from disk will first read in all values to be set into the potentiometers of the Analog computer. At this point a block of instructions is printed on the cathode ray tube shown in figure 14. The Pacer shown in figure 15 will then set all the potentiometers used in the experiment to the values entered through the data statement. The Pacer program then will initialize the data arrays and set the initial conditions of the integrators to zero. At this point the experimental apparatus is ready to be placed into operate and the test runs are ready to start. After the operator starts the test run the Pacer will wait for a pulse to come from comparator 99 of the Analog computer. When this comparator sends a high pulse to the Pacer the values of the time ramp generator, and the values of the galvanic skin response are read into a storage array. The Pacer will then reset all the initial conditions of the integrators to zero and place the integrators back into the

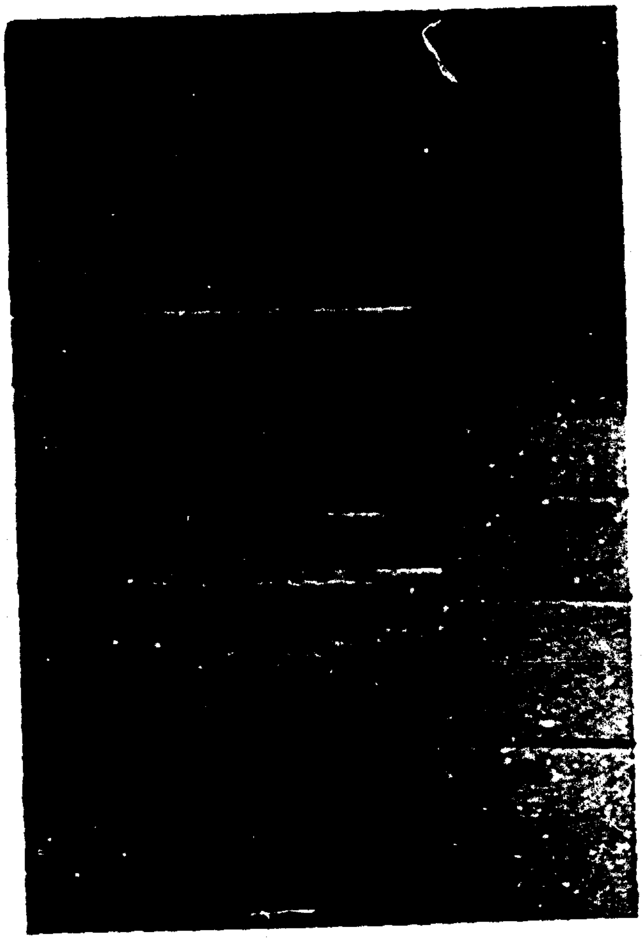

Figure 14. EAI 600 Pacer, Cathode Ray Tube and Keyboard.

Figure 15. The EAI 600 Pacer Console.

operate mode. The Pacer will then wait until Comparator 99 sends a high pulse to the Pacer. At this point the Pacer will then take the required readings and reset the integrators. This will continue throughout the experiment. Comparator 99 essentially measure the cumulative amount of error and checks this error against a preset level of error. At the end of the experimental run the Pacer will calculate the mean and standard deviation of both the time ramp generator values and the galvanic skin response in blocks of ten and for the entire run. At this point the Pacer will plot the time ramp values on the Cathode Ray Tube of the Pacer keyboard.

The Experimental Procedure

At the beginning of the experimental run each subject received a short briefing on the system and what to expect during the course of the experiment. At this time the subject was given a copy of the instructions contained in Appendix I to read, the test room was closed, and the subject began the required dark adaption time of approximately thirty minutes. The comparitor button 74 which will ring the buzzer and signal to the subject to begin was rang. At this time the Analog system is placed into the operate mode and the subject begins his two minute practice period. After two minutes of operation the Analog computer is put into the initial condition mode for fifteen seconds. This operate mode. The Pacer will then wait until Comparator 99 sends a high pulse to the Pacer. At this point the Pacer will then take the required readings and reset the integrators. This will continue throughout the experiment. Comparator 99 essentially measure the cumulative amount of error and checks this error against a preset level of error. At the end of the experimental run the Pacer will calculate the mean and standard deviation of both the time ramp generator values and the galvanic skin response in blocks of ten and for the entire run. At this point the Pacer will plot the time ramp values on the Cathode Ray Tube of the Pacer keyboard.

The Experimental Procedure

At the beginning of the experimental run each subject received a short briefing on the system and what to expect during the course of the experiment. At this time the subject was given a copy of the instructions contained in Appendix I to read, the test room was closed, and the subject began the required dark adaption time of approximately thirty minutes. The comparitor button 74 which will ring the buzzer and signal to the subject to begin was rang. At this time the Analog system is placed into the operate mode and the subject begins his two minute practice period. After two minutes of operation the Analog computer is put into the initial condition mode for fifteen seconds. This signals the subject that the practice is over and the test run is ready to begin. At this time, push button number 1 is set low and the Analog computer is placed into the optic mode and the test run is started. At periodic intervals into the run a glare is initiated by pressing push button 2 high, which resets the time ramp generator to zero and starts the counter going again. The Comparator button 104 is then pressed high which activates the glare source which consists of two automotive type headlights. The glare source is coupled to a timer which allows the headlamps to remain on for five seconds and then the headlamps are turned off. During this time the Pacer will automatically take a reading when the level of error reaches a preset value on the Comparator 99. Whenever this Comparator is tripped the Pacer records the data point number, the value of the time ramp, and galvanic skin response value.

This process of glare, recovery, and data taking is repeated at specified times into the run, with the times between flashes remaining constant for each subject's run.

At the end of the complete testing series the subject was asked to fill out the post run questions on the data sheet contained in Appendix II.

CHAPTER IV

ANALYSIS OF EXPERIMENTAL DATA

In addition to the recording of data on a printout the data of the experiment may also be recorded on paper tape for later compilation or a brush chart recorder as shown in figure 16. The four channels of the brush chart recorder, depicted in figure 16, contain in channel five the vertical error signal, in channel six the horizontal error, in channel seven the values of Comparator 99 and in channel eight the values of the time ramp generator. The tick marks at the bottom of the figure are graduated in increments of one second per tick mark. In this portion of the strip chart the line at point A indicates the point at which a glare is introduced. It is interesting to note that at this point the subject lost control of the dot and, as a result, the values of the time in channel eight were extremely small. The responses shown in figure 16 are typical of all the subjects that were tested.

The data was ranked, then plotted on probability paper. This plot closely approximates a straight line. This indicates that the data is essentially from a normal population. The same procedure was repeated for the control

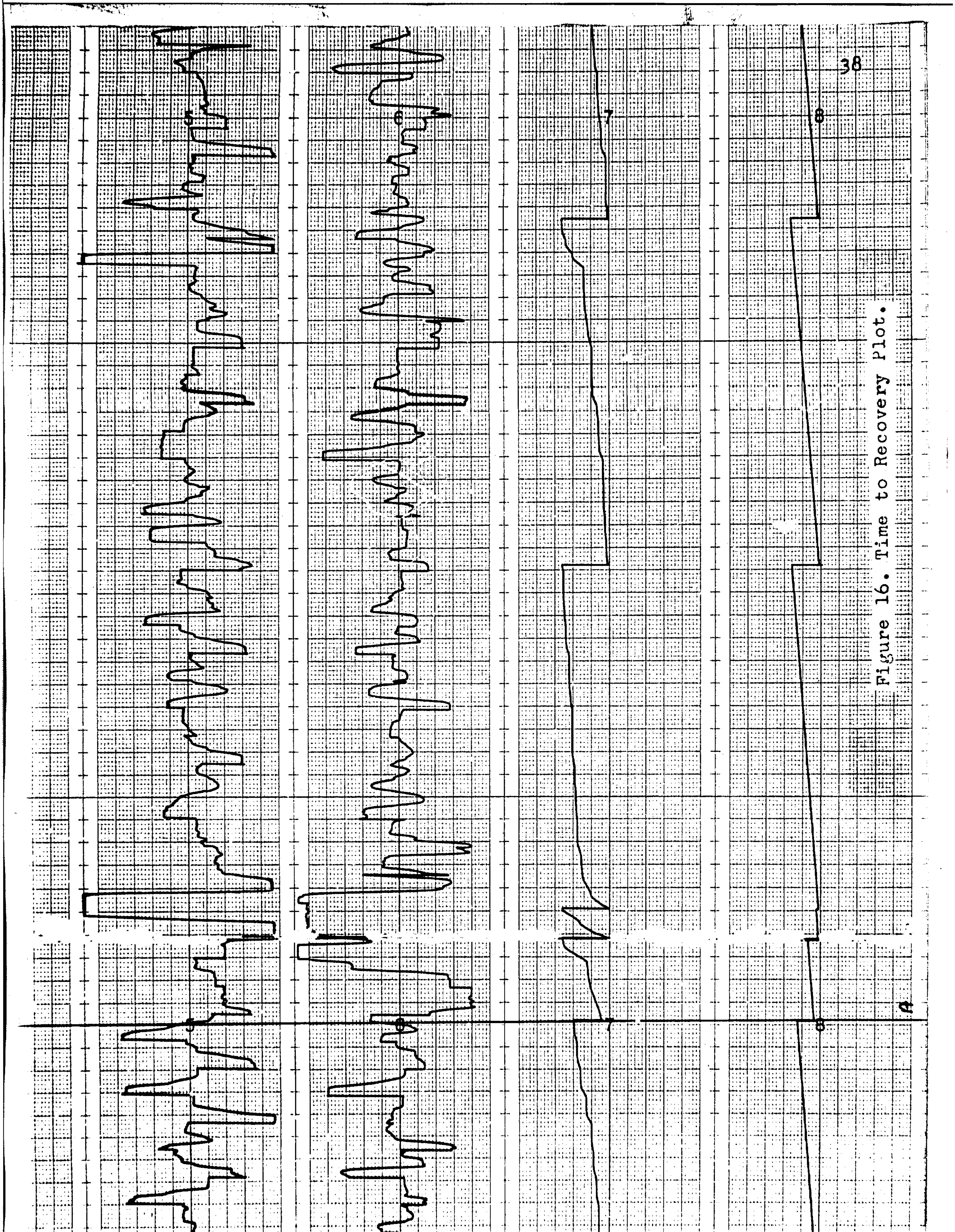

Figure 16. Time to Recovery Plot.

runs of each of the subjects.

The data shown in Table 2 is a condensed version of the total data of all of the runs for each subject. The values inside the blocks are the summation of the time values of the first four data points for each flash of the run.

When the means of the data are found as shown in Table 3 and plotted as in Figure 17, it can be seen that the blue filtered light system was one of the better colors for the time to reach the level of error which was checked by Comparitor 99. The subjects also stated that the blue lighting system produced less eyestrain and fatigue as the run progressed.

The AMDAL 470 computer utilizing the Statistical Analysis System was used for data analyzations and output was set in the form of an Analysis of Variance (ANOVA) shown in Table 4. The model that was employed was

$$Y_{ijk} = \mu + S_i + C_j + S_i{*}C_j + \varepsilon_{ijk}.$$

where

Y_{ijk}	is the data point taken at the flash
μ	is the mean of the data
S_i	is the error due to the subject
C_j	is the error due to the colors
$S_i{*}C_j$	is the error due to the subject color interaction

Color (C_j)	Subject (S_i): 1	2	3	4	5
W	38.164	63.296	54.962	46.271	26.546
	51.952	77.014	64.654	55.597	38.556
	56.488	74.759	54.865	37.152	35.254
	53.656	78.674	48.663	56.897	35.100
R	39.630	76.410	58.301	42.737	24.981
	48.108	64.512	58.538	56.797	36.566
	35.605	71.741	62.933	56.994	39.416
	50.248	58.069	61.974	54.883	47.735
B	35.962	77.289	81.916	55.237	49.830
	49.359	67.212	74.093	58.850	54.047
	56.133	85.803	79.652	76.954	27.527
	56.622	78.479	89.789	64.221	39.710
OR	40.277	72.912	77.209	49.066	40.314
	41.351	68.304	66.271	32.697	53.190
	38.714	63.946	61.682	6.507	39.105
	42.983	62.640	60.590	59.161	45.276

Table 2. Reduced table of data.

	Subject (S_i)				
	1	2	3	4	5
W	12.516	18.484	13.946	12.244	8.466
R	10.849	16.920	13.109	13.984	9.293
B	12.379	16.975	20.340	15.953	10.694
OR	10.208	16.737	16.609	9.214	11.117

Table 3. Means of reduced table of data.

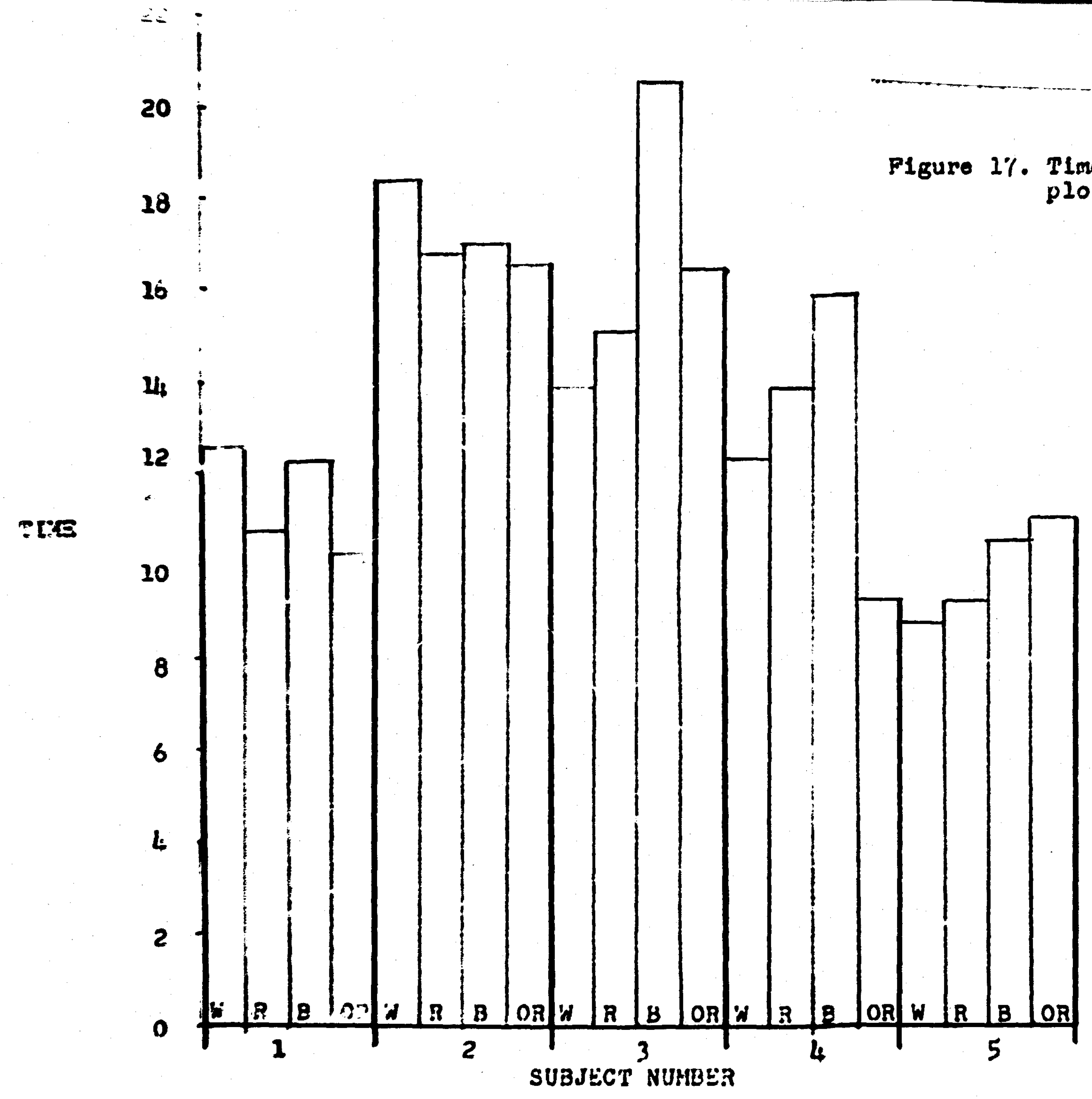

Figure 17. Time to recovery plot

ANALYSIS OF VARIANCE FOR THE VARIABLE F

SOURCE	DF	SS	MS	F VALUE
SI	4	12558.5202	3139.63006	30.13581
CJ	3	1166.6981	388.89937	3.73286
SI*CJ	12	2691.6375	224.30729	2.15302
RESIDUAL	60	6250.9624	104.18271	
CORRECTED TOTAL	79	22667.8682	286.93504	

Table 4. Glare Recovery ANOVA.

ϵ_{ijk} is the error due to the residual.

The use of this model indicated that the effect of the colors of the experiment should be included in the model. The F statistic which resulted due to the color error term was found to fall between alpha values of .025 and the .010 levels. The next object was to determine if one color overall was found to be significantly different from the rest with respect to the time to recovery after the four flashes.

The analysis of the individual colors was conducted first through the use of the Scheffé Test, and then through the use of the Newman-Keuls Range Test.

In order to conduct the Scheffé Test the totals over the subjects and the individual data points was found. The values of these totals are 1050.520, 1046.176, 1258.679, and 1022.205 for white, red, blue, and the orange-red filtered light respectively. At this point a contrast between the blue and red filtered light systems was found. By the use of these contrasts it was found that the times for the blue filtered light was significantly longer than the red filtered light, and significantly larger than the combination of the red, white, and the orange-red.

The Newman-Keuls Range Test similarly indicated at the 95% confidence level that the blue filtered light was significantly better than the red, white, and the orange-red light. The test however indicated that the white light was not significantly different from that of the red light, and that both the red and the white light systems were better than the orange-red filtered light.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Through out the testing of the subjects it was noted that while the subjects were all of the normal population one of the subjects, who held a current pilot's license, did considerably better than the other subjects. This would tend to explain part of the large variation in the mean square error of the ANOVA for the subjects given in Table 4. It is possible that should future tests be run the subjects have equivalent pilot experience.

Another problem that was encountered was that several times a subject would tend to look below the glare source and more to the bottom of the display screen. In this experiment the location of the glare source with respect to the display screen of the oscilloscope was approximately 22^{o} above the display screen. The results of the experiment could also have been affected by this equipment location problem in which the subjects were forced to look below the glare source instead of directly into the area of the glare. In the original configuration of the experiment a meater was to have been built which would have been composed of two millivolt meaters. This would have been smaller and would have allowed the glare source to be moved closer to the display screen.

Under the assumptions made in the experiment it was shown that the blue filtered light tended to have a significantly greater time before the reset error level was reached. The level of error, although kept at a constant throughout the experiment, could have been varied by changing the value of a potentiometer in the Pacer program. This would yield a higher sensitivity of the Comparitor. The selection of the blue filtered light also tended to point out the fact that all the subjects preferred the blue filtering system over the three other colors used in the experiment. The red filtered light, which is similar to the lighting systems that are used today, was reported several times to be fatiguing and cause eyestrain during the glare periods.

Based on the results of this study it would appear that because the greatest portion of today's aviation activities are using the instrument flying techniques, the best color selection for the instrument lighting system would be that of a blue nature. However, appropriate further tests of how the blue lighting would effect the pilots dark adaption and his ability to go from the instrument flying conditions to that of a visual controlled flight would be necessary in order to select the best color system for the flight.

As found in Chapter 3 there was no signifance between the red and the white lighting system. In the case of a mixture of an instrument flight and a visual flight one of these could be selected. One possibility would be that the pilot could select between the colors which would be appropriate for his expected flight condition.

A P P E N D I X I

INSTRUCTIONS

At the beginning of the experiment you will be given thirty minutes in which to become accustomed to the control of the equipment.

The control stick at your right hand controls the movement of the dot on the screen. If you move the stick back the dot moves up, if you move the stick forward the dot will move down, moving the stick to the right and left will cause the dot to move in that direction. Your objective is to hold the dot on the cross hairs of the screen, or as close as you can.

At the end of your practice run you will be placed in a darkened room for about thirty minutes in order to allow your eyes to become dark adapted. After this time the buzzer will sound and you will be given two minutes of practice time, and then the operators will place the Analog computer into the initial condition mode for fifteen seconds. This will move the dot to the center of the screen and hold it there. At this time the machine will be placed into the operate mode and will begin taking data.

During the run there will be from two to five flashes, with each run lasting approximately thirty minutes. At the end of the run an operator will change the filters on the screen. You will then be given a short rest period to readjust your eyes to the room and the next run will begin.

If you have any questions ask the operator at this time.

A P P E N D I X II

I. EN. 685 DATA SHEET

Subject Number ________ Sex ______

Name ________________ Age ______

Date Tested __________ Does the Subject:

Time of Test __________ Wear Glasses ______

Amount of Practice Time ________ Wear Contact Lens ______

Practice Sample Mean __________ Smoke ______

Practice Standard Deviation ______ Drink ______

if yes, when was last time ____________

****

POST RUN QUESTIONS

Did you feel fatigued during a run ______________

If so, when ____

What effect did the glare have ___________________________

What effect did the buzzer have __________________________

Did you lose sight of the grid ___________________________

Did you lose sight of the dot ____________________________

If so, when ____

Was any color better than the other _______________________

Best ____________

Worst ___________

****

COMMENTS:

____

____

____

____

APPENDIX III

```
JOB
EX,RTFOR
      DIMENSION A(200,2)
      DIMENSION VAL(10),PT(10),VALUE(200),GSR(200)
      INTEGER HPT
      LOGICAL LOGVAL,SET,RESET
      DATA ICARD,IPRINT,ITV,IKBD/6,16,1,2/
      DATA PT(1),PT(2),PT(3),PT(4),PT(5),PT(6)/4HP042,
     14HP043,4HP063,4HP082,4HP100,4HP102/
      DATA PT(7),PT(8)/4HP004,4HP009/
      DATA PT(9)/4HP040/
      DATA VAL(1),VAL(2),VAL(3),VAL(4),VAL(5),VAL(6)/.9999,.5,
     1.5,.01,.9999 ,.25/
      DATA VAL(7),VAL(8)/.75,.75/
      DATA VAL(9) /.0300/
      DATA PT(10)/4HP108/
      DATA VAL(10)/.0010/
      DATA SET,RESET/.TRUE.,.FALSE./
      HPT=40
      CALL QSHYIN(IERR,680)
      CALL QSDLYR(2.,IERR)
      INSTRUCTION CARDS
 16   CONTINUE
      TYPE115
 15   FORMAT(33H   INSTRUCTIONS                )
      TYPE 215
 15   FORMAT(41H SET PUSH BUTTON 1 ON, PUSH BUTTON 4 OFF )
      TYPE 315
 15   FORMAT(30H PLACE IN 10**6, AND RUN MODE )
      TYPE 415
 15   FORMAT(35HTURN ON SCOPE AND SELECT CROSSPLOT )
      TYPE 515
 15   FORMAT(48HPLACE COUNTERS AND MONOSTABLES AT DESIRED VALUE )
      TYPE 525
 25   FORMAT(31H PLACE INTO NORMAL AND SECONDS )
      TYPE 615
 15   FORMAT(50H WHEN YOU WISH TO STOP RUN PLACE PUSH BUTTON 4 ON )
      TYPE 715
 15   FORMAT(32H IF YOU HAVE DONE THIS TYPE A 1 )
      READ(IKBD, 40)JAA
      IF(JAA-1)116,216,116
 16   CONTINUE
      DO 10 I=1,10
      CALL QWPR(PT(I),VAL(I),IERR)
      CALL QSDLYR(300.,IERR)
 10   CONTINUE
      CALL QSIC(IERR)
      CALL QSDLYR(13.,IERR)
      CALL QWCLL(1,SET,IERR)
      CALL QSDLYR(2.,IERR)
      TO INPUT THE NUMBER OF SUBJECTS PREVIOUSLY TESTED
      CALL QSUP(IERR)
      CALL QSDLYR(13.,IERR)
      WRITE(ITV,11)
   11 FORMAT (40HENTER THE NUMBER OF SUBJECTS PREVIOUSLY TESTED)
      READ(IKBD,121)ISPT
```

```
      WRITE(ITV,13)
 13   FORMAT (38HSET PUSH BUTTONS TO ZERO THEN TYPE  1 )
 14   READ(IKBD,40)IA
 40   FORMAT(I1)
      IF (IA-1)12,50,50
 50   CALL QWCLL(1,RESET,IERR)
      CALL QSDLYR(4.,IERR)
      CALL QWCLL(1,SET,IERR)
      CALL QSDLYR(2.,IERR)
      C=0
      J=0
      ISPT=ISPT+1
 15   CALL QRCPL(99,LOGVAL,IERR)
      CALL QSDLYR(2.,IERR)
      IF(.NOT.LOGVAL)GO TO 15
      CALL QRBADR(VALOC,6,1,IERR)
      CALL QRBADR(GSRE,7,1,IERR)
      TYPE 1,J,VALOC,GSRE
      FORMAT(I3,G18.6,G18.6)
      CALL QSDLYR(2.,IERR)
      CALL QWCLL(1,RESET,IERR)
      CALL QSDLYR(4.,IERR)
      CALL QWCLL(1,SET,IERR)
      CALL QSDLYR(2.,IERR)
      C=C+1.
      J=J+1
      VALUE(J)=VALOC/VAL(4)
      GSR(J)=GSRE
      IF(J-200)911,911,912
      TYPE 913
      FORMAT(40H EXCEEDED J VALUE LIMIT                              )
      TO STOP AFTER 30 MINUTES
      CALL QRSLL(0,LOGVAL,IERR)
      CALL QSDLYR(2.,IERR)
      CALL QRSLL(0,LOGVAL,IERR)
      CALL QSDLYR(2.,IERR)
      IF(.NOT.LOGVAL)GO TO 15
      CALL QSH(IERR)
      CALL QRBADR (BT,8,1,IERR)
      CALL QSDLYR(13.,IERR)
      WRITE(ITV,9)
  9   FORMAT (99HIF YOU WISH A PRINTOUT OF THE VALUES OF THE
     1ARRAY THEN TYPE 1 )
      READ(IKBD,40) IC
      IF(IC-1)123,6,123
      BEGIN COMPILATION OF DATA
      WRITE(ITV,16)
 16   FORMAT (42HCOMPILATION OF DATA AND PRINTOUT BEGINNING)
      WRITE(IPRINT,26)ISPT
 26   FORMAT (1H1,20X,43HPRINTOUT OF ARRAY VALUES FOR SUBJECT NUMBER,
     1I5)
      WRITE(HPT,51) J
  1   FORMAT(I3)
      DO 17 I=1,J
      TB=BT/VAL(10)
      WRITE(HPT,52) I,VALUE(I),GSR(I)
  2   FORMAT(I3,F10.3,F10.3)
      WRITE(IPRINT,13)I,VALUE(I),GSR(I),TB
```

```
1  CONTINUE
   JQ=1
   MMM=-9
   I=0
   DO 1000 JJJ=1,20
   MMM=MMM+10
   I=I+10
   IF (I-J)1222,1222,1111
2  CONTINUE
   CALL SQPG(I,GSR,JQ,10.,MMM)
2  CALL SQPM(I,VALUE,JQ,10.,MMM)
1  I=J
   CALL SQPG(I,GSR,JQ,C,1)
   CALL SQPM(I,VALUE,JQ,C,1)
3  CONTINUE
   TO PLOT ON CRT
   WRITE(ITV,19)
.  FORMAT(50HDO YOU WISH THE VALUES OR THE ARRAY TO BE PLOTTED ,
  1/,20HIF YES THEN TYPE  2 )
   READ(IKBD,40)IB
   IF(IB-2)122,24,122
   CONTINUE
   PLOT PROGRAM
   DO 63 I=1,J
   A(I,1)=I
   A(I,2)=VALUE(I)
,  CONTINUE
   CALL APLOT(A,200,1,J)
   CONTINUE
   TO STOP OR HOLD AT THE END OF A RUN
   WRITE(ITV,101)
   FORMAT( 45HTYPE  1     IF YOU WISH TO STOP THE EXPERIMENT,
  1 / ,37H2  IF YOU WISH TO START A NEW SUBJECT,
  1  / ,45H  3 IF YOU WISH TO HOLD WAITING A NEW SUBJECT)
,  READ(IKBD,102)JA
,  FORMAT(I1)
   GO TO(100,10,10),JA
   SHUT DOWN SEQUENCE
,  CONTINUE
   END
   SUBROUTINE APLOT(A,N,NPLOT,NPNT)
   DIMENSION A(1)
   CALL BEGIN(9600,1)
   CALL ERASE
   CALL VECTOR
   XMAX=A(1)
   XMIN=A(1)
   DO 33 I=1,NPNT
   IF(A(I).LT.XMIN)XMIN=A(I)
   IF(A(I).GT.XMAX)XMAX=A(I)
   CONTINUE
   NDX=N+1
   YMIN=A(NDX)
   YMAX=YMIN
   DO 90 I1=1,NPLOT
   DO 80 I2=1,NPNT
   NDX=I1*N+I2
   IF(A(NDX).LT.YMIN)YMIN=A(NDX)
   IF(A(NDX).GT.YMAX)YMAX=A(NDX)
```

```
      CONTINUE
      CONTINUE
      XFACT=800./(XMAX-XMIN)
      YFACT=500./(YMAX-YMIN)
      XORG=(1023.-800.)/2.
      IF(XMIN.LT.0.)XORG=223.-800.*XMIN/(XMAX-XMIN)
      YORG=140.
      IF(YMIN.LT.0.)YORG=140.-500.*YMIN/(YMAX-YMIN)
      CALL SCALE(XFACT,YFACT,XORG,YORG)
      XLOW=XMIN
      IF(XMIN.GE.0.)XLOW=0.
      YLOW=YMIN
      IF(YMIN.GE.0.)YLOW=0.
      XLNG=(XMAX-XMIN)
      YLNG=(YMAX-YMIN)
      XTIC=XLNG/10.
      YTIC=YLNG/10.
      MARKX=1
      MARKY=1
      CALL AXIS(XLOW,YLOW,XLNG,YLNG,XTIC,YTIC,MARKX,MARKY)
      DO 1000 I2=1,NPLOT
      CALL VECTOR
      DO 2000 I1=1,NPNT
      IF(I1-1)10,20,10
      IPEN=0
      MARK=0.
      GO TO 40
      IPEN=1
      CONTINUE
      NDX=I2*N+I1
      X=A(I1)
      IF(XMIN.GE.0.)X=A(I1)-XMIN
      Y=A(NDX)
      IF(YMIN.GE.0.)Y=A(NDX)-YMIN
      CALL TPLOT(X,Y,IPEN,MARK)
      CONTINUE
      CALL TPAUSE
      CONTINUE
      RETURN
      END
      SUBROUTINE SQPM(I,VALUE,JQ,C,MMP)
      DIMENSION VALUE(1),JQ(1),S(100),AMEAN(100),B(100)
      DIMENSION FFF(100)
      ASUM=0.0
      SUM=0.0
      DO 9122 K=MMP,I
      B(K)=VALUE(K)**2
      SUM=SUM+B(K)
      ASUM=ASUM+VALUE(K)
    / CONTINUE
      S(JQ)=SQRT(SUM-(ASUM**2)*(1./C))*(1./(C-1.))
      AMEAN(JQ)=ASUM/C
      FFF(JQ)=(S(JQ)**2/AMEAN(JQ))*100.
      WRITE(16,8151)C,S(JQ),AMEAN(JQ),FFF(JQ)
    ) FORMAT(F20.0,27HSAMPLE STANDARD DEVIATION IS ,G18.6,
     114HSAMPLE MEAN IS ,G18.6,11H INFACT IS ,F8.4)
      RETURN
      END
      SUBROUTINE SQPQ(I,VALUE,JQ,C,MMM)
      [illegible](1),S(1 ),AMEAN(100),B(100)
```

```
      DIMENSION FFF(100)
      ASUM=0.0
      SUM=0.0
      DO 9122 K=MMM,I
      B(K)=VALUE(K)**2
      SUM=SUM+B(K)
      ASUM=ASUM+VALUE(K)
   22 CONTINUE
      S(JQ)=SQRT(SUM-(ASUM**2)*(1./C))*(1./(C-1.))
      AMEAN(JQ)=ASUM/C
      FFF(JQ)=(S(JQ)**2/AMEAN(JQ))*100.
      WRITE(16,815)C,S(JQ),AMEAN(JQ),FFF(JQ)
    5 FORMAT(F15.0,5HGSR   ,29HSAMPLE STANDARD DEVIATION IS ,G18.6,
     114HSAMPLE MEAN IS ,G18.6,11HWINFACT IS ,F8.4)
      RETURN
      END

 ?TCIG

 TPLOT,.DK3
 THRTL,.DK3
 TRTL,.DK3



 H1,50
 T1,.CU
```

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REFERENCES

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