AD-A236 289

WL-TM-91-309-FIGK

PERCEPTUAL LIMITATIONS OF PERIPHERALLY DISPLAYED COLORS ON CRTs

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WL/FIGK

MARCH 1991

Wright Laboratory
Wright-Patterson AFB OH 45433

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1991

3. REPORT TYPE AND DATES COVERED
Final Jan 90 - Jan 91

4. TITLE AND SUBTITLE
Perceptual Limitations of Peripherally Displayed Colors on CRTs

5. FUNDING NUMBERS
PE: 62201F
PR: 2403
TA: 04
WU: 86

6. AUTHOR(S)
Capt Eileen Ancman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Wright Laboratory/FIGK
Wright-Patterson AFB OH 45433-6553

8. PERFORMING ORGANIZATION REPORT NUMBER
WL-TM-91-309-FIGK

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Wright Laboratory/FIGK
Wright-Patterson AFB OH 45433-6553

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Colors on a peripherally located CRT may be misperceived. Subjects wrongly identified the color of a peripherally located, 1.3° circle displayed on a CRT 5% of the time if it was blue, 63% of the time if red, and 62% of the time if green. Blue could not be seen further than 83.1° off of the fovea (along the x-axis). Red had to be closer than 76.3° and green nearer than 74.3° before the subjects reported seeing the colors. These average color field dimensions changed with differing subject psychological states due to the observed "visual field narrowing" (i.e.: reduction of the subject's peripheral field of view) in both the relaxed and stressed states. A significant degree of visual field narrowing was noted for the relaxed state (8%) with a trend noted for the stressed state (2%). This observed visual field dimension reduction for both the relaxed and stressed states exemplified the Yerkes-Dodson inverted "U" performance model. These color perception limitations must be kept in mind when designing CRT color formats for aircraft cockpits.

14. SUBJECT TERMS
Peripheral color vision, visual field narrowing, tunnel vision, stress, relaxation, high arousal, low arousal, CRT, Yerkes-Dodson inverted "U" performance model.

15. NUMBER OF PAGES
43

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

FOREWORD

This Technical Memorandum (TM) documents the first research study accomplished for a new in-house effort, Stress P.I.T. (Psychologically Induced Tension) at the Cockpit Integration Directorate, Wright Patterson AFB, OH. The Stress P.I.T. facility is set-up to study the ability to recognize basic colors and/or aircraft cockpit symbology in one's peripheral vision when experiencing various psychological states (normal, stressed, relaxed). The results will be used to determine the best cockpit format color usage for retrofit and future aircraft designs.

This Technical Memorandum has been reviewed and was approved.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Thanks are given to Mr Richard Moss, for letting me do "my own thing"; Mr Tony Ayala, for writing the Stress P.I.T. program and helping to set-up the laboratory; Dr. James Olsen, Chief Scientist and Col Borowski of the Flight Dynamics Laboratory, for recommending me for, and providing an in-house grant; Dr John Reising and Ms Kristen Barthelemy, for being program advisors as well as helping out with the statistical analysis; Dr Michael Vidulich, Dr David Post, Dr Thomas Moore, Lt Col Stephenson and my other Armstrong Aerospace Medical Research Laboratory advisors; the Cockpit Council - including the Acting Director, Mr Paul Blatt and the Chief Engineer, Mr Terry Emerson - for their support; and Dr Hancock and Dr Tassinari, two of my master's degree professors at the University of Southern California, for inspiring me to conduct research on visual field narrowing and introducing me to stress management through skin conductance monitoring.

1.0 SUMMARY

CRTs are currently used in aircraft cockpits to relay important color coded information necessary for mission completion and pilot survival. Color CRTs presently used are as large as 6"x6", but are projected to increase in size until the "all glass cockpit"[1] is achieved. As the display gets larger, peripheral vision may be relied upon even more heavily. Peripheral vision is also important in present situations involving more than one CRT display used in a row, and especially when the pilot is in a head-up mode[2].

The research in this report dealt with a subject's ability to recognize in their peripheral vision the three primary colors, blue, green and red, on a cathode ray tube (CRT) with all three guns adjusted to achieve equal luminance. Data for various subject psychological states (normal, stressed, and relaxed) was collected. Percent error (e.g., how many times red was perceived as green or blue) was recorded for each state and color. A second performance measure, visual field dimension (e.g., degrees off of fovea where the color of the circle was correctly perceived) along the x-axis, was also collected for each color and psychological state.

Subjects wrongly identified the color of a peripherally located, 1.3° circle displayed on a CRT 5% of the time if it was blue, 63% of the time if red, and 62% of the time if green. Blue could not be seen further than 83.1° off of the fovea (along the x-axis). Red had to be closer than 76.3° and green nearer than 74.3° before the subjects reported seeing the colors. These average color field dimensions changed with differing subject psychological states due to the observed "visual field narrowing" (i.e.: reduction of the subject's peripheral field of view) in both the relaxed and stressed states. Noted was a significant degree of visual field narrowing for the relaxed state (8%) and a trend for the stressed state (2%) versus the normal, baseline. This observed visual field dimension reduction for both the relaxed and stressed states exemplified the Yerkes-Dodson inverted "U" performance model. It was interesting to note that until this research, visual field narrowing has not been equated with relaxation, but only stress.

When relying upon color coding as a cue, designers must realize that some colors are perceived easier in the far periphery than others. Various colors may not even be perceived at all, depending upon how many degrees off of the user's fovea they appeared. At other times, the psychological state of the user could cause visual field narrowing; when this occurred, colored cues that normally fell within the bounds of one's peripheral

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[1] A cockpit where most of all the usable display area is covered by an electronic display, projecting formats of currently used aeronautical hardware (dials, buttons, etc.)

[2] Looking out of the canopy, not at the cockpit displays.

vision may now lie outside the shrunken visual field and therefore, would not be perceived by the user.

2.0 INTRODUCTION

The color of a fovea centered object may appear different if seen peripherally. In the far periphery, a person would not be able to tell the object's color immediately, but just know the object was there - a function of rods versus cones (Wertenbaker, 1981). As the object got closer and the person started to perceive its color, he/she may not have perceived the correct color. The object's color may actually have appeared to change several times until the correct color was perceived during the remainder of its trek across the visual field towards the fovea (Dudek & Colton, 1970; Kinney, 1979).

Different colors can first be perceived at different locations in the periphery (Johnson, 1986 and Kelsey & Schwartz, 1959). The color blue, for instance, can be perceived correctly further out in the periphery than either red or green. Mappings of these color field dimensions appeared in the literature, but authors' did not specify subject psychological state (i.e., normal, relaxed, stressed) when addressing experimental stipulations. It should be noted that under stress a phenomenon known as "visual field narrowing" (e.g., tunnel vision) occurs (Easterbrook, 1959; Hancock & Dirkin, 1983; Williams, 1985, 1988) which in theory should affect visual field dimension. According to theory, visual field narrowing should bring the point of recognition closer towards the fovea, thereby reducing the range of one's peripheral vision. The literature revealed nothing on how relaxation affected a person's ability to perceive color using their peripheral vision.

This study strove to get an understanding of these phenomena for three distinct psychological states: normal, stressed and relaxed. To do this, a color naming/reaction time task was employed. Subject's visual field was measured along the x-axis and percent color naming error were recorded and analyzed.

3.0 METHOD

3.1 Subjects

The subjects for this study were ten Air Force civilian/ military volunteers with non-corrected 20/20 visual acuity and full color vision. An all male, 23 to 34 year old subject pool was used. Subjects had hearing tests to confirm hearing was within normal range.

3.2 Design

This study employed a 3 x 3 factorial within-subjects design with two independent variables: (1) color (red, green, blue), and (2) psychological state (stressed, normal, relaxed). Each subject was tested in the normal state first, which defined their baseline. A counterbalanced design was used to alternately expose every other subject to either the stressed or relaxed state first. The Experimental Matrix used in this study can be found in Appendix A.

A color naming/reaction time task was utilized. The subject focused on a spot of white light set directly in front of him. By placing a 10.75" monitor screen as one leg of an equilateral triangle with respect to the subject's right eye, 30° to 90° arc of the subject's vision off of the fovea along the x-axis was covered. This comprised the total range under study for the experiment. 1.3° circles continuously moved at the rate of 1.6° per second from the right to left of the screen (subject's far to near periphery) along the x-axis. The instantaneous position of the circle of color (degrees off of the subject's fovea) was recorded for each time the circle's perceived color was called out by the subject, whether he/she correctly identified it or not. If the color of the circle was misperceived, the circle would continue its trek across the subject's visual field towards his fovea. When the color was perceived correctly, the circle would disappear from the screen, and after a 1.5 second delay another circle of color per the experimental matrix (see Appendix A) would start across the screen. All lights were turned off in the room and the experimental area was dark, with the exception of the instrumentation lumination. The monitor was adjusted to have all three guns (red, blue, green) at an equal luminance of approximately 8.7 candela per square meter. Different headrests were used for each state (see Figure 3.4-2); their relative degree of comfort level, ranging from extremely comfortable (used in relaxed state) to extremely uncomfortable (used in stressed state) was determined in a pre-test validation study.

3.3 Psychological State

Psychological state was determined objectively via instantaneous skin conductance readings. Subject instantaneous skin conductance had to be at least 50% higher or lower than the baseline (normal state) to qualify as a change in state, as determined from a pre-test validation study. Psychological state was determined objectively via a post test questionnaire.

3.3.1 Relaxed State. To achieve a state of relaxation, an autogenics relaxation technique was used. This is a short, fifteen minute technique concentrating on "warm and tingly feelings" to relax a person's body and is classically used for stress management (Edelberg, 1972). Subjects were exposed to this through headphones via a pre-recorded tape. Appendix B contains a transcript of the tape. Subjects had their eyes shut throughout the entire relaxation procedure. During the pre-brief, subjects were instructed to open their eyes after the relation procedure and to think of something tranquilizing and restful while focusing on the white light at the far end of the room. The post test questionnaire (see Appendix C) queried the subjects on their thoughts employed as well as their subjective level of relaxation.

3.3.1 Stressed State. Two different auditory sound icons were used to stress subjects. The sounds of crying babies (Sound Ideas, Sound Effects Library, CD/Track# 1016-03-01) were used along with a pulsating broadband noise (e.g., static), germane to an aircraft environment. This latter noise was produced by a Commodore VIC 20's white noise function option. The sound intensity of these noises was set at 97 and 94dB(A), respectively. For the first half of the colored circles' trek across the CRT, the crying babies icon was heard continuously. For the remainder of the colored circles, the broadband noise was heard. Subjects were exposed to the noise via headphones. During the pre-brief, subjects were instructed to think of something stressful while focusing on the white light at the far end of the room. The post test questionnaire (see Appendix C) queried the subjects on their thoughts employed as well as their subjective level of stress.

3.4 Apparatus

Figure 3.4-1 shows the experimental set-up for this study. Apparatus on the foreground table are as follows:

- -Kenwood amp (top rear)
- -Tektronix tape deck (middle rear)
- -Zenith 248 computer (bottom rear)
- -Zenith CGA monitor showing ORION skin conductance display (front left)
- -Commodore VIC 20 key board (front left)
- -Commodore tape drive (front middle)
- -ORION skin conductance unit (front middle)
- -Tektronix speaker (front right)
- -Small monochrome monitor showing Commodore display (front right)
- -Zenith keyboard (front right)
- -Pen light (front left)
- -Ruler (front left)

Apparatus behind the screen (extreme right of picture) are as follows:

- -Multicolored cushioned chair
- -Zenith EGA monitor

Not shown are the headphones. Sennheiser model 250 was chosen for its degree of comfort and closed ear design.

Figure 3.4-2 shows the three headrests used in this study. The one on the left was for the normal state, the middle one was for the relaxed state and the right one was for the stressed state.

3.5 Procedure

Upon entering the laboratory facility, each subject received a standardized briefing to explain the purpose of the experiment; how to interact with the Z248; what the Orion measuring device was and how the band around their finger would measure skin conductance; and what would be used to relax and stress them. Appendix D contains a transcript of the pre-brief. After receiving

Figure 3.4-1: Experimental Set-Up

Figure 3.4-2: Headrests

this pre-briefing, the subject was required to read and sign a Privacy Act statement (see Appendix E).

Subjects were seated in a comfortable chair; headsets and the skin conductance band were put on. The subjects were then told to stare straight ahead at a small white spot of light at the opposite end of the room, call out and depress a mouse button as soon as they "recognized" the color of the circle slowly moving towards the center of their visual field, displayed on the monitor off set on their right. If the right color was called out, the experimental operator hit the space bar on the computer keyboard. This function stopped the trek of the current circle of color across the screen and replaced it with the next circle of color. If the subject called out the wrong color, the experimental operator made note of the wrong color on the subject's matrix sheet and did not hit the space bar on the computer keyboard. By not hitting the space bar, the circle of color continued to travel towards the subject until the correct color was called out. Each time the subject hit the mouse button or the experimental operator hit the computer space bar, the computer recorded the exact location of the circle of color in degrees off the axis of the subject's fovea, normal to the wall.

Prior to the baseline data collection, sufficient time was allowed for the subject to adjust to the experimental surroundings and to dark adapt through the use of a practice run.

If the stressed state was the last one to be experienced by the subject, the subject had the option to be re-relaxed prior to exiting the experimental laboratory, using the same relaxation tape used for the relaxation runs. Upon leaving, subjects were given a questionnaire to subjectively rate their feelings of relaxation and/or tension during each phase of the experiment. They were also asked about their thoughts used to conjure up stress and relaxation; if there was any color they could perceive faster than the others; and if they perceived their psychological state made any difference in how quickly they perceived the colored circles.

4.0 RESULTS

Data was analyzed using the multivariate analysis of variance (MANOVA) subprogram of the Statistical Package for the Social Sciences (SPSS) (Hull and Nie, 1981). A further analysis of the results was performed using the Finite Intersection Test (FIT). FIT, a simultaneous comparison test for both univariate and multivariate data, was used to determine what level of the independent variable most affected the dependent variable (Cox, Krishnaiah, Lee, Reising, and Schuurman, 1980).

4.1 Independent Variable: Psychological State

A main effect for the independent variable, psychological state, was found ($F(4,36) = 3.196$; $p<.024$). The FIT test showed differences between the relaxed state and the normal state with the visual field dimension as the dependent variable ($F(1,87) = 7.305$; $p<.025$) [see Figure 4.1-1]. No interaction effects were found.

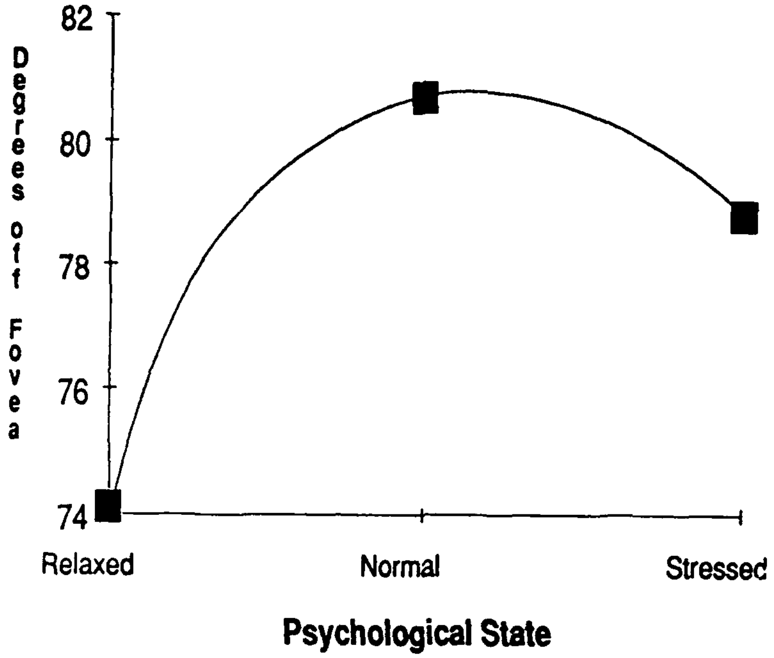

Figure 4.1-1: Visual Field Dimension vs. Psychological State

4.2 Independent Variable: Color

A main effect for the independent variable, color, was found ($F(4,36) = 4.798$; $p<.003$). The FIT test showed differences between blue and red for both dependent variables, visual field dimension and color perception error ($F(1,87) = 7.984$; $p<.025$), ($F(1,87) = 11.342$; $P<.025$), as well as between blue and green for both dependent variables, visual field dimension and color perception error ($F(1,87) = 13.975$; $p<.025$), ($F(1,87) = 8.490$; $p<.025$) [see Figures 4.2-1 & 4.2-2]. No interaction effects were found.

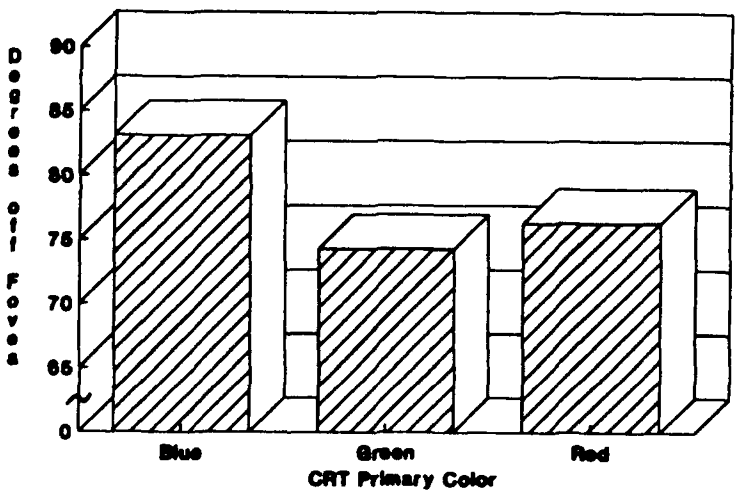

Figure 4.2-1: Visual Field Dimension vs. Color

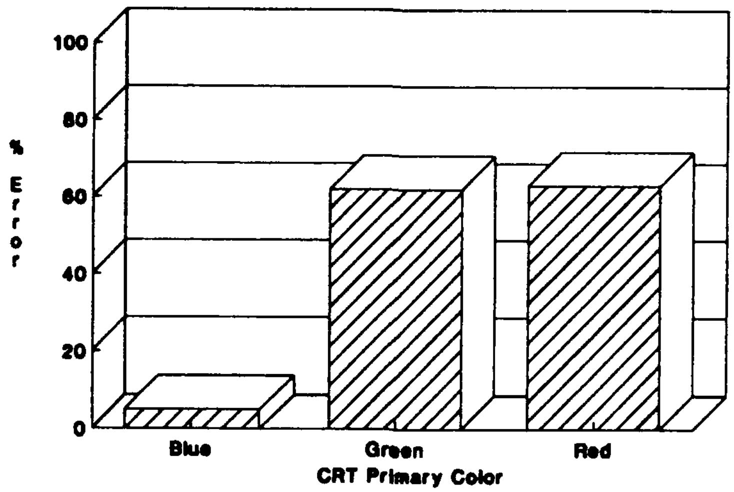

Figure 4.2-2: Color Perception Error vs. Color

5.0 DISCUSSION

5.1 Visual Field Narrowing

Visual field narrowing, the reduction of one's peripheral field of view, was obtained in both the relaxed and stressed states. The average visual field shrunk 2% in the stressed state and 8% in the relaxed state from the baseline, normal state, based on the average values for all three states regardless of color (see Figure 4.1-1).

A visual field narrowing trend was also noted for each of the three primary CRT colors. The average color fields shrunk accordingly, as shown in Table 5.1-1, based on the average values for all subjects.

COLOR	RELAXED	STRESSED
BLUE	7%	3%
GREEN	7%	3%
RED	11%	2%

Table 5.1-1: Color Field Shrinkage

These findings are quite interesting, because the literature reveals visual field narrowing addressed only in the stressed state, mentioning nothing about this phenomenon in the relaxed state. With performance degradation shown at both psychological extremes, the inverted "U" theory of performance (Yerks & Dodson, 1908) was exemplified (see Figure 4.1-1). When the visual field data for all colors was plotted (Figure 5.1-1), the inverted "U" function was also observed for each of the three colors.

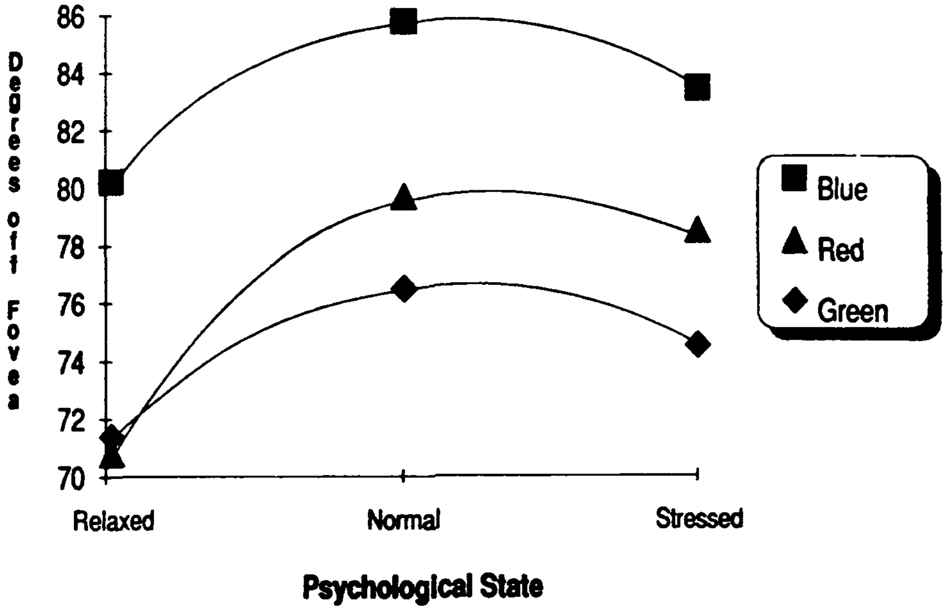

Figure 5.1-1: Color Field vs. Psychological State

In a truly inverted "U" function, there should be no significance between the stressed state's and the relaxed state's data if maximum stress or relaxation was achieved and the resultant data points fell at the feet of the inverted "U". The only significance should be between both extremes (stressed and relaxed states) with the pinnacle (normal state). But, since the stressed state's data point in this study fell approximately midway between the relaxed and normal values (see Figure 4.1-1), a lack of significance was found not only between the stressed and relaxed states, but between the stressed and normal states as well. To achieve significance, the subject's level of stress must rise, thereby bringing the data point further down the inverted "U" function.

The approximately 100dB(A) of obnoxious noise in this study resulted in only a trend towards visual field narrowing in the stressed state. From the questionnaire response (see Appendix C) it was clear that the subjects did not achieve a maximum stress level (i.e., life or death quandary). The average response to the degree of stress experienced centered around 4 rather than the maximum response rating of 5 (Question #7). Things stress/annoy different people differently. There is no universal stressor. According to the questionnaire results, the average person was bothered more by the crying babies than by the white noise (Questions #9 & #10) and subjects thought numerous different ideas to create a feeling of relaxation or stress (Questions #11 & #12).

An additional study will be run trying to achieve a higher level of stress in the subjects, hopefully bringing the stressed state's data point further down the inverted "U" to see if significance, rather than trend data is generated. It is not reasonable or ethical to achieve a peak level of life or death type stress during the laboratory experiment, but a slightly higher levels of stress is desired. Stressors may have to be tailored to the individual subject and a secondary, non-interfering task may also be required to bring up the level of stress.

With regards to the degree of relaxation achieved, the questionnaire revealed that all but one person peaked their response for maximum relaxation (Questions #4 & #5). Therefore, the relaxed data point represents a point close to maximum relaxation for each subject and the autogenics relaxations technique need not be changed for future experimentation.

5.2 Color Field Dimension

Blue was perceived correctly the furthest away from the fovea of the three colors, thereby giving it the largest color field dimension along the x-axis: 8% larger than the red and 11% larger than green (see Figure 4.2-1). This finding supports the relative results found in other studies using several different mediums and techniques other than a CRT with slowly moving circles for displaying colors (Johnson, 1986; Kensey, 1959).

It was quite interesting to note how much further away from the fovea blue was perceived correctly than red or green. This may be due to the fact that blue appeared brighter[3] (a subjective measurement) than the other colors even though all three colors were matched in luminance (a quantitative measurement). A person could quickly differentiate the color blue from the others based on its brightness differential even before they actually perceived the circle's color to be blue. To counter this effect, subjects were informed of this phenomenon during the pre-brief. They were told not to "guess" color based on brightness differential, but rather to wait until they can actually "see" a color before calling one out. To theorize that subjects did not rely on brightness differential alone to determine color, the color naming error associated with red and green can be cited. Figure 5.3-1 shows that red and green, though noticeably not as bright, were still confused with the brighter blue.

As discussed in Section 5.1, visual field narrowing, experienced during the stressed and relaxed states, was shown to

[3] Pre-test studies, questionnaire comments as well as the literature (Neri, Luria & Kobus, 1984) corroborated the fact that this phenomenon existed.

effect color field dimension (see Figure 5.1-1). Inverted "U" functions were observed for all three colors.

5.3 Color Perception Error

Color perception in one's peripheral vision was apt to be misperceived. Figure 5.3-1 shows a breakout via color of the data in Figure 4.2-2. Shown are the colors subjects believed they were perceiving and verbally called out during the experiment. In some instances, the color of the circle appeared to change two to three times to the subject during its trek towards their fovea.

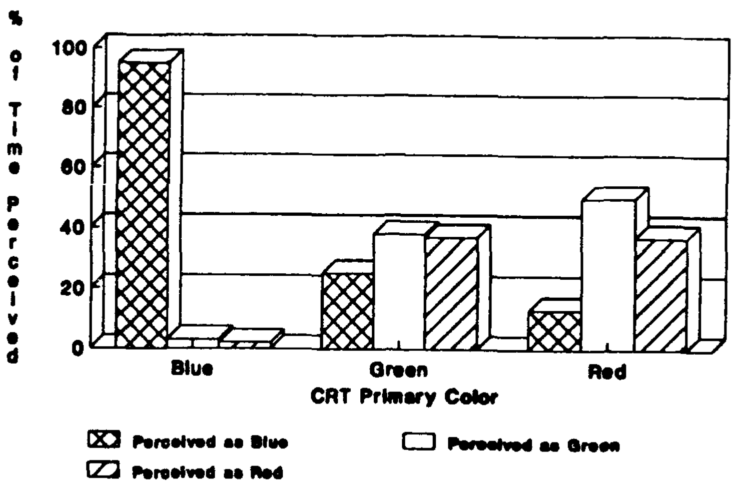

Figure 5.3-1: Actual Color vs. Perceived Color

More than half the time, both red and green were perceived as a color other than red or green, respectively. Only the color blue proved to be reliable. To account for this significant difference in amount of color naming error per color, one must look at the brightness differential among the three colors. As previously discussed in Section 5.2, blue appeared brighter than either red or green, even thought all colors were matched for luminance. The brightness differential could account for blue being perceived with fewer errors, for the subjects could have been relying on two types of symbology coding: color and brightness. This redundant coding, in theory, should reduce percent color naming error. To reduce the possibility of subjects relying on redundant coding, subjects were informed of the brightness differential during the pre-brief and told to ignore this cue during the color naming task. Subjects could not have relied solely on brightness, for as shown in Figure 5.3-1, red and green, though noticeably not as bright, were still confused with the brighter blue. If brightness was the primary determinant, blue should not have been significantly confused with red and/or green.

Dudek & Colton (1970) reported similar color perception errors for these three colors in subject's peripheral vision. They did not breakout the color naming error (e.g., what color was named instead of the actually presented color), as was reported in this study (see Figure 5.3-1).

Psychological state did not significantly affect how well or poorly a subject did in this color naming task. Therefore, the inverted "U" performance model would not apply. It is interesting to note that for one performance measure studied in this effort, visual field dimension, this performance model did apply and for the other, color perception error, it did not.

5.4 Understanding the Phenomena

To understand the above mentioned phenomena associated with peripheral color vision, one must study the eye's physiology. The three principal parts of the eye which must be addressed are cones, rods, and macular pigmentation.

5.4.1 Cones and Rods. The human eye contains two distinct types of photoreceptors: cones and rods. Cones discriminate fine details and are the primary receptors for color. Rods are good for low levels of illumination and detecting motion Cones inherently show a greater relative sensitivity to longer wavelengths, and rods to shorter wavelengths. The majority of cones are located at the center of the retina; no rods are located centrally (see Figure 5.4-1). At the edge of the retina, the few cones that exist are basically lost in a sea of rods (see Figure 5.4-1). Therefore, due to the spatial location of these photoreceptors, cones are primarily used for foveal vision and rods for peripheral vision (Wertenbaker, 1981).

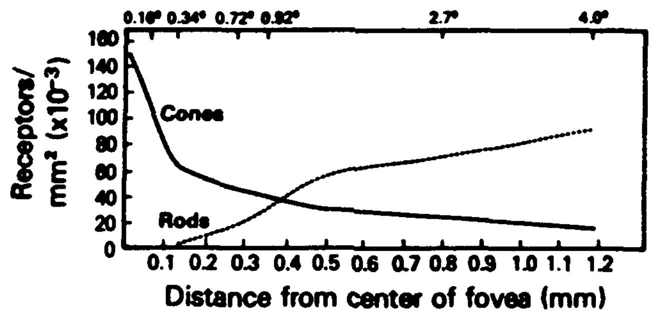

Figure 5.4-1: Photoreceptor Distribution
(Pugh, 1988)

5.4.2 Macular Pigmentation. Macular pigmentation is an inert, non-photosensitive yellow pigment located throughout the foveal portion of the retina. This pigmentation absorbs short wavelengths when presented foveally and has little to no effect when short wavelength stimuli are peripherally located. It is theorized that macular pigmentation protects the eyes from harmful ultra-violate rays.

5.4.3 Phenomenon #1: Ability to Perceive Blue Further in the Periphery than Red or Green. A phenomenon noted throughout this experiment was blue (short wavelength) could be perceived further in the periphery than green and red (medium/long wavelength). One explanation could be that blue appeared brighter in the periphery than either red or green.

The shorter wavelengths appeared brighter due to the symbiotic effect of increased rod activity (peak sensitivity to shorter wavelengths) and the lack of macular pigmentation (absorbs short wavelengths). All three colors could have been adjusted for equal peripheral brightness. But at what degree off of fovea should brightness be matched? As the circles of color slowly moved from the far to near periphery, their brightness also changed with each degree. Also, equalizing brightness was not chosen for this experiment for brightness is subjective; an objective measurement, luminance, was chosen. Peripheral luminance was not used for there exists no standard luminosity function for other than the fovea (Kinney, 1879).

Another explanation involves a recent theory stating that peripheral visual acuity/overall discrimination is greater for blue than red or green due to the smaller size of the yellow/blue color opponent receptive field[4] versus the red/green color opponent receptive field. Therefore, one should be able to detect both yellow and blue further in the periphery than red or green (Plenum, 1991).

5.4.4 Phenomenon #2: Lack of Color in Far Periphery. Subjects could see something whitish moving in their far periphery, but could not yet tell the color of it until the circle continued its trek closer towards the fovea. For detecting moving peripherally located targets, the rods are the primary sensor. Since cones, which are used for determining color, are not plentiful at the outer edges of the retina used for peripheral vision (see Figure 5.4-1), object movement will be perceived by the rods prior to the cones sensing color. Also, subjects were dark adapted; therefore, rod activity was much greater than the cone's.

Color fields have been mapped for several decades, beyond which the color cannot be identified (Kelsey & Schwartz, 1959). In this study, the x-axis boundary of the color field was mapped and adequately displayed the point where a subject lost the ability to

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[4] A color opponent receptive field is an organization of inputs from cones within the brain (Wyszecki & Stiles, 1982).

perceive color.

5.4.5 Phenomenon #3: Targets Appeared to Change Color. Subjects reported seeing the colored circles as other than their actual color. In some cases, the color of the circles actually appeared to change several times as the circle continued it trek towards the subject's fovea. This phenomenon occurs with moving targets, or if an operator scans a display causing display items to move from his/her fovea or near periphery to far periphery, or vice versa. Not only is the color perceived to change, but the brightness is also constantly changing across the visual field. As reported in Section 5.4.4, all colors first appeared whitish in the far periphery.

Due to the broad over-lapping spectral distributions of the phosphors on a CRT, possibly a different color cone was stimulated than was intended. This random occurrence could account for the subject perceiving blue or green when actually red is presented, for instance. Figure 5.4-2 shows the spectral distributions of all three phosphors used in this experiment.

5.5 Use of Color Coding

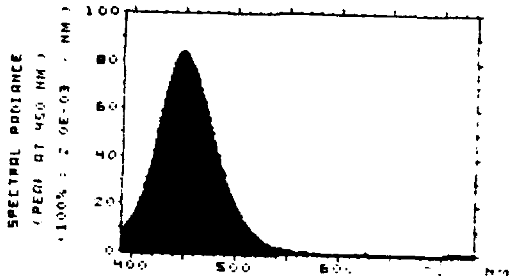
When relying upon color coding as a cue, designers must realize that some colors are perceived easier in one's far periphery than others. Various colors may not even be perceived at all, depending upon how far away from the user's fovea they appear. At other times, the state of the user can cause visual field narrowing, reducing the peripheral field to such an extent that normally noticed colored cues may not be noticed.

Red normally has a warning connotation and green a safe one when used for color coding (e.g.: cockpit color symbology for friendly versus unfriendly aircraft). As can be seen in Figure 5.3-1, there was a 50% chance of confusing red with green in the periphery. This could have grave operational impact when relying on color coding as a cue.

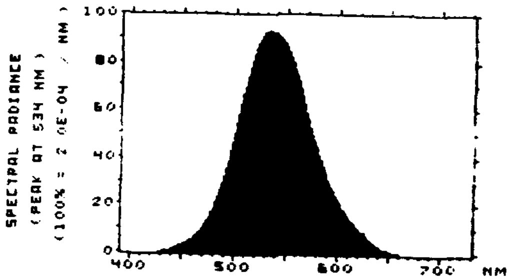
Certain operational issues and procedures may shift the limits of the user's visual field, thereby putting colored cues normally falling within the user's fovea out to their periphery. For instance, when a pilot is in a head-up mode or studying a display at an extreme location within the cockpit, he/she may find a once fovea centered display now peripherally located. Therefore, designers must be aware of the possible limitations of color coding in the periphery even for displays designed to be fovea centered attention getters containing time critical information.

As reported in Section 5.3, the color of the circles appeared to change to the observer as many as three times during their trek across the subject's visual field. This phenomenon may cause serious problems when relying upon color coding for a moving image, or if the pilot quickly moves his/her head from one end of the display console to the other depending upon the size of the arc.

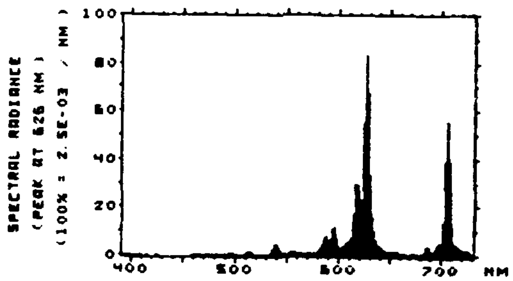
The color blue appeared to be the best choice for the quickest and most reliable detection in one's periphery. The designer must weigh this fact against the user's learned and expected connotation



BLUE



GREEN



RED

Figure 5.4-2: Spectral Distribution of CRT Phosphors[5]

[5] Graph produced by Photo Research Spectrascan. Luminance: 8.7 candela per square meter.

of a color with regards to a specific symbol or environment. As stated previously, red is currently used to denote warning (i.e., unfriendly aircraft approaching). To change this color of choice to blue, which is quicker to recognize and more reliable to see in one's periphery, may prove to be unsatisfactory. Color choice must be picked and judged in light of real world color coding considerations.

6.0 CONCLUSION

Of the three primary colors, blue appeared to be the color of choice to use for easiest peripheral perception, via a CRT medium with all three guns set at equal luminance. The least amount of error was associated with it during color naming and it was the color to be perceived correctly the furthest in one's periphery.

There existed a good deal of confusion in color naming, especially with the colors green and red. The designer must keep this in mind when choosing color usage for coding. Redundant coding (i.e., color and shape) is currently utilized in cockpit CRT displays; but, how clearly can one differentiate a red triangle with a tail (enemy) from a green circle with a tail (friendly) using their peripheral vision? One must also keep in mind that visual acuity is poorer in the periphery than in the fovea region. Designers may want to use additional means of coding cockpit CRT displayed information. For instance, the brightness of various colors might be increased and/or flashing of the colored coded symbol employed.

As shown in this study, visual field narrowing due to stress or relaxation plays a role in where the color is first perceived in one's periphery. Data reported in literature makes no reference to psychological state when color fields are mentioned and mapped (Johnson, 1986; Kelsey & Schwartz, 1959; Dudek & Colton, 1970; Kinney, 1979). This may account for several of the above cited sources mentioning that peripheral vision fields vary greatly among people - perhaps the subjects were experiencing differing psychological states?

Understanding and accommodating for selective and/or poor color perception in the periphery is important for good job performance, especially for occupations such as military pilots. Large scale panoramic displays incorporating most of the usable display area are projected within the next fifteen years for military aircraft. Peripheral vision usage will be relied upon more and more the larger the cockpit display area gets. Will the pilot be able to see the entire display while in a head-up mode via his/her peripheral vision? What happens when visual field narrowing sets in? As shown in this study, a lot may depend upon the choices regarding color usage on these large scale displays. One set of authors, Dudek & Colton, 1970, felt so strongly about the need for good peripheral color vision for observing color cues on the job, that they concluded their paper with the following statement, "It is justifiable for an industrial firm to institute testing procedures to obtain workers that meet specific peripheral color vision requirement". The designer can also help via appropriate color usage.

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APPENDIX A:

Experimental Matrix

EXPERIMENTAL MATRIX

Random Sequences		KEY:	
1:	B R G R G B	B	= Blue
2:	R B G G B R	R	= Red
3:	G B R R B G	G	= Green
4:	B B R R G G	N	= Normal
5:	B G R R G B	R	= Relaxed
6:	G R B B R G	S	= Stressed

Subject	Condition (Sequence) Order
1	N (6,4)
	R (3,5)
	S (1,2)
2	N (5,6)
	S (3,1)
	R (4,2)
3	N (3,5)
	R (6,1)
	S (4,2)
4	N (3,4)
	S (1,5)
	R (2,6)
5	N (4,2)
	R (3,1)
	S (5,6)
6	N (3,5)
	S (2,4)
	R (1,6)
7	N (1,6)
	R (5,3)
	S (4,2)
8	N (3,4)
	S (1,6)
	R (5,2)
9	N (4,1)
	R (5,3)
	S (6,2)
10	N (3,4)
	S (5,1)
	R (2,6)

APPENDIX B:

Autogenics Relaxation Technique

RELAXATION TAPE

-Please get comfortable in the chair

-Take a deep breath and relax

-Allow the tension to escape when you exhale

-Take another deep comfortable breath and relax

-Now without moving any parts of your body I would like you to think the following thoughts

-My right arm is heavy and relaxed **(x2)**

-I can feel the warmth in my right arm **(x2)**

-The finger tips on my right hand are getting tingly and warm **(x2)**

-My left arm feels heavy and relaxed **(x2)**

-I can feel the warmth throughout my left arm **(x2)**

-The finger tips of my left hand feel tingly and warm **(x2)**

-Both of my arms feel heavy and relaxed **(x2)**

-Now lets move on to the right leg

-My right leg feel heavy and relaxed **(x2)**

-I can feel the warmth extending throughout my right leg **(x2)**

-I can feel a warm and tingly sensation in the toes of my right foot **(x2)**

-My left leg feels heavy and relaxed **(x2)**

-I can feel the warmth extending throughout my left leg **(x2)**

-I can feel a warm and tingly sensation in the toes of my left foot **(x2)**

-Both of my legs feel heavy and relaxed, very deeply relaxed **(x2)**

-I am at peace **(x2)**

-Feel the relaxation throughout your body **(x2)**

-Now I'm going to count to five. With each number I say I want you to feel a deeper relaxation. 1, 2, 3, 4, 5.

-You are at peace **(x2)**

-I will shortly be telling you to open your eyes. When I do, I want you to remember this feeling of relaxation. Please stare ahead at the light and we will start the experiment again.

-Please now, slowly open your eyes........

APPENDIX C:

Post Test Questionnaire

QUESTIONNAIRE

1. Prior to the experiment, I was feeling tense.

   disagree 1 2 3 4 5 agree

2. Prior to the experiment, I was feeling relaxed.

   disagree 1 2 3 4 5 agree

3. During the **normal** session, I was feeling tense.

   disagree 1 2 3 4 5 agree

4. During the **normal** session, I was feeling relaxed.

   disagree 1 2 3 4 5 agree

5. During the **relaxed** session, I was feeling tense.

   disagree 1 2 3 4 5 agree

6. During the **relaxed** session, I was feeling relaxed.

   disagree 1 2 3 4 5 agree

7. During the **stressed** session, I was feeling tense.

   disagree 1 2 3 4 5 agree

8. During the **stressed** session, I was feeling relaxed.

   disagree 1 2 3 4 5 agree

9. I thought the crying babies were stressful.

   disagree 1 2 3 4 5 agree

10. I thought the white noise was stressful.

    disagree 1 2 3 4 5 agree

11. I thought of the following to make me feel stressed:

____

____

12. I thought of the following to make me feel relaxed:

____

____

13. Is there any color you could perceive faster than the others?

-Color___________________

14. Did you notice any change in how quickly you perceived a color among the three conditions?

____

____

____

15. Is there anything about the experiment that you would change?

____

____

16. Comments:

Questionnaire Results

The average value and standard deviation for the first ten questions are shown below in Table A2-1.

Question #	Ave Value	Stand Dev
1	2.6	1.07
2	3.3	1.16
3	2.7	1.34
4	3.5	1.27
5	1.2	0.63
6	4.8	0.63
7	4.2	0.63
8	1.6	0.70
9	4.4	0.52
10	3.9	1.10

Table A2-1: Average Value of the First Ten Questionnaire Responses

The following are comments received for questions #11 through #16:

Question #11: Mother-in-law; homework; car accident on an icy road; eye of wild animal; dragon; having to give a speech that I was not prepared for; thesis project; paperwork; spider.

Question #12: My puppy; beaches and tides; laying in a field of flowers on a warm spring day; laying in front of a warm fireplace; Hawaii; Mrs. A's garden in the Spring; watching the sunset from the front porch of a country home; floating.

Question #13: One person said "no"; eight people said "blue"; one person said "red".

Question #14: Three people said "no". Other comments: "Yes, red hard in normal, green hard in stressed"; "I believe I could perceive a color faster in the relaxed state"; "I seemed to do worst when relaxed and better when tense"; "I thought I perceived color quickest in the normal condition, next quicker in the stressed condition, and slowest in the relaxed condition".

Question #15: Four people said "no". Other comments: "Maybe you could add a distracting task to increase stress"; Use higher pitched static like the noise of an HF radio".

Question #16: "The crying babies was stressful. If you would have played that longer before testing I believe I would have not performed as well as I did"; "If the actual stress could be increased, you might see a drop in performance".

APPENDIX D:

Pre-brief

PRE-BRIEF
STRESS P.I.T.

(-Headrest for normal condition should be on chair)

1. Welcome. Please have a seat. First I would like to have you read and sign the "Privacy Act"....(hand subject privacy act document).

(-Good time to insure all equipment is up and running while subject is busy reading document. White noise generator should already be preprogrammed, Orion turned on and preset, tapes put into the tape deck, printer plugged into Orion, light set out on table.
-Make sure experiment is setup for correct subject #.)

2. Let me explain to you what the apparatus is in this room. First you will notice the monitor offset to your right. Upon this display will appear round botches of color, slowly coming towards you. You will interface with the display through this mouse (hand subject mouse). Notice only one button is exposed. You will hit this button and <u>call out the color of the ball</u> as soon as you can identify its color. As for most people, you will first see something moving but not be able to tell its color. Also, for most people, color in their peripheral vision is apt to change. Therefore, you may actually perceive the ball of color to be the wrong color. This is fine. If you call out the wrong color (while at the same time pressing the mouse), the ball will continue to travel towards you. Press the mouse again, as well as call out the color as soon as you perceive the color to change. You will keep calling out the color of the ball until you perceive it to be the correct color. It is possible to "game" any system...please be conservative and be sure you can actually "see" a color before calling one out. Don't call out a color based on its brightness difference from the proceeding ball; but, wait until you can actually see the color of the ball. Each run will consist of six balls of color, two sets for each condition -- normal, stressed and relaxed. You will be given a practice run to familiarize yourself with the experiment. Only three colors will be used: red, blue, and green.

3. Straight ahead on the table will be a small spot of white light. You will be staring at this light throughout the whole experiment. If you feel your eyes start to wander, let me know and I can stop the experiment at anytime to let you rest your eyes. At this point, I would like to reemphasize that you can stop the experiment at anytime if you feel uncomfortable or for any other reason.

4. The instrumentation on the table behind the screen is composed of a tape deck with amp, a white noise generator, and the skin conductance unit. You will be wearing headsets at all times as well as two skin conductance bands around your fingers. Also, the lights will be off during the entire experiment. You will be using

different headrests for each state.

5. We'll start with a practice run. Don't forget, press the mouse button and call out the color of the ball when you can first perceive its color. Remember, if it is the correct color, the ball will disappear and a new one will appear. But, if it is the wrong color, the ball will continue its movement across the screen, and I'll be waiting for you to call out another color -- don't forget to press the mouse button each time. Again, please be conservative; be sure you can actually "see" a color before calling one out.

6. Do you have any questions?

7. I'll need to make some quick measurements with a ruler (measure distance of eye from both edges of display).

8. Which hand do you feel more comfortable to use the mouse with? Let me now put on the skin conductance bands on the other hand after you put on these headsets (give headsets and put on bands). You'll hear nothing through them during the practice run.

9. I'll now turn off the lights and we can begin.

(-Prior to starting, remember to hit the go/stop button on the Orion to reset its session number.
-Do not need to print out this session's data)

==================

(That was good!)
10. Your first condition is the **normal** one. We'll repeat the same procedures as before in the practice run. Remember, stare straight ahead at the light. If you feel your eyes wandering, let me know. Remember, please don't call out a color based on its brightness difference from the proceeding ball; but, wait until you can actually see the color of the ball, call out the color and press the mouse.

11. Do you have any questions?

12. Good. We'll begin in just a moment.

(-Prior to starting, remember to hit the go/stop button on the Orion to reset its session number.
-Hit print button at end of this session.)

==================

(That was good!)
13. We'll briefly take a rest if needed....? Your next condition is the **relaxed** one. Let's change pillows please and remeasure your head's position. Please close your eyes; I'll need to use a flashlight and I don't want it to bother your eyes.

14. Sit back and relax. We'll repeat the same procedures as before. This time, when you see the light on the table, think of something pleasant...a light of hope and tranquility, or anything

else that you find restful. I'll play a tape. Listen and think the thoughts described to you: you'll relax your arms then your legs and end with a relaxation countdown technique. After the tape, you'll hear some "relaxation" music as you open your eyes. Let yourself get into the music and relax. Then we'll start the experiment again. You may at this point, as soon as you open your eyes, hit the mouse button one or two times to get a good feel for where the mouse button is.

15. Do you have any questions?

16. Good. We can begin in just a moment. Don't forget, please call out the color as well as press the mouse button. Shut your eyes now and I'll play the relaxation tape.

(-Prior to starting, remember to hit the go/stop button on the Orion to reset its session number.
-If subject does not stay relaxed, after first set of six colors stop experiment and re-relax using the tape.
-Shut off tape and hit print button at end of this session.)

==================

(That was good!)
17. We'll briefly take a rest if needed...? Your next condition is the **stressed** one. Let's change pillows please and remeasure your head's position. Please close your eyes; I'll need to use a flashlight and I don't want it to bother your eyes.

18. This pillow should feel uncomfortable. Stare ahead at the light on the table. Imagine that it is the eye of someone or something that is stressful to you. You can also think about something that you must get done tomorrow but don't have the time to do it, or think about anything else that you find stressful.

19. I'll start by playing the sounds of a crying baby followed by static. The sound will be on continuously. The first set of six balls will start shortly after you hear the crying babies, followed immediately by the static and the remaining six balls. Remember stare ahead and call out the color as well as press the mouse button.

20. Do you have any questions?

21. Good. We can begin in just a moment.

(-Prior to starting, remember to hit the go/stop button on the Orion to reset its session number.
-Start out with acoustic level below 84 dB(A). If subject is not achieving elevated skin conductance level, raise sound level up to but not exceeding 100 dB (A).
-First set of six should be done with the crying babies. Second set of six with the white noise, pulsing one second on/one second off. ***Hit 'Tape' button to switch on or off tape to VIC which is plugged into the Tuner input***
-Shut off white noise generator and hit print button at end of

this session.)

====================

22. (**option:** if stressed state is last condition) You have the option to be put back into a relaxed state again through the use of the relaxation tapes.

(-If yes, play relaxation tape.)

====================

23. Thank you for participating. Do you have any questions? An ear recheck will be scheduled for you tomorrow.

APPENDIX E:

Privacy Act Statement

INFORMATION PROTECTED BY THE PRIVACY ACT OF 1974

Title: Stress P.I.T. (Psychologically Induced Tension)
Work Unit Number: ILIRF016

1. a) I understand that I have been invited to participate in an experiment concerning peripheral vision versus subject psychological state (high demand, normal, relaxed). The objective of this experiment is to map my visual field with regards to color and/or various display symbologies while I am either relaxed, under minimal stress, or just my everyday self. These experiments are needed to determine if peripheral items on a large scale display are noticeable under various pilot psychological states (high demand, normal, relaxed). In the high demand state peripheral vision has been shown to shrink, possibly causing an item that would normally appear in one's "corner of the eye" not to be noticed at all. The antithesis, whether or not relaxation can overcome this phenomenon, is therefore also of interest.

b) The experiment should require between one to three hours of my time. After this experiment, I may be asked if I would like to participate throughout the year in other experiments, variations on this current theme.

2. As a participant in this experiment, I will perform a routine color and/or symbol recognition task. Basically, I will be letting the computer know when I first notice a ball of color or a symbol moving towards me on the monitor. I will have a pair of headsets on at all times. I will also have bands around two fingers. These bands are measuring my skin conductance, one of the main measurements taken by lie detectors. But in this experiment skin conductance will measure my psychological state (high demand, normal, relaxed). I will get no sensation (i.e., shock) from these finger bands. Through the headsets I will hear nothing during the "normal" psychological state run. During the "high demand" run I will hear loud, but safe exposure levels of noises (i.e., crying babies, static). During the "relaxation" run I will hear a voice describing various mental images and/or telling me to relax different muscles in my body.

3. Any risk or discomfort I shall experience shall be minimal. The risk for temporary threshold shift (TTS) does exist if the noise levels heard in the high demand state exceed 84 dB (A). To reduce this risk to almost nil, if 84 dB (A) is exceeded safe exposure time limits per AFR 161-35 will be strictly enforced. During the past 17 years of experimental acoustic studies at AAMRL/BBA, "no one has incurred a temporary threshold shift that has not recovered, nor incurred a permanent hearing loss as a result of noise exposure." (Experimental Protocol, March 1989)

Initials__________ **Date**___________

Noise will be used as the primary stressor to achieve the high demand state. As stated above, only safe acoustic exposures will be utilized. The objective is not to expose subjects to extremely high levels of "life or death" stresses, but rather to benign everyday levels through the use of common sound icons (i.e., crying babies) or germane broadband noise. In the pre-brief I will be reassured that I can halt the experiment at anytime, for any reason.

4. The Air Force will reap great benefits from the data gathered during these series of experiments. Using this data to design and retrofit aircraft cockpits should improve upon the critical man-machine interface. This data shall also serve to increase the worldwide data base in this area of study. I understand that I shall receive no personal gain or benefit from my participation.

5. There are no effective alternate procedures available that will furnish the data required.

6. I ________________________, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program. ________________________ has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are set forth above, which I have read. I understand that the Principal investigator or his/her designee 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 Medical Consultant for this study may terminate my participation in this study if he/she feels this to be in my best interest. I may be required to undergo certain further examinations, if in the opinion of the Medical Consultant such examinations are necessary for my health or well being.

7. I have considered and accept the unlikely but theoretical possibility as follows:

a) If physical exams and or monitoring of physiological parameters related to this experiment are conducted, it is possible for an unknown physical defect to come to light which might result in disqualification from flight or other special duty.

b) If physical injury were to occur it could result in physical disqualification from flight or other special duty.

Initials__________ Date___________

8. I understand that my entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and that if I desire further information I may contact the Principal Investigator.

I understand that I will not be paid for my participation in this experiment.

I understand that my participation in this study may be photographed, filed or audio/videotaped. I consent to the use of these media for training purposes and understand that any release of records of my participation in this study may be disclosed according to federal law, including the Federal Privacy Act, 5 5 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

Volunteer signature____

Volunteer SSAN________________________ **Date**________________

Witness Signature____

Date_______________

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