PERIPHERALLY LOCATED CRTs: COLOR PERCEPTION LIMITATIONS

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ABSTRACT
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%). These color perception limitations must be kept in mind when designing CRT color formats for aircraft cockpits.

INTRODUCTION
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" 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 mode².

Because of the inclusion of color CRTs in modern cockpits, it is very important to study the ability of subjects to identify color symbology using their peripheral vision. A study was conducted to measure a person's ability to perceive 1.3" circles of the three primary colors (red, green, blue) on a CRT display in their periphery while experiencing three differing psychological states: stressed, normal, relaxed. Two performance measures were studied, color naming error and degrees of off of the fovea (along the x-axis) where the color was correctly identified.

BACKGROUND
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 would know the object was there - a function of rods versus cones. 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 (Kinney, 1979).

Different colors can first be perceived at different locations in the periphery (Johnson, 1986). 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) 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.

METHOD
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.

The 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). 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

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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 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 illumination. The monitor was adjusted to have all three guns (red, blue, green) at an equal luminance of approximately 8.7 candela per square meter.

Psychological state was determined objectively via instantaneous skin conductance readings and a post test questionnaire. The normal state, used as the subject's baseline, was the subject's unadulterated, off-the-street psychological condition. To achieve a state of relaxation, an autogensics relaxation technique was used. Two different auditory sound icons were utilized 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. 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.

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).

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 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 2 & 3]. No interaction effects were found.

DISCUSSION

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 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 1, based on the average values for all subjects.

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 1). When the visual field data for all colors was plotted (Figure 4), the inverted "U" function was also observed for each of the three colors.

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 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 a post-test questionnaire response, it was clear that the subjects did not achieve a maximum stress level (i.e., life or death quandary). Things stress/annoy different
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 2). 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 (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 shows that red and green, though noticeably not as bright, were still confused with the brighter blue.

Visual field narrowing, experienced during the stressed and relaxed states, was shown to effect color field dimension (see Figure 4). Inverted "U" functions were observed for all three colors.

Color Perception Error

Color in one's peripheral vision was apt to be misperceived. Figure 5 shows a breakout via color of the data in Figure 3. 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.

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. Blue appeared brighter than either red or green, even though 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, 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).

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.

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, 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.

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
can 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 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.

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
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.

REFERENCES

Cox, C., Krishnaiah, P., Lee, J., Reising, J. &
Intersection Test for Multiple Comparisons of
Means." In Krishnaiah (Ed.) Multivariate
Analysis (Vol V). Published by Amsterdam:
North Holland Publishing Company.

and Background with Common Signal Lights
on Human Peripheral Color Vision." Human
Factors, 12 (4), pp 401 - 407

Utilization and the Organization of
pp 183 - 201

Retina." American Journal of Optometry &
Physiological Optics, 63 (2), pp 97 - 103

Displays". Proceedings of S.I.D. Vol 20/1,
First Quarter. pp 33 - 40

Various Targets - Background Color Combinations Under Different Chromatic Ambient Illuminations. Report #1027, Research Work Unit # M0100.001-1019, Naval Medical Research & Development Command.


Figure 1: Visual Field Dimension vs. Psychological State
Figure 2: Visual Field Dimension vs. Color
Figure 3: Color Perception Error vs. Color
Figure 4: Color Field vs. Psychological State
Figure 5: Actual Color vs. Perceived Color
<table>
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<tr>
<th>COLOR</th>
<th>RELAXED</th>
<th>STRESSED</th>
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</thead>
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<tr>
<td>BLUE</td>
<td>7%</td>
<td>3%</td>
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<tr>
<td>GREEN</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>RED</td>
<td>11%</td>
<td>2%</td>
</tr>
</tbody>
</table>

Table 1: Color Field Shrinkage

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.

3. A short, fifteen minute technique concentrating on "warm and tingly feelings" to relax a person's body - classically used for stress management (Edelberg, 1972).

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