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RESOLVING POWER OF THE EYE USING COLOR CATHODE-RAY TUBES. (POUV--ETC(U)
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RESOLVING POWER OF THE EYE USING COLOR CATHODE-RAY TUBES

Article by Chief Physician G. F. Santucci, head of the Division of Psychophysiology of Visual Perception, Aviation Medicine Research Center, 5bis, Avenue de la Porte de Sevres, Paris, France, 75996

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Summary

Thanks to an original method and apparatus, it has become possible to study angular visual acuity with simultaneous color contrast on an RVB television screen. The colors tested were red, green, light blue, violet, dark blue, yellow and white, as well as the brightness overall. The brilliance contrast was also studied.

This work, covering a group of 60 flying personnel ranging in age from 20 to 50, made it possible:

To define the optimal character size to guarantee recognition of form with good probability, and

To determine the color contrasts guaranteeing the greatest speed in perception.

The data thus gathered will make it possible to optimalize the reading of information from cathode-ray tubes.

Introduction

Pilots, engineers and physicians agree in recognizing that the development of aircraft missions and performance in future combat requires the preparation of new methods of presenting flight data. In fact, it is recognized that the saturation level both from the physiological and the technological point of view is very close to being surpassed.

Technological mastery of the cathode-ray tube now justifies the conception of new instrument panels and new methods of presenting information.

In order to optimalize this new interface between man and machine, it is necessary to acquire a more profound knowledge of certain physiological parameters of visual perception.

Among the many questions which may arise, we have chosen the study of angular visual acuity in color contrast on a television screen observed by distance vision.

The important role of color in the presentation of data has been demonstrated by a number of works, as the bibliographical summary by Cook (1974) and that by Semple (1971) demonstrate. Very recently Christ (1975) made a certain number of studies on color in visual data presentation systems.

The study of the conclusions of these works as a whole suggests the desirability of using color because the performance is in most cases improved and in no case worsened.

If this idea is accepted, it becomes necessary to optimize presentation and to define a hierarchy for the different colors contributing to speedier information grasp. Studies have been made and references to them are found in the writings of the authors mentioned above. It should be noted that these studies were undertaken for the most part by presenting one color on a black or white background. Now the technology of electronic visualization is well enough advanced to allow presentation in simultaneous color contrast.

I--Status of the Problem

The phenomena of color contrast perception have long been under study (Chevreul, Pieron, Helmoltz, Land). The authors have focused their attention above all on the changes in color sensation produced by the simultaneous presentation of two areas of different color.

In the biotechnological realm, color contrast must be regarded in one of two ways, either such that color in itself carries the message (bulb lighted or not) or color can be supported by a form also playing a part in the message. In such a case it is necessary to recognize a colored form on a colored background. Visual acuity is one function pertinent to such a scheme.

A study of the publications dealing with the subject does not yield, as we will see, consistent data. This is due on the one hand to the numerous parameters governing color perception and visual acuity. The problem is complicated moreover by the fact that the terminology and the measurement system were only recently codified by the CIE. Where we are concerned, the terminology and measurement system used will be those in accordance with the CIE norms.

The data in the literature we are presenting can be classified in two categories: the first group includes the older results pertaining to experiments done with color presentation systems based on the projection of colored areas, using lamps with filters or spectral sources and pigmentary stimuli (generally paper) illuminated by a lamp. The second group has to do with more recent work using electronic visualization of the cathode-ray tube type (most frequently) or electroluminescent diodes, etc.

1.1--Display Systems Based on Lamps

MacAdam (1949) measured visual acuity by presenting optotypes of various colors against an isoluminous grey background. In each instance he sought with achromatic stimuli to find the brightness contrast yielding the same performance. Thus he showed that the higher the saturation of the color the better visual acuity is, because it becomes the equivalent of that obtained with ever-greater brightness contrast. He believed, moreover, that visual acuity for color contrast is closely related to the chromatic differential threshold.

In 1957, Mercier reported on the results obtained by Ferree and Rand, indicating that with equal luminosity the colors lend themselves to best visual acuity in the following order: yellow, yellow-green, orange, green, red, blue-green, blue. However, Roux (1958) described the results obtained by Arnulf and Flement, to the effect that if brightness is truly the same, acuity is identical for all colors and white light.

In 1956, Legrand reported in his book on the contradictory results obtained by a number of authors. "In short, this problem of acuity with colored light is extremely confusing."

In 1966, Cavonius and Schumacher made a study with two subjects of color visual acuity using a grid with equally bright alternating bars, but with different wave lengths, which comes to the same as a color test on a colored background. Their experimental apparatus enabled them to make color tests with very high saturation. A fixed wave length was assigned to a series of bars, while the other series was illuminated successively by the whole visible spectrum. The greater the ( ) between the wave length of the test and that of the background, the greater acuity proved to be. But very interesting results were obtained in that the effect of this wave-length difference is not the same for the entire spectrum. Acuity is good with a feeble ( ), when the test and the background were illuminated with short wave lengths, while the ( ) would have to be much greater to obtain the same level of acuity with the long wave lengths in the visible spectrum.

In 1968 Pokorny et al. used a grid to measure visual acuity in five individuals, varying the test wave length and the brightness levels. Visual acuity increased asymmetrically with the brightness of the test. It was lowest for blue in four of the test subjects, while for one individual visual acuity also remained at the lowest point while brightness increased in the red range.

1.2--Color Contrast and Electronic Visualization

Puig (1976), in his bibliographical survey, described a certain number of works devoted to the study of the contribution of color to the detection and recognition of the target on television screens. This research had to do with overall simulation studies, and in no case with the study of visual acuity.

Work pertaining to the readability of information on television screens had as its theme the comparison of performance yields with different display systems and direct viewing (Hennesy 1973, Long 1969, Puig 1976).

Two publications pertaining to color perception on television screens should be mentioned. Haeusing (1976) sought to establish the number of colors which could be recognized without confusion, using a tricolor Shadow Mask television system. He demonstrated that six colors can be distinguished with good probability: red, green, light blue, yellow, dark blue and violet.

Dupont-Henius (1977) established the chromatic differential thresholds using a tricolor Shadow Mask television screen. His study of 20 subjects did not enable him to confirm the results obtained by MacAdam in 1942. The points measured were not located on an ellipse but formed a broken ovoid figure.

Thus we did not find in the literature any works which can provide precise data to answer the problems confronting us.

The data we reported in section 1.1 cannot be transposed directly because they were not obtained using cathode-ray tubes.

Now the mechanisms utilized in the visual perception of images presented on a cathode-ray tube are very probably different from those used when the stimulus is "stable."

In connection in particular with television scanning tubes, the image received by the eye is an image constructed sequentially in time and in space.

We thus found it necessary to develop and construct an apparatus for the study of the following points:

What is the role of brightness contrast in angular visual acuity measured on a television screen?

Are there differences in visual acuity for simultaneous color contrast depending on the colors used if there is equality of brightness for the test and the background?

What is the smallest size for significant detail in a test guaranteeing good perception?

Does the color of the background or the test have a preponderant influence?

II--Experimental Methodology

For technical reasons we undertook two experiments differing one from the other in the colors tested and the television screens tested. In the course of the experiments we designated them A and B.

A) The Apparatus

1) Television Monitors

Experiment A

A Schlumberger RC6 V3 color television of the RVB type equipped with an A67150X video color tube with a diagonal measurement of 63 centimeters was used. This monitor is of the tricolor Shadow Mask type with a 625-line scan.

Experiment B

This was done using a Sony PVM 1300E/AS monitor equipped with a trinitron tube, diagonal measurement 33 centimeters.

2) Image Generating System

The apparatus allowed the electronic overlay of a colored test on a background of another color. Since television scanning did not make the establishment of a circular image precise enough to obtain a ring possible, we selected an E developed in accordance with the rules of the Landolt ring. The thickness of the bars was equal to the width of the intervals. The E was encompassed within a square of five base units, the unit being defined by the thickness of the bar. The significant detail was thus the gap the eye should perceive.

This E could be oriented upward, downward, to the left or to the right of the screen, being always centered upon it.

It could be presented in any one of nine sizes.

Characteristics of the Sizes Presented

Size Number	0	1	2	3	4	5	6	7	11
Angular Value of Significant Detail	1'25"	1'46"	2'08"	2'30"	2'51"	3'13"	3'34"	3'55"	5'21"

The system offered a palette range of six colors for the test and the background. Three times six channels were available. Each channel permitted the creation of a color by the mixing of the three basics: red, green, blue.

3) The Control System

This was directed by a perforated tape produced by a computer on the basis of a program established as a function of the type of experiment chosen. On the tape were shown the image, presentation time and order of succession.

4) The Response System

The subject responded by means of a manipulator with four positions corresponding to the four orientations of the optotype. Thus the nature of the response and the response time of these subjects were obtained. These results were recorded on the perforated tape, along with the characteristics of the image giving rise to the response.

There were three possible types of response:

a) Subject recognizes or thinks he has recognized the orientation of the symbol and so indicates.

b) Subject does not recognize it and presses a button indicating "I do not know."

c) Subject chooses not to respond.

In all cases, the image remains on display during the time established by the program.

B) The Experiments

Experiment A

We studied the three basic television colors: red (R), green (V), and light blue (B) and two mixtures: yellow (J) and white (W), as well as violet and dark blue. Colorimetric analysis with a "Gamma Scientific" type 3000 A spectrophotometer made it possible to calculate the tricolor coordinates in the X Y Z system.

	R	V	B	J	W
x	0.67	0.34	0.15	0.44	0.28
y	0.33	0.57	0.08	0.42	0.29

Along with these five colors, black was tested. In all we thus had six possibilities for the background and six for the test. Since letters and backgrounds of the same color were not programmed, this yielded 30 simultaneous contrast possibilities.

Experiment B

In addition to the three fundamental colors, red, green and light blue, the study included white, violet and dark blue, with the following tricolor coordinates: violet--x 0.40 and y 0.22; dark blue--x 0.24 and y 0.34.

There were thus 30 simultaneous contrast possibilities.

2) Subjects

Thirty air crew members were studied during each of the experiments, making 60 subjects in all. Their ages ranged from 20 to 50, and there were 3 groups of 10 subjects each, aged 20 to 29, 30 to 39 and 40 to 50 years of age.

These subjects had normal vision, as they were all flying personnel. We had access to their periodic examination records and could eliminate any anomalies, however slight.

3) Test Presentation Conditions

We studied visual acuity in distance vision. The television set was situated eight meters (Experiment A) and four meters (Experiment B) from the subject, at the far end of a large grey canvas tunnel, which provided a neutral environment from the point of view of color. The tunnel was lighted by fluorescent tubes making it possible to ensure uniform lighting at 300 lux 1 meter from the floor (eye level for subjects sitting in adjustable armchairs).

4) Screen Brightness

Brightness was kept constant for all colors. The level established was 15 nits, measured with a radio-photometer equipped with a CIE corrected cell, on which a telescope with an opening of 2° was mounted. Since the test range was more than 2°, we had foveal vision conditions. The brightness of the immediate surroundings of the television set was 12 to 13 nits.

C) Organization of Each Session

In order to measure visual acuity, we had to display to the subject a range of character sizes such that there was at least one size always correctly perceived and one size which was not. The definition provided by the television screen did not enable us to obtain non-perceived sizes for certain colors. Ten sizes were displayed.

In order to avoid chance responses, each size was displayed four times (up, down, right and left).

All sizes and positions were displayed for each color pair. In all, we had to display 900 images. Each image was constructed by dividing the display time (1,500 ms), size and orientation of the letter, background color and color of the letter.

The computer program provided a random order for display. In each interval between images the computer inserted in the display order one second of iso-luminous white area with colors, in order to eliminate the effects of consecutive color contrast.

Each session lasted approximately 45 minutes.

III. Results

Two types of analysis were undertaken:

Qualitative analysis of the percentage of accurate responses; and

Quantitative analysis based on the study of response time.

The statistical processes used for the purpose (analysis of variance and comparison of consecutive averages) were applied separately for the two experiments, the results being shown for each of the procedures.

3.1--Experiment A

This experiment involved color pairs formed on the basis of the colors red, green, blue, yellow, white and black.

3.1.1--Study of Color Pairs

3.1.1.1--Quantitative Study

The comparison of consecutive averages according to the method of Newmans and Keuls yielded the data for Table 1, which shows the response time as a function of the background color, all sizes taken together.

In this table one can differentiate two groups of colors, on the one hand blue and red, and on the other white, yellow and green.

Blue and red produced well-grouped and good average response times, while the average response time was more scattered with yellow, white and green backgrounds.

The black background yielded the best results with equal average values for all character colors except blue. This is explained by the contrast in brightness. This data was expected and confirmed the initial hypothesis.

Examining the response time as a function of lighter color with backgrounds of different colors, the results proved identical to those set forth above and thus are not detailed.

3.1.1.2--Qualitative Analysis

Table II shows in synthetic form the average percentage of correct responses for a given background color as a function of the character color. The classification of colors closely paralleled that obtained in the study of average response times. It can be noted that all of the response times included between 590 and 633 ms correspond to a correct response rate of 95 percent or more. The same observations held true in examining performance for a given letter color as a function of various background colors.

3.1.2--Analysis of Angular Visual Acuity by Color

Figure III shows the average response time for a given background color as a function of character size (all character colors taken together).

It can be noted that performance was best for all sizes when there was brightness contrast (black background).

For the smallest size corresponding to significant detail seen at an angle of 1'25", the red, blue and yellow backgrounds produced the longest response times. But beginning with size 2, it can be seen that the colors red and blue yielded the greatest speed of perception for all sizes.

However, the differences among the colors decreased as character size increased, yielding equal performance on the level of the largest size (5'21").

3.1.3--Analysis of Variance

The study of variance revealed a greater scattering of response times based on background color, while on the contrary there was greater homogeneity for lighter colors. This suggests that the background color plays a more important role in perception and contributes to better differentiation of color pairs than does letter color.

This result becomes clear if one looks at the relative importance of the major radiation produced by the background and the more feeble quantity emitted by the character.

3.2--Experiment B

This experiment was designed to study angular visual acuity by color contrast obtained with the colors red, green, light blue, dark blue and violet.

The methodology was in every way comparable to that used for Experiment A.

However, unlike the case in Experiment A, two pairs of colors (green/dark blue and red/violet) yielded results clearly differentiated from the others. Therefore, for certain statistical procedures, they were excluded in order to avoid affecting the general results.

3.2.1--Study of Color Pairs

3.2.1.1--Qualitative Study

Table IV shows the average response time (all sizes taken together) for colored letters against a solid background.

As in Experiment A, it can be noted that blue as a background color produced the most clearly grouped and best results.

The white background yielded slightly more scattered results than the blue background, but clearly more homogeneous than in Experiment A.

The results were grouped for red and violet backgrounds, except when these colors were displayed together as a color pair.

The same phenomenon was seen for the colors green and dark blue.

The very considerable increase in response time with color pairs should be noted.

In considering the effect of the background color for a letter, a hierarchy similar to that described above was found, and so the detailed results have not been set forth.

3.2.1.2--Qualitative Analysis

Table IV shows the average percentage (all sizes taken together) of correct responses according to background color for the various letter colors. It clearly shows the effect of the green/dark blue and red/violet pairs, which yielded a very low percentage of accurate responses.

The color pairs used in Experiment A yielded identical results. It can be noted that the two new colors tested, violet and red, yielded the best performance when they were not contrasted.

3.2.3--Angular Visual Acuity and Color

A study of the results described above led us to eliminate the green/dark blue and red/violet pairs as too unsatisfactory for the study of the effects of character size.

Also, Figure 5 gives an evaluation of the average response time (all character colors taken together) for a given background as a function of the size of the optotype.

Taking the elimination of the unfavorable color pairs into account, one can then see a rapid improvement in the response time with an increase in the optotype size. This result was identical to that obtained in Experiment A.

3.2.3

An analysis of variance showed a preponderance of the background over the letter for Experiment B as in Experiment A.

This analysis was not as refined as for Experiment A because of the scattering introduced by the particular pairs already mentioned.

Discussion

The results we have just described are difficult to compare with earlier work because the stimulus used is very different. In fact, the televised image is constructed sequentially in time and space and in this way is different from the "light box" type of stimulation system.

From the colorimetric point of view, one can however consider the results obtained by MacAdam. That author showed that among the three parameters of color stimulation (tonality, brightness, saturation), saturation was the major factor in acuity at constant brightness. He also stressed the concept of the link between visual acuity and the chromatic differential threshold. Our results also suggest that the more saturated a color is, the better acuity becomes.

Also, if one examines the tricolor coordinates of our stimuli, they can be said to be equidistant in the 1931 CIE x, y, z triangle (Figure 7) and the differences in performance noted are inadequately explained in this diagram. The same parameters, shown on a 1964 UCS triangle (Figure 8) show that in fact this equidistance is not maintained, above all for the mixtures involving blue (violet and dark blue).

Our study design was so constructed as to minimize the psychosociological influence of the color, the nature of the patch, and possible fatigue, in an attempt to observe as pure a phenomenon as possible.

Consequently we took a homogeneous sampling of the population made up of air crew members. The response system was designed to avoid, among other things, any verbalization on the part of the subject.

The patch was as basic as possible in view of the fact that one cannot in a biotechnological study dissociate the motor response from the perception.

The length of the experiment and the program for presenting images were conceived in such a way that possible fatigue would not interfere with the results. Although we have not set forth these results above, we were able to establish that no deterioration of performance occurred in the course of the tests.

Again with the reduction of causes of fatigue in mind, the light environment of the screen was such as to involve no excessive contrasts. It is true that we did not have here the operational conditions in which violent contrasts might be encountered. Thus it is necessary to verify this data at high and low luminance.

The form of the stimulus needed for an accurate study of acuity was relatively neutral as to data content.

Also, it must be realized that the results we have set forth are but basic elements for a needed study on the various parameters of readability of data in real saturation.

From a technological point of view, it should be noted that blue and the mixtures containing it were among the colors yielding the best results. Now the cathode system which can currently be mounted is based on the principle of the variable penetration tube, which allows only the colors obtainable from a mixture of red and green. In this connection, one can wonder however if this limitation could not be offset in part by the better definition of random or chance scanning associated with the penetration tube. Also we are pursuing a physiological study in relation to this display system.

Conclusions

In order to specify certain physiological parameters of visual perception with cathode-ray tubes, an original method and apparatus were designed and perfected.

The first subject for application was the study of visual acuity with simultaneous color contrast on a television screen.

The contrasts tested were obtained on the basis of the colors red, green, light blue, yellow, dark blue and violet, as well as white and black.

The results show that when a brilliance contrast is provided performance is best, whatever the color used. On the other hand, if equal brightness is ensured, the speediest response times were found for the colors red and blue. Violet also yields good perception except if contrasted with red.

The influence of the background color is greater than that of the letter color.

These results represent basic data making it possible to draft systems for displaying data in color with cathode-ray tubes.

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Table 1--Results of Experiment A

Legend: 1--Average response time by color pairs--the response times, expressed in milliseconds, are shown for the corresponding letter colors. The results fall within a given framework, showing no significant difference (at the one percent level) from the comparisons of consecutive averages by the Newman-Keuls method. 2--Black. 3--Blue. 4--Red. 5--Yellow. 6--Green. 7--White background. 8--White. 9--Green background. 10--Red background. 11--Blue background. 12--Black background.

Table 2--Results of Experiment A

Legend: 1--Average percentages of correct responses by letter color for color pairs. 2--White background. 3--Yellow background. 4--Green background. 5--Red background. 6--Blue background. 7--Black background. N--Black. B--Blue. R--Red. V--Green. W--White.

Table 4--Results of Experiment B--Average Response Time in Milliseconds

Legend: 1--The colors fall within a given framework, showing no significant difference (at a level of one percent), according to the Newman and Keuls method. 2--Violet. 3--Red. 4--Light blue. 5--White. 6--Dark blue. 7--Background. 8--Green. 9--Blue-green. 10--Green-blue. 11--Red-blue.

Table 5--Results of Experiment B--Percentages of Correct Responses by Background Color

Legend: 1--White background. 2--Green background. 3--Dark blue background. 4--Red background. 5--Violet background. 6--Light blue background. B--Light blue. R--Red. P--Violet. C--Dark blue. V--Green. W--White.

Figure 6--Results of Experiment B--Response Time by Size and Background Color (Green-Dark Blue and Red-Violet Pairs Eliminated)

Legend: 1--White. 2--Light blue. 3--Dark blue. 4--Green. 5--Red. 6--Violet. 7--Size.

Figure 3--Results of Experiment A--Development of Accurate Response Time by Size According to Background Color

Legend: 1--Background color. 2--Black. 3--Red. 4--Blue. 5--Green. 6--Yellow. 7--White. 8--Optotype size.

Figure 7--Positions of Stimuli Used for Experimenting with the X Y Z Triangles--Spectral Location, CIE 1931

Legend: 1--Wave length in nm. 2--Green. 3--Yellow. 4--Dark blue. 5--White. 6--Red. 7--Violet. 8--Light blue.

Figure 8--Positions of Stimuli Used in Experimentation with the UCV Triangle

Legend: 1--UCS diagram, CIE 1960. 2--Green. 3--Yellow. 4--Red. 5--Dark blue. 6--White. 7--Violet. 8--Light blue.