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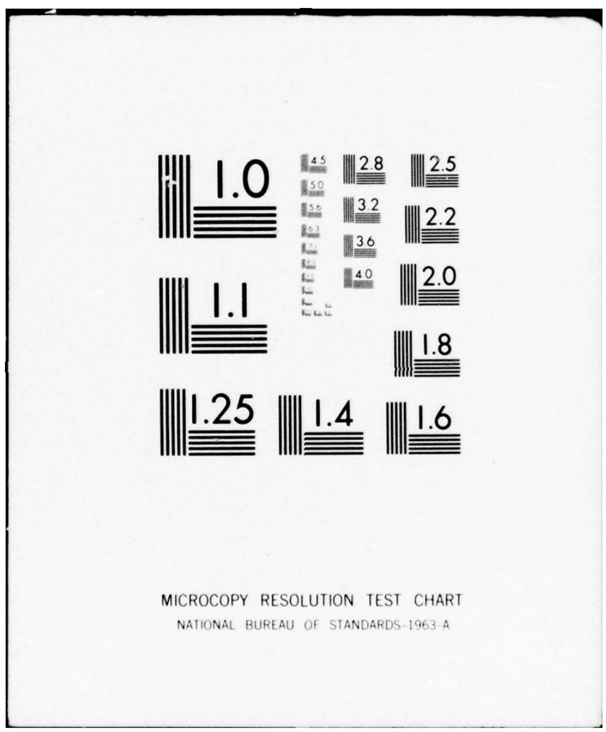
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COLOR CODING EFFECTS ON HUMAN PERFORMANCE, AN ANNOTATED BIBLIOGRAPHY

ELLEN BARKER AND MARJORIE J. KREBS

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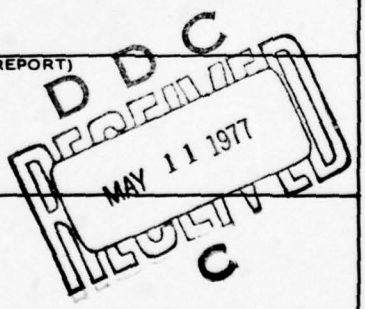

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color coding
color vision
bibliography
peripheral vision
ambient lighting

20. ABSTRACT (CONTINUE ON REVERSE SIDE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

Abstracts and references for 78 studies and review articles are provided which are concerned with one or more aspects of color effects on human performance. Major emphasis was placed on including studies of the effect of color as a coding dimension in various tasks. However, articles on a variety of other topics related to the use of color have been included such as: the number of identifiable colors, selection of specific colors, peripheral vision for color, issues of legibility and acuity, etc. In addition, seven reviews of color literature are cited.

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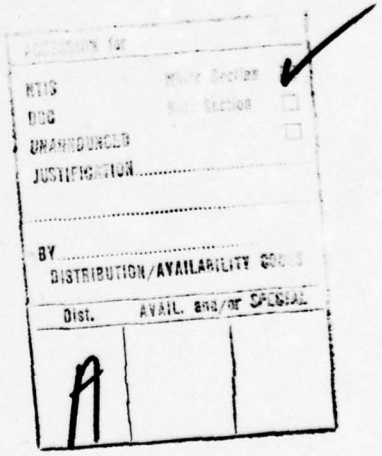

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SECTION I

INTRODUCTION

This bibliography includes abstracts of 78 studies and review articles which are concerned in some way with the effects of color on human performance. While emphasis has been placed on studies of the effects of color as a coding dimension, articles on a variety of other related topics have been included.

At the end of this section, Table I-1 provides a categorization of studies by topic area. Where a given study is appropriate to more than one area it is referenced more than once.

In Section II, abstracts of each report are presented alphabetically by author. In Section III, the references for all studies are provided for easy referral.

In general, the results of the performance studies can be summarized by stating that the relative effectiveness of color is dependent upon the task of the subject. Color coding appears to be most effective when the position of the target(s) is unknown. This is particularly evident in tasks involving search over cluttered display fields. Other tasks such as target identification tend not to be beneficially influenced by color coding.

Many studies were located which dealt with the maximum number of colors which could be absolutely identified under various conditions. For a given alphabet size (number of colors used) other studies were concerned with the selection of maximally discriminable hues. Other topic areas include: color acuity, legibility, peripheral sensitivity to color and ambient lighting.

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An attempt was made to include those studies in which the conditions of the experiment approximated in some way the aircraft pilot's environment. Therefore, very little of the extensive psychophysical-threshold literature is included. Also, theoretical studies without data were, for the most part, excluded. A number of literature reviews and/or design guides dealing with color have been referenced.

Table I-1. Studies Organized by Major Topic Area

PERFORMANCE STUDIES BY TASK:

Detect

Bartlett, et al, '68
Christ and Corso, '75
Connors, '68
Connors, '69
Fowler and Jones, '72
French, '67
Harvey, '71
Loeb, et al, '67
Muller, '55
Pollack, '68
Poock, '69
Reynolds, '72
Sperling and Jolliffe, '65
Wagner, '75a
Wallace, '71

Locate (Search)

Beyer, et al, '71
Brooks, '65
Cahill and Carter, '76
Christ and Corso, '75
Christner and Ray, '61
Eriksen, '53
Green and Anderson, '56
Green, et al, '53
Hitt, '61
Rizy, '65
Rizy, '67
Saenz and Riche, '74
Shontz, et al, '68
Shontz, et al, '71
Smith, '62
Smith, '63a

Identify/Recognize

Beyer, et al, '71
Christ and Corso, '75
Christner and Ray, '61
Fowler and Jones, '72
Hitt, '61
Markoff, '72
Wagner, 75b

Compare

Hitt, '61
Smith, et al, '65
Smith and Farquhar, '65

Count

Christner and Ray, '61
Hitt, '61
Lee, '69
Smith, 63a
Smith, 63b
Smith, et al, '65
Smith and Farquhar, '65
Smith and Thomas, '64

Track

Beyer, et al, '71
Chase, '76

Recall

Anderson and Fitts, '58
Kanarick and and Petersen, '71

STUDIES OF COLOR SELECTION:

Alphabet Size (How many colors)

Bishop and Crook, '61
Connolly, et al, '74
Conover, '59
Conover, and Kraft, '58
Haeusing, '76
Halsey and Chapanis, '51
Halsey and Chapanis, '54
Hanes and Rhoades, '54

Color Discriminability (Which colors?)

Conover, '59
Conover and Karft, '58
Garner and Creelman
Halsey, '58a, b
Reed, '51
Reynolds, et al., '72
Rizy, '65
Siegel and Siegel, '71

STIMULUS FACTORS:

Legibility

Connolly, et al, '74
Ellis and Burrell, '75
McLean, '65
Smith, '63b
Snadowsky, '66

Luminance/Brightness Matching

Chapanis and Halsey, '55
Christman, '65
Connors, '68
Connors, '69

Acuity

Cavonius, '65
Cavonius and Schumacher, '66
Pokorny, et al, '68

Ambient Lighting

AGARD proceedings, '67
Barnes, '70

VISUAL FACTORS

Peripheral Vision

Bartlett, et al, '68
Connors and Kinney, '61
Dudek and Colton, '70
Haines, et al, '74
Haines, et al, '75
Sperling and Jolliffe, '65
Weissman and Kinney, '74

Reviews of Color Literature

Christ, '74
Christ, '75
DeMars, '75
Farrell and Booth, '75
Heglin, '73
Jones, '62
Semple, et al, '71

Anomalous Effects

Hennessey and Borden, '73
Ronchi, '61

Color Vision Defects

AGARD proceedings, '72
Jones, et al., '75

SECTION II

BIBLIOGRAPHY

TITLE: Aircraft Instrument and Cockpit Lighting by Red or White Light

DATE: October, 1967

ABSTRACT: Eighteen papers covering fundamental work, practical applications, surveys of user opinion and engineering aspects of instrument and cockpit lighting were presented. Valid arguments were put forward for almost every possible combination and type of lighting. Scanning an instrument panel illuminated by dim white light causes only a slight loss of dark adaptation compared to that which it is possible to achieve after looking at equally legible red lit instruments. There is little difference in the level of adaptation associated with either low-temperature-white or lunar-white lit instruments. There is insufficient evidence to state whether the differences in threshold associated with red or with white lighting are significant operationally, for this depends upon a variable factor: the precise nature of the visual task. User opinion in favor of red light is often not valid since these users often have had little or no experience of a comparable white lighting system. At an experimental level, it is generally felt that the disadvantages of red integral lighting (loss of color coding, accommodation difficulties) outweigh the advantages (slightly lower threshold). Floodlighting should be easily changeable from red to white. When the visual task requires the aviator to detect external objects and features, it should be red. When map reading is required, a small part of the floodlit visual field (sufficient to read the particular part of the map being scrutinized) should be white, as this will tend to prevent loss of dark adaptation in the peripheral parts of the visual field. In order to help define the visual task, the proportions of "head out" and "head in cockpit" flying in different aircraft and in different roles should be determined.

Laboratory and/or Contractor: North Atlantic Treaty Organization
Advisory Group for Aerospace Research
and Development

Identification: Conference Proceedings No. 26, 286 pp.

Key Words: cockpit lighting, dark adaptation, color discrimination, preadaptation, peripheral vision, red lighting, white lighting

TITLE: Color Vision Requirements in Different Operational Roles

DATE: November 1972

ABSTRACT: Conference participants covered the relationship between clinical and theoretical concepts of color vision, the description and application of color vision testing methods and the extent to which color vision is required for aviation careers. Some types of color vision deficiencies such as mild anomalous trichomats are able to fly safely. Many military aviation activities do not require normal color vision. Passing a color lantern test may be sufficient for acceptance for flight training. If normal color vision is required, the best screening method involves pseudo-isochromatic tables. Dichromats and extremely abnormal trichromats (both groups being totally red-green blind) should be excluded from aviation activities that require any degree of color perception.

Laboratory and/or Contractor: Advisory Group for Aerospace Research and Development

Identification: Report No.: AGARD-CP-99
AD No.: 755-085, 83 pp.

Key Words: color vision, color vision testing, color vision requirements

TITLE: Amount of Information Gained During Brief Exposures of Numerals and Colors

DATE: 1958

ABSTRACT: The question of how much is perceived during the brief exposure of a group of stimulus objects was examined. Groups of homogeneous color or shape symbols, or combined color-numeric symbols, were exposed for 0.1 sec to 12 subjects. The information content of the groups of symbols (messages) varied from 9.51 to 25.36 bits per message. Performance at first increased and then decreased as information content per message was systematically increased, reaching different maxima for each of the three coding schemes studied. Maximum average information transmitted about color was 10.44 bits per exposure, with messages that contained four color symbols. Maximum average information transmitted about numerals was 14.94 bits, with messages that contained six symbols. Maximum information transmitted about the color-numeric symbols was 18.64 bits, with four symbols; this was significantly greater than the information transmitted with just color or numerals alone. Thus, coding of information that is exposed for 0.1 second can help performance in recall, with color-numeric symbols being recalled better than either color or numerals alone.

Laboratory and/or Contractor: Office of Naval Research and Ohio State University Research Foundation

Principal Investigator(s)/Monitor: Nancy S. Anderson and Paul M. Fitts
Ohio State University

Identification: Contract No.: Nonr-495(02)
Journal of Experimental Psychology,
Vol. 56, No. 4, 1958, pp. 362-369

Key Words: short-term memory, color-numeric symbols, color-numeric coding, maximum information transmission, brief exposures

TITLE: The Effect of Cockpit Lighting Systems on Multicolored Displays

DATE: December, 1970

ABSTRACT: This report analyzes the performance of 42 subjects reading aircraft instruments comprising various combinations of pointer/background colors viewed with both Army/Navy Instrument and Panel Lighting Red and Air Force Blue-White cockpit lighting systems. The results rank the pointer/background color combinations according to the least number of scale-reading errors they produced.

The greater the contrast between background and pointer the fewer the errors. Results were presented in tabular form for all lighting conditions. Black background was the best and white the worst for both lighting systems. At the lowest luminance levels a white, yellow or orange pointer on black background yielded best results.

Laboratory and/or Contractor: Human Engineering Laboratories
U. S. Army Aberdeen Research and Development Center
Aberdeen Proving Ground, Maryland

Principal Investigator(s)/Monitor: John A. Barnes

Identification: Report No.: 30-70
AMCMS Code: 502 F.11.81900
AD No.: 716610, 33 pp.

Key Words: multicolored displays, display reading, instrument lighting

TITLE: Effects of Wavelength and Retinal Locus on the Reaction Time to Onset and Offset Stimulation

DATE: 1968

ABSTRACT: This study measured onset and offset reaction time to a long and a short wave band in both the fovea and periphery. The wave bands were selected with the intention of isolating foveal and peripheral systems. Three males with normal color vision and ten hours pretraining were dark adapted for 30 minutes prior to each of eight experimental sessions. With the right eye, subjects responded to offset or onset of red or blue light at three luminance levels. Reaction time to onset stimulation in the periphery is significantly faster than to offset. The difference between onset and offset reaction time in the fovea was not significant. On-off differences are independent of wavelength. Moreover, because a common function for intensity, independent of wavelength, existed in the periphery as well as in the fovea only when correction was made in the peripheral data for the peripheral luminosity function, it appears that those data, with their on-off differences, reflect the activity of the peripheral (rod) system.

Laboratory and/or Contractor: University of Arizona

Principal Investigator(s)/Monitor: Neil R. Bartlett, Thomas G. Sticht and Victor P. Pease
University of Arizona
Human Resources Research Organization
Monterey, California and
St. Lawrence University

Identification: NSF Grant No.: GB 3955
Journal of Experimental Psychology, Vol. 78, No. 4, 1968, pp. 699-701

Key Words: onset reaction time, offset reaction time, retinal locus

TITLE: Investigations on the Readability and Interpretability of Electronic Displays: Investigations on the Effectiveness of Brightness Coding and Color Coding of Display Elements

DATE: 1971

ABSTRACT: This study compared the effectiveness of color coding with that of brightness coding on CRT displays. Four experiments involving 68 subjects were run: locating a coded number in a 4 by 5 matrix of digits, tracking a coded symbol with other similar non-coded symbols on the screen, tachistoscopic identification of coded symbols and the gathering of subjective evaluations of various color codings of an experimental electronic display. Responses to color coding were faster than to brightness coding but the difference, while statistically significant, was probably not of practical importance. A subjective preference was found for color-coded displays.

Laboratory and/or Contractor: Deutsche Luft-und Raumfart

Principal Investigator(s)/Monitor: R. Beyer, H., D. Schenk and E. Zietlow

Identification: Publication No.: DLR FB 71-57
Translation No.: 1641
AD No.: 914694
Date: 1971, 80 pp.

Key Words: color coding, brightness coding, electronic displays

TITLE: Absolute Identification of Color for Target Presented Against White and Colored Backgrounds

DATE: March 1961

ABSTRACT: The number of stimulus colors which can be absolutely identified when viewed against various colored backgrounds was investigated. Additive mixtures of light passed through narrow-band and Illuminant-C filters were projected onto a device which permitted independent control of target and background characteristics. Ten subjects (not all involved in every experiment) took 10 to 14 practice runs to learn to identify 28 colors of maximum purity from 10 hues (with white) at three luminances (2 to 200 times background luminance) against a white background. Targets at no less than 50 percent purity combined with colored backgrounds of no more than 50 percent purity could be learned with moderate amounts of additional practice. Background purity interacted with target luminance, high purity producing increased errors at the lower luminances. Reduction of target luminance below the luminance of a colored background was found to make identification very difficult. No significant effect of round versus rectangular target shape was found. Decreasing diameter of round target size from 0.12 in to 0.06 in impaired identification. Conditions which appear to interfere with the subjective reference standard, such as distracting tasks, lapse of time, and increase in the number of items in a set, tended to impair color identification.

Laboratory and/or Contractor: Behavioral Sciences Laboratory
Wright Air Development Division
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Principal Investigator(s)/Monitor: Harold P. Bishop and
Mason N. Crook
Institute for Applied
Experimental Psychology
Tufts University

Identification: Contract No.: AF 33 (616) - 5087
Project No.: 7184; Report No. 60-611, 42 pp.

Key Words: color identification, luminance, target size

TITLE: Search Time and Color Coding

DATE: 1965

ABSTRACT: To determine the effect of color coding on search time, six groups of ten subjects each were asked to respond to ten different displays containing 60 symbols, some of which were color coded. Coding consisted of adding a bar of color beneath the target. Subjects were informed in advance how the targets were coded. Comparisons among conditions revealed that there was a significant difference in search times only between a "color" and a "no color" condition.

Laboratory and/or Contractor: New York University

Principal Investigator(s)/Monitor: Richard Brooks
New York University

Identification: Psychonomic Science, Vol. 2
1965, pp. 281-282

Key Words: color coding, search time

TITLE: Color Code Size for Searching Displays of Different Density

DATE: 1976

ABSTRACT: The purpose of this experiment was to examine the effects of display density and color code size (the number of items that are one color) on search time. Twenty subjects searched for three-digit numbers on displays ranging in density from 10 to 50 items coded in one through ten colors. Search times increased from one to five seconds as density increased from 10 to 50 items. Search time decreased from 5.2 to 1.7 seconds as the number of colors increased from 1 to 7. With more than seven colors, search time increased from 1.7 seconds with seven colors, to 3.5 seconds with ten colors. Search times increased as more colors were added to the code, even when the number of items per color category was constant. The detrimental effect on search times of larger code sizes is interpreted as a camouflage of the color contour of the target's class by the multiple color boundaries in the heterogeneous background.

Laboratory and/or Contractor: Department of Psychology
Rensselaer Polytechnic Institute
Troy, New York

Principal Investigator(s)/Monitor: Mary-Carol Cahill
Robert C. Carter, Jr.

Identification: Human Factors, 1976, 18 (3), pp. 273-280

Key Words: color code size, display density, search time

TITLE: Human Visual Acuity Measured with Colored Stimuli

DATE: September 1965

ABSTRACT: Previous studies of visual acuity have dealt almost exclusively with achromatic brightness differences. The present study measured acuity under conditions in which the target and surround were equated in brightness but differed in wavelength. It has been suggested that acuity should always be less under these conditions, such monochromatic stimuli may stimulate fewer foveal color sensitive receptors than white stimuli. Light from two monochromators illuminated alternate bars of a grating target. The resulting stimuli were presented in modified Maxwellian view and appeared to the observer as a one-degree grating of colored lines in a neutral surround. A zoom system varied the angular subtense of the lines. When the grating consisted of alternate colored and black lines acuity was fairly constant (about 1.30) from 430 nm to 670 nm. Equally good acuity could be obtained when alternate lines were matched for brightness, provided that the wavelength separation between adjacent lines was adequate. This separation is minimum in the blue and increases toward the red; it does not appear to be simply related to wavelength separation. No further improvement can be made by introducing a brightness difference. It was concluded that wavelength difference can be a sufficient condition for good visual acuity.

Laboratory and/or Contractor: Human Sciences Research, Inc.
McLean, Virginia

Principal Investigator(s)/Monitor: Carl R. Cavonius

Identification: Report No.: HSR-RR-65/8-Cr
Contract No.: DA-49-193-MD-2666
AD No.: 472-253, 45 pp.

Key Words: visual acuity, color vision, wavelength separation, luminance

TITLE: Human Visual Acuity Measured with Colored Test Objects

DATE: February 28, 1966

ABSTRACT: Visual acuity is a measure of an observer's ability to perceive fine detail. Most tests of visual acuity use patterns in which there is a change in brightness. In this experiment, acuity was successfully measured in two subjects with a grating test in which alternating bars were matched in brightness but differed in wavelength. If the wavelength difference between adjacent bars was great enough, acuity scores were obtained which were as high as those obtained with tests in which there was a large brightness difference between adjacent bars. These results help to demonstrate the discriminability of colors of different wavelengths.

Laboratory and/or Contractor:

Principal Investigator(s)/Monitor: Carl Richard Cavonius
Eye Research Foundation
Bethesda, Maryland 20014

Anne W. Schumacher
Human Sciences Research Inc.
McLean, Virginia 22101

Identification: Science, Vol. 152, 1966, pp. 1276-1277

Key Words: visual acuity, brightness, wavelength

TITLE: Luminance of Equally Bright Colors

DATE: January 1955

ABSTRACT: An analysis was made of the luminances of 342 colored filters which had been previously matched in brightness by direct visual comparison. The CIE diagram was partitioned into 20 zones and the average luminance calculated for the colors in each zone. The results show regular shifts in the average luminance values over the CIE diagram. Supplementary experiments support the principal findings. In general, the data agree with other recent studies which show that for colors of equal brightness, saturated colors require less luminance than desaturated ones. However, there is a reversal of this trend in the yellow area since the point of maximum luminance for a given brightness occurs there. The latter finding agrees closely with recent predictions by MacAdam based on his model of visually homogeneous color space.

Laboratory and/or Contractor: Office of Naval Research
Psychological Laboratory
The Johns Hopkins University
Baltimore, Maryland

Principal Investigator(s)/Monitor: Alphonse Chapanis and
Rita M. Halsey

Identification: Contract No.: N5-ORI-166
Report No.: 166-I-188
Project No.: NR 145-089
Journal of the Optical Society of America
Jan. 1955, Vol. 45, No. 1, pp. 1-45

Key Words: luminance, color, color vision

TITLE: Effect of Color on Pilot Performance and Transfer Functions Using a Full-Spectrum, Calligraphic, Color Display System

DATE: April 26-28, 1976

ABSTRACT: A study was conducted with a full-spectrum, calligraphic, computer-generated display system to determine the effect of chromatic content of the visual display upon pilot performance during the landing approach maneuver. This method was selected to more fully explore the effects of visual color cues used by the pilot. A landing approach scene was presented with either red runway lights and blue taxiway lights or with the colors reversed, and the perspective array with red lights, blue lights, or red and blue lights, or red and blue lights combined. The vertical approach performance measures indicated that the pilots performed best with the blue and red or all blue displays, and worst with the red displays. The describing function system analysis showed more variation with the red displays. The crossover frequencies were lowest with the red displays and highest with the combined red/blue displays which provided the best overall tracking performance. Describing function performance measures, vertical performance measures, and pilot opinion support the bypothesis that specific colors in displays can influence the pilot's control characteristics during the final approach.

Laboratory and/or Contractor: Ames Research Center
NASA Moffett Field, Ca. 94035

Principal Investigator(s)/Monitor: Wendell D. Chase

Identification: Presented at the AIAA Vision Simulation and Motion Conference

Key Words: color displays, computer-generated display system

TITLE: Color Research for Visual Displays

DATE: October 1974

ABSTRACT: The experimental literature on the effects of color on visual search and identification performance was reviewed. Forty-three studies published between 1952 and 1973 were located that gave results which could be used to determine the effectiveness of color codes relative to various types of achromatic codes. Quantitative analyses of these results indicated that color may be a very effective performance factor under some conditions, but that it can be detrimental under others. Tentative conclusions about the nature of these conditions were derived from the results. A guide for design decisions and an indication of knowledge gaps are also provided.

Laboratory and/or Contractor: New Mexico State University

Principal Investigator(s)/Monitor: Richard E. Christ

Identification: Proceedings, Human Factors Society, 18th Annual Meeting. 1974, pp. 542-546

Key Words: color code, achromatic codes

TITLE: Review and Analysis of Color Coding Research for Visual Displays

DATE: 1975

ABSTRACT: The experimental literature on the effects of color on visual search and identification performance was reviewed. Forty-two studies published between 1952 and 1973 were located that gave results which could be used to determine the effectiveness of color codes relative to various types of achromatic codes. Quantitative analyses of these results indicated that color may be a very effective performance factor under some conditions, but that it can be detrimental under others. Tentative conclusions about the nature of these conditions were derived from the results. A guide for design decisions and an indication of knowledge gaps are also provided.

Laboratory and/or Contractor: Department of Psychology
New Mexico State University
Las Cruces, New Mexico

Principal Investigator(s)/Monitor: Richard E. Christ

Identification: Human Factors, 1975, 17(6), pp. 542-570

Key Words: color codes, achromatic codes

TITLE: Color Research for Visual Displays

DATE: July 1975

ABSTRACT: A series of ten experiments are reported which used highly practiced subjects to investigate the use of letters, digits, familiar geometric shapes, and color dots as coding dimensions in visual displays. These experiments were concerned with unidimensional and bidimensional displays and with relatively simple, single tasks (choice reaction, search and locate, and multiple target identification). The results were analyzed in terms of absolute levels of performance for each coding dimension and in terms of the effectiveness of color relative to the achromatic codes.

Results indicated that color is most likely to benefit performance in any task if the subject must deal with more complex, multiple stimulus formats and when he must distinguish one class of stimuli (e.g., one stimulus dimension) from another. Presumably, color helps the subject organize or reorganize displayed information. The results of this research program also point out the importance of practice with any coding variable and with any task. Even when the different coding dimensions led to relatively large differences in performance, there was a tendency for practice to attenuate the differences. Finally, even when there were relative differences in performance attributable to color, it is not certain that color was the only coding variable or the best coding variable that could produce those results. Familiar geometric shapes produced results quite similar to those found for color.

Laboratory and/or Contractor: Office of Naval Research
800 N. Quincy Avenue
Arlington, Virginia 22209

Principal Investigator(s)/Monitor: Richard E. Christ and
Gregory M. Corso
Department of Psychology
New Mexico State University
Las Cruces, New Mexico 88003

Identification: Report No.: ONR-CR213-102-3
Contract No.: ONR N00014-76-0306, 108 pp.

Key Words: color coding, visual displays, choice reaction time task, search/locate task, identification task

TITLE: Specification of Primary Intensities for Seven-Color Additive Displays

DATE: July 1968

ABSTRACT: Five subjects served in a laboratory experiment to determine the effects of luminance degradations in the three primary color channels of a seven-color film projection additive color display. Positive performance and the incidence of errors were determined for a control condition and four levels of output reduction (20, 50, 62.5, and 84%) in each of the primary channels. Effects were determined for overall performance as well as ability to read characters in each of the seven resultant colors: red, blue, green, yellow, magenta, cyan, and white. Recommendations are provided concerning tolerances for luminance reduction of the primary channels, colors to be selected for coding purposes, and application of the data to non-projection systems such as CRT phosphors and electro-luminescent displays.

Laboratory and/or Contractor: Rome Air Development Center
Rome, New York

Principal Investigator(s)/Monitor: R. J. Christman

Identification: Report No.: RADC-TR-68-319
AD No.: 674-539

Key Words: color displays

TITLE: An Evaluation of the Effect of Selected Combinations of Target and Background Coding on Map-Reading Performance - Experiment V

DATE: 1961

ABSTRACT: The objective of this study was to determine the relative effectiveness of selected target-background coding combinations. Three target codes were: color, number and enclosed shape. Five types of background were: all white, solid gray, five shades of gray, five pastel hues, and five different patterns. These target-background coding combinations were evaluated under eight different complexity conditions and for five different operator tasks. The major findings in this study were: 1) no significant differences were found in background coding, 2) numeral coding is superior for the "identifying" task, and 3) color coding is superior for the "locating" and "counting" tasks.

Principal Investigator(s)/Monitor: C. A. Christner and H. W. Ray

Identification: Human Factors, 1961, 3, 131-146

Key Words: color coding, target detection, target identification, target color, background color

TITLE: Luminance Requirements for Hue Perception in Small Targets

DATE: February 1968

ABSTRACT: This study investigated the luminances necessary to perceive red (642 nm), green (521 nm), and blue (468 nm) at nine visual angles from over 1 degree to 21 seconds of arc diameter. Monocular, foveal measurements were made by the method of constant stimuli at exposures of 44 and 700 msec duration. Three color-normals served as observers. The results show that, with sufficient luminance, these hues can be seen even for stimuli as small as 0.35 minutes of arc diameter. Red is generally perceived at lower luminances than blue or green. There is an inverse relationship between stimulus size and luminance necessary for hue perception which can be represented as two linear functions. At small angles, the area-luminance slopes bracket, but tend to be somewhat larger than the slope predicted by Ricco's law; at larger angles, the function resembles that predicted by Piper's law. The change of function from approximately $A \cdot I = C$ to approximately $A^{\frac{1}{2}} \cdot I = C$ occurs at larger visual angles for shorter exposures.

Laboratory and/or Contractor: Ames Research Center
National Aeronautics and
Space Administration
Moffett Field
California 94035

Principal Investigator(s)/Monitor: Mary M. Connors

Identification: Journal of the Optical Society of America, Feb. 1968, Vol. 58, No. 2, pp. 258-263

Key Words: color, color vision, luminance, vision

TITLE: Luminance Requirements for Hue Perception and Identification, for a Range of Exposure Durations

DATE: December 27, 1969

ABSTRACT: This study investigated the effect of exposure duration on the luminances required to reach absolute, detection, chromatic, and correct-hue thesholds, with 64.5- and 2.5-minute diameter stimulus sizes, for a series of nine exposure durations ranging from 5 to 1413 msec. The results show that there is a tendency for the two longer wavelengths to be seen at lower luminances than the two shorter wavelengths, for all thresholds and exposures. The extent of the differences among wavelengths changes as a function of the kind of threshold; the greatest difference occurs for the correct-hue threshold. Photochromatic intervals are smallest for the 642-nm stimulus, over the range of durations. At this wavelength, the four thresholds can be described by a single function relating luminance and exposure duration. The largest photochromatic intervals are found for the 521-nm stimulus. The results are discussed in terms of the relative reaction time among hues and the threshold-tritanopia hypothesis.

Laboratory and/or Contractor: Ames Research Center
NASA
Moffett Field
California 94035

Principal Investigator(s)/Monitor: Mary M. Connors

Identification: Journal of the Optical Society of America, 1970, Vol. 60, No. 7, pp. 958-965

Key Words: color, color vision, luminance

TITLE: Relative Red-Green Sensitivity as a Function of Retinal Position

DATE: May 1961

ABSTRACT: Hue cancellation was employed to obtain sensitivity curves for red and for green by the method of constant stimuli. Data were taken at the fovea, and at points every two degrees along the lower vertical meridian of the visual field. The results show that sensitivity to red, relative to green, is highest at the fovea, and decreases as the peripheral angle is increased. The relative sensitivity to green is highest in the near periphery, from two to ten degrees from the fovea. Beyond this point it falls rapidly, and is no longer measurable at positions where red responses are still obtained.

Laboratory and/or Contractor: Naval Medical Research Lab
New London, Connecticut

Principal Investigator(s)/Monitor: Mary M. Connors and
Jo Ann S. Kinney

Identification: Report No.: 377
AD No.: 631 981
Journal of the Optical Society of America,
Vol. 52, No. 1, Jan. 1962, pp. 81-84

Key Words: red-green sensitivity, color vision, retinal position

TITLE: The Amount of Information in the Absolute Judgment of Munsell Hues

DATE: June 1959

ABSTRACT: Using surface colors provided by the Munsell 50-hue series of colored papers, a preliminary equal discriminability scale for the absolute recognition of colors was developed. Seventeen observers responded to presentations of 21 colors one at a time using numbers rather than color names. Based on these data, 16 colors (including black and white) were selected that represented an equally spaced series. This scale was validated with a second group of 21 subjects. The results indicated that no adjacent pair of colors was confused with much greater frequency than any other pair. Both the initial and validating data indicate that the average color-normal individual can identify, on an absolute basis, nine surface colors. The literature on the theory of color vision and color discrimination was reviewed at length.

Laboratory and/or Contractor: Aero Medical Laboratory
Wright Air Development Center
United States Air Force
Wright-Patterson Air Force Base
Ohio

Principal Investigator(s)/Monitor: Donald W. Conover
Laboratory of Aviation Psychology
The Ohio State University and
The Oslo Research Foundation

Identification: Contract No.: AF 33(616) 3612
Report No.: WAD C 58-262, 48 pp.

Key Words: color judgment, Munsell colors, color discrimination

TITLE: The Use of Color in Coding Displays

DATE: October 1958

ABSTRACT: The objectives of this study were to a) determine the maximum number of absolutely identifiable hues, b) construct an equal discriminability scale of hues, and c) validate the scale on an independent population sample. Surface colors from the Munsell fifty-hue series of colored paper provided the stimulus material. Results indicate that for practical coding purposes a maximum of five to eight colors can be used, with the exact number depending on the viewing condition and the proportion of the population that must read the code without error. Advantages and disadvantages of color in coding are discussed and current engineering practice is reviewed. A color plate gives examples of 8, 7, 6, and 5 category codes. Specification for these codes are given in the text.

Laboratory and/or Contractor: Wright Air Development Center
Wright Patterson AFB, Ohio

Principal Investigator(s)/Monitor: D. W. Conover and
C. L. Kraft

Identification: WADC Technical Report 55-171,
AD 204-212

Key Words: color coding, color identification, Munsell hues

TITLE: Color Display Evaluation for Air Traffic Control

DATE: August 1974

ABSTRACT: Three experiments and a survey-analysis of the state of the art were performed for the purpose of assessing the operational utility potential and the technical feasibility of penetration phophor cathode-ray tube (CRT) displays in air traffic control applications. The experiments, designed to test the usefulness of color as an aid to air traffic information presentation involved collection of data on several hundred responses from each of 25 to 30 subject-observers. Experiment I found that four colors (red, orange, yellow and green) could be identified with 97 to 99 percent accuracy. Experiment II demonstrated that use of color where display symbology overlaps (target data blocks commonly will) can increase accuracy of interpretation by a factor of three or more over monochromatic display. Experiment III determined that use of color to augment or reinforce altitude information or future route-of-flight information did not improve controller performance in the prediction of separation rule violations although there was no pre-training on the color codes. Use of color as the sole source of essential information was not tested. The engineering evaluation concluded that large (i.e., 22-inch) penetration phosphor screens are not readily available in production quantity. Similar source problems exist for the requisite CRT bottles, and high-voltage switching hardware.

Laboratory and/or Contractor: U. S. Department of Transportation
Federal Aviation Administration
Systems Research and
Development Service
Washington, D.C. 20590

Principal Investigator(s)/Monitor: Donald W. Connolly, Gerard
Spanier and Florence Champion
Federal Aviation Administration
National Aviation Facilities
Experimental Center
Atlantic City, New Jersey 08405

Identification: Contract No.: 161-111-000
Report No.: FAA-RD-75-39

Key Words: color coding, information displays, CRT

TITLE: Human Factors Considerations for the Use of Color in Display Systems

DATE: January 1975

ABSTRACT: This report contains the results of a review and analysis of the literature to identify and assess those human factors considerations impacting an operator's ability to perform when information is displayed in color as contrasted to monochrome (black and white only). The findings should provide valuable guidelines for the assessment of the advantages (and disadvantages) of using a color display system.

The use of color provides an additional sensory channel (color perception) which is not available with black and white. The degree to which one can exploit the use of this channel is highly dependent on available display technology, mission information display requirements, and the acceptable operational modes.

Only the human factors aspects are considered in this study. Other factors such as display technology, alternate design approaches, requirements, and systems costs are essentially disregarded to allow an in-depth, objective assessment of the value of color itself in information display systems.

Laboratory and/or Contractor: Systems Engineering Division
John F. Kennedy Space Center
NASA

Principal Investigator(s)/Monitor: S. A. De Mars

Identification: NASA Report No.: TM-X-72196

Key Words: color displays, color coding

TITLE: Effects of Lighting and Background with Common Signal Lights on Human Peripheral Color Vision

DATE: August 1970

ABSTRACT: The purpose of this study was to determine when colors could be recognized in the peripheral visual field and what apparent colors were reported when background color and ambient light were varied. Four male subjects with a similar peripheral vision were selected for the study. Subjects displayed a large difference in the distances into peripheral vision at which they recognized colors and in the percentage of errors that were made. Blue and yellow panel lights on a gray background with a low level of ambient light gave the best results. The relative color fields of red and green were less than those of blue and yellow. Use of a white background caused more errors to be made. Colors were recognized at greater peripheral distances as ambient light was reduced and as proportionately more light from the test sources entered the subjects' eyes.

Laboratory and/or Contractor: Department of Industrial Engineering
Texas Technological College
Lubbock, Texas

Principal Investigator(s)/Monitor: Richard A. Dudek and
George A. Colton

Identification: Contract No.: DAA DO 5-69-C-0102
AD No.: 720 657
Journal of the Human Factors Society,
Vol. 12, No. 5, Aug. 1970, pp. 401-407

Key Words: peripheral vision, color vision, color coding

TITLE: The Format and Colour of Small Matrix Displays for Use in High Ambient Illumination

DATE: May 1975

ABSTRACT: Studies of 7 x 5 matrices with a 4mm character height show that for characters of equal luminance a green display is significantly less legible than a red display in 10^5 lux. For characters of a given color and equal luminous intensity, a format with larger, more nearly contiguous dots is superior to one with smaller, brighter dots. All the experiments used the Huddleston fount and this was found to be very satisfactory in nearly all respects. Consideration is also given to the variation of performance with age and to other human factors.

Laboratory and/or Contractor: Ministry of Defense
Royale Aircraft Establishment
Farnborough, Hants
United Kingdom

Principal Investigator(s)/Monitor: B. Ellis, G. J. Burrell,
J. H. Whorf, and T. D. F. Hawkins

Identification: Technical Report No.: 75048

Key Words: color displays, legibility, matrix displays

TITLE: Object Location in a Complex Perceptual Field

DATE: 1953

ABSTRACT: The present study was concerned with the perceptual variables that determine the speed with which designated objects can be located from among a large field of objects. Two variables, field heterogeneity and target definition, were studied.

Field heterogeneity, as determined by the number of ways that the objects in the field differed from one another, was found to be an important determiner of location time. Location was quickest when the fields varied in hue, hue and form, and hue, form, and brightness, and slowest when the field was heterogeneous in hue, form, size and brightness, and form, brightness, and size.

Under comparable field heterogeneity, target objects that were multiply defined by assigning them unique values on each of several dimensions were located more rapidly than objects defined on only one dimension.

Principal Investigator and/or Monitor: C. W. Eriksen

Identification: Journal of Experimental Psychology
Volume 45, 1953, pp. 126-132

Key Words: visual search, background complexity, color coding, size coding, shape coding, brightness coding

TITLE: Design Handbook for Imagery Interpretation Equipment

DATE: December 1975

ABSTRACT: This report is a comprehensive review of factors which influence imagery interpretation equipment design and utility. The section on color begins by summarizing techniques used to define color space such as the Munsell color system and the CIE chromaticity system. Most color vision tests detect only gross anomalies and there are no adequate tests of color discrimination. Factors which affect the matching of colors such as target size and luminance, the luminance, hue and saturation of the surround, and adaptation were examined. Great care must be taken to assure constancy of viewing conditions to allow for accurate color discrimination. The use of psuedo color to increase the number of discriminable signals was discussed but the method has not been demonstrated successfully. Twenty-eight figures are included which summarize and interpret results.

Laboratory and/or Contractor: Boeing Aerospace Co.
Box 3999
Seattle, Washington 98124

Principal Investigator(s)/Monitor: Richard J. Farrell and
John M. Booth

Identification: Contract No.: D180-19063-1

Key Words: color vision, color vision tests, luminance, hue, saturation, adaptation, chromaticity, pseudo color, metameric color

TITLE: Target Acquisition Studies: (1) Transition from Direct to TV Mediated Viewing; (2) Target Acquisition Performance: Color versus Monochrome TV Displays

DATE: January 1972

ABSTRACT: Two aspects of air-to-ground daylight target acquisition were investigated. Study I examined the task of finding a target displayed on a cockpit-mounted CRT after the pilot had acquired it visually through the cockpit canopy. The effect of three different TV camera fields-of-view on the subject's ability to transition from outside to inside conditions was studied. The second experiment evaluated the differences in acquisition performance elicited by color and monochrome TV display presentations of ground targets. Both tests used 2-D building type target silhouettes which provided a range of contrasts relative to their backgrounds, in terms of brightness and color differences. These tests utilized the Martin Marietta Guidance Development Center Simulation facility, including the 40 ft x 40 ft 600:1 scale terrain model, for basic stimulus generation. Results of Study I showed that the experienced pilot subjects detected and then recognized the targets by direct vision before detecting them on the TV monitor. The primary target characteristic influencing detection within each FOV condition appeared to be brightness contrast. Study II results showed that color contrast did not affect displayed target acquisition performance for this type of mission over the range of target/background conditions used. Again, brightness contrast appeared to determine acquisition distance more than any other factor. It is concluded, therefore, that color contrast normally plays a secondary role in airborne target acquisition.

Laboratory and/or Contractor: Engineering Psychology Branch
Office of Naval Research
Washington, D.C.

Principal Investigator(s)/Monitor: Frank D. Fowler and
Daniel B. Jones

Identification: Contract No.: N00014-67-6-0340
Report No.: 196-071
AD No.: 736244, 29 pp.

Key Words: target detection, target recognition, color versus monochrome, field of view

TITLE: An Investigation of Target Enhancement Through Use of a Multi-Phosphor Cathode Ray Tube

DATE: May 1967

ABSTRACT: Utilizing a specially manufactured multi-phosphor cathode ray tube (CRT), this study investigated the hypothesis that target detectability on a simulated radar/sonar-type display is enhanced if the target abruptly changes color as it moves across the display. A secondary objective of the study was to obtain information on the relative detectability of the target in each of the eight phosphors tested. The task for each of 52 Navy sonar school students was the detection of a moving target imbedded in visual noise. The special design multi-phosphor CRT contained eight commonly used radar and television phosphors arranged in wedge-shaped sectors around the tube face. The subject's task was to scan the entire tube face during the brief period of target presentation and to determine in which phosphor the target appeared. The test consisted of 64 trials during which two experimental conditions were presented on alternate trials. Under one set of conditions, the target appeared at a sector boundary and moved 45° to an adjacent sector boundary entirely within a given phosphor color. Under the alternate set of conditions, the target appeared at the medial line of a sector and moved to the medial line of an adjacent sector, resulting in an abrupt change of color midway in the target path. The major sources of variance tested were: a) color-change/no-color-change, b) orientation of the tube face, c) phosphor difference, and d) clockwise/counter-clockwise rotation of the target. The results of the study showed that the no-color-change condition enhanced detectability when compared to the color change condition. The only other significant source of variance was identified with differences in detectability of the various phosphors used.

Laboratory and/or Contractor: Engineering Psychology Branch
Office of Naval Research
Washington, D.C.

Principal Investigator(s)/Monitor: R. S. French

Identification: Stromberg Carlson Report No.: 9991021
AD No.: 652980

Key Words: color displays, target detection

TITLE: Effect of Redundancy and Duration on Absolute Judgments of Visual Stimuli

DATE: 1964

ABSTRACT: Absolute judgments of stimuli which varied in size, in hue, or in size and hue combined in a correlated fashion, were made at two different durations. The results showed considerable gain in discrimination with combined size-hue stimuli, but no effect of duration at all. It is suggested that such tasks are of judgmental discrimination rather than perceptual discrimination, and that while absolute judgments can be limited by perceptual factors, other factors are ordinarily more important.

Principal Investigator(s)/Monitor: W. R. Garner and
C. D. Creelman

Identification: Journal of Experimental Psychology,
Vol. 67, 1964, pp. 168-172

Key Words: target discrimination, color coding, size coding

TITLE: Color Coding in a Visual Search Task

DATE: 1956

ABSTRACT: Two experiments were reported in which search times for colored symbols (two-digit numbers) on a visual display were measured as a function of the relative number of symbols of each color, and the number of different colors used. When observers knew the color of the target, the search time was approximately proportional to the number of symbols of the target's color. There is also a slight increment in search time due to the presence of the wrong-colored targets. When observers did not know the target's color, search time depended primarily on the total number of symbols on the display. However, search times were slightly longer for multicolored displays than for comparable single-colored displays.

Principal Investigator(s)/Monitor: B. F. Green and
L. K. Anderson

Identification: Journal of Experimental Psychology,
Vol. 51, 1956, pp. 19-24

Key Words: color coding, visual search

TITLE: The Time Required to Search for Numbers on Large Visual Displays

DATE: August 1953

ABSTRACT: Several experiments were conducted to determine the time lost in searching for numbers on typical visual displays. Groups of 11 to 17 subjects viewed circular displays of colored numbers in a variety of orientations and located numbers which had been specified in advance. The major results were:

1. For legible numbers on a large visual display, the most important variable is the number of alternatives that must be scanned. For a moderate number of alternatives, the average search time in seconds is approximately one-fifth the number of alternatives.
2. The search time is shorter for large numbers than for small numbers, unless there are so many numbers that the display becomes crowded. Smaller numbers are preferable on crowded displays.
3. If the numbers on the display are all in an upright orientation, the search time is shorter than if the numbers are oriented at random on the display. However, if the numbers are all oriented in the same way and this orientation is not upright with respect to the observer, the search time depends on the particular orientation. The average search time for all single orientations is equivalent to the search time for a display in which the various numbers are randomly oriented.
4. If the numbers are clearly legible, typical background clutter has no effect on search time.
5. When the color of the number to be searched for is specified in advance, the presence of numbers of clearly different color does not affect the search time.

Laboratory and/or Contractors: Massachusetts Institute of Technology
Lincoln Laboratory

Principal Investigator(s)/Monitor: Bert F. Green, William J. McGill
and Herbert M. Jenkins

Identification: Contract No.: AF 19(122) - 458
Report No.: 36, 15pp.

Key Words: color coding, target orientation, target size

TITLE: Color Coding of Information on Electronic Displays

DATE: 1976

ABSTRACT: The effectiveness of human information processing depends largely on information coding. This paper reports an experiment on color codes suitable for use on electronic raster-scan displays (color TV-monitors). The experiment was designed to determine if results of color code experiments with surface and projected colors are also applicable to TV colors. The objectives were to select and optimize a multi-element color code suitable for TV displays that will permit each color to be correctly and reliably identified even when presented one at a time thereby requiring absolute judgments; and to determine the smallest TV symbol sizes which can be used with the color codes assuming that contrast ratio and luminance levels are within recommended ranges. For color symbols subtending a visual angle of 45 min arc or more and which were presented on the display screen one at a time, six color regions could be found that were judged correctly with a frequency of 90% or better. With symbols of less than 30 min visual arc only four colors were reliably and correctly judged. It is possible that comparative judgment situations and training with the use of color codes could expand considerably the number of colors that could be used for coding purposes and also improve judgment reliability. Future research in this direction is recommended. Color regions from where coding colors should be selected, are shown by their representation in the CIE chromaticity plane. Some additional design recommendations for the use of color on raster-scan displays are provided.

Laboratory and/or Contractor: University of Maryland
College Park, Maryland

Principal Investigator(s)/Monitor: Michael Haeusing,
Forschungsinstitut fuer Anthropotechnik
Meckenheim, West Germany

Identification: Proceedings, 6th Congress of the International Ergonomics Association, 8 pp.

Key Words: color coding, electronic displays, color TV, electronic raster-scan displays, absolute judgments of color

TITLE: Peripheral Visual Response Time to Colored Stimuli Imaged on the Horizontal Meridian

DATE: June 1974

ABSTRACT: The purpose of the experiment was to determine response time to various colors in central and peripheral vision. Two male observers were administered a binocular visual response time task to small (45 min arc), flashed, photopic stimuli at four dominant wavelengths (632 nm red; 683 nm yellow; 526 nm green, 464 nm blue) imaged across the horizontal retinal meridian. The stimuli were imaged at 10 deg arc intervals from 80 deg left to 90 deg right of fixation. Testing followed either prior light adaptation or prior dark adaptation. Results indicated that mean response time (RT) varies with stimulus color. RT is faster to yellow than to blue and green and slowest to red. In general, mean RT was found to increase from fovea to periphery for all four colors, with the curve for red stimuli exhibiting the most rapid positive acceleration with increasing angular eccentricity from the fovea. The shape of the RT distribution across the retina was also found to depend upon the state of light or dark adaptation. The findings are related to previous RT research and are discussed in terms of optimizing the color and position of colored displays on instrument panels.

Laboratory and/or Contractor: National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

Principal Investigator(s)/Monitor: R. F. Haines, M. M. Gross, D. Nylen, and L. M. Dawson

Identification: Report No.: NASA-TM-X-3086, 16 pp.

Key Words: color vision, responses, visual stimuli, visual tasks, experimental design, fovea, retinal adaptation, time response

TITLE: Response Time to Colored Stimuli in the Full Visual Field

DATE: March 1975

ABSTRACT: The purpose of this experiment was to determine reaction time to different colored lights in the peripheral visual field. The results of this experiment could be used by instrument panel designers who must locate warning lights where they are most likely to be seen the quickest. Seven volunteer, dark-adapted subjects were presented small (45 min arc), brief (50 msec), colored (blue, yellow, green, red) and white stimuli imaged at 72 locations within their binocular field of view. The blue, yellow, and green stimuli were matched for brightness at about 2.6 $\log_{10}$ units above their absolute light threshold, and they appeared at an unexpected time and location. These data were obtained to provide response time and no-response data for use in various design disciplines involving instrument panel layout. The results indicated that the retina possesses relatively concentric regions within each of which mean response time can be expected to be of approximately the same duration. These regions are centered near the fovea and extend farther horizontally than vertically. Mean foveal response time was fastest for yellow (288 msec) and slowest for blue (341 msec). Three and one-half percent of the total 56,410 trials presented resulted in no-responses. These data are discussed in relation to findings by other investigators and are related to several hypothetical instrument panel/cockpit design problems.

Laboratory and/or Contractor: National Aeronautics and Space Administration
Washington, D.C. 20546

Principal Investigator(s)/Monitor: Richard F. Haines, L. Markham Dawson, Terye Galvan, and Lorrie M. Reid
NASA Ames Research Center
Moffett Field, California 94035

Identification: Report No.: NASA TN D-7927, 27 pp.

Key Words: reaction time, retinal sensitivity, peripheral visual, sensitivity, visual performance, color perception, peripheral retinal response capability, aircraft instrument panel layout

TITLE: Identification of Signal Lights
I. Blue, Green, White, and Purple

DATE: June 27, 1958

ABSTRACT: This experiment looked at individual differences in identifying colored signal lights. One hundred subjects had to identify 50 colors by using the six responses of red, yellow, green, blue, purple, and white, although only the last four colors were actually shown. The signal lights were shown at a small visual angle (viewing distance = 10 to 17.5 feet, symbol size = $\frac{1}{4}$ inch) with dark surroundings, and at two levels of intensity, high (8.3 to 122 mile candles, depending on color) and low illuminance (30 percent of high). The results were expressed as chromaticity zones within which the test colors were assigned a given color name with various degrees of certainty. Large individual differences in color naming were found, with colors in the blue region being called purple, whites being called yellow, and purples called red. The green boundaries are reasonably consistent. Variability due to intensity and viewing distance was also demonstrated, with lower illuminance decreasing color identification. The results of the experiment can be applied to the specification of boundaries for colored signals.

Laboratory and/or Contractor: U. S. Naval Medical Research Lab
U. S. Naval Submarine Base
New London, Connecticut

Principal Investigator(s)/Monitor: Rita M. Halsey

Identification: Journal of the Optical Society of America, Vol. 49, No. 1, January 1959, 11. 45-55

Key Words: color identification, high illuminance, low illuminance, signal lights

TITLE: Identification of Signal Lights
II. Elimination of the Purple Category

DATE: August 8, 1958

ABSTRACT: This experiment looked at the individual differences in identifying colored signal lights. This experiment differs from an earlier one in that no "purple" response was allowed. One hundred subjects identified fifty test colors in the violet-green-white region of the chromaticity diagram. The responses allowed were red, yellow, green, blue and white. Small areas (visual angle about five minutes) and low illuminances (2.79 to 122 mile-candles, depending on the saturation of the color) were used to stimulate conditions under which signal lights must be recognized. The results are expressed as chromaticity zones within which the test colors were assigned given color names with various degrees of certainty. In comparison with earlier data obtained under identical conditions but with a "purple" category, these results show improved identification of blue signals. Other changes and sources of variability are discussed. The data can be applied to the specification of boundaries for colored signals.

Laboratory and/or Contractor: U. S. Naval Medical Research Lab
U. S. Naval Submarine Base
New London, Connecticut

Principal Investigator(s)/Monitor: Rita M. Halsey

Identification: Journal of the Optical Society of America,
Vol. 49, No. 2, February 1959, pp. 167-169

Key Words: color identification, illuminance, signal lights

TITLE: On the Number of Absolutely Identifiable Spectral Hues

DATE: December 1951

ABSTRACT: This experiment was undertaken to provide an estimate of the number of absolutely identifiable spectral hues that can be used for practical coding purposes. This experiment differed from others in that the subject could call the color anything he wanted to, i.e., no color categories were assigned. The number of hues were varied from 10 to 17. The percent total judgments correct ranged from 97.5 for 10 hues, to 72.4 for 17 hues. Fewer hues can be distinguished when observers are required to identify the hues singly and with nearly perfect accuracy, than when they are shown in pairs.

Laboratory and/or Contractor: Department of Psychology
The Johns Hopkins University
Baltimore, Maryland

Principal Investigator(s)/Monitor: Rita M. Halsey and
A. Chapanis

Identification: Journal of the Optical Society of America,
Dec. 1951, Vol. 41, No. 12, pp. 1057-1058

Key Words: hues, color differentiation, absolutely identifiable differences

TITLE: Chromaticity - Confusion Contours in a Complex Viewing Situation

DATE: June 1954

ABSTRACT: The purpose of this experiment was to select colors which will never, or rarely ever be confused with each other, even when many colors may be present. This experiment measured confusion contours for 58 standard colors distributed throughout the CIE constant-luminance diagram. Matches were made to these standards from an assortment of 342 heterogeneous colors arranged in a display which presented 171 of them simultaneously. The viewing conditions approximate those found in certain complex display situations. Twenty subjects were used in the experiment. Each subject was required to indicate those colors on the display board which provided satisfactory matches for each of the standard colors. Contours on the CIE diagram were drawn to show the percentage of times various chromaticities were confused. From these contours have been selected colors which can be discriminated with high levels of accuracy and so are suitable for coding qualitative and quantitative information. In general, the contours follow trends suggested by extrapolation from precise threshold data.

Laboratory and/or Contractor: Office of Naval Research and The Johns Hopkins University

Principal Investigator(s)/Monitor: Rita M. Halsey and A. Chapanis

Identification: Contract No.: N5-ori-166
Report No.: 166-I1179
Project Designation No.: NR 145-089
Journal of the Optical Society of America
June, 1954, Vol. 44, No. 6, pp. 442-454

Key Words: color confusion, chromaticity-confusion, complex color displays, color coding

TITLE: Color Identification as a Function of Extended Practice

DATE: November 1959

ABSTRACT: The use of color as a coding device has been limited in some important applications because a practical maximum of only about 15 absolutely identifiable colors have been found experimentally. This investigation was undertaken to determine whether or not substantial improvement in color identification could be obtained as a result of extended practice. One subject practiced color identification using Munsell color chips for about five months with weekly tests. Performance improved continuously, and at the end of the practice period the subject was able to identify 50 colors with almost perfect accuracy. However, errors increased markedly during three months of no practice immediately following the training period. Most errors were hue shifts to darker or lighter colors depending on whether the chroma values were low or high.

Laboratory and/or Contractor: Applied Physics Laboratory
The Johns Hopkins University

Principal Investigator(s)/Monitor: R. M. Hanes and M. V. Rhoades
The Johns Hopkins University

Identification: Contract No.: NO rd 7386
Journal of the Optical Society of America
Vol. 49, No. 11, November 1959, pp. 1060-1064

Key Words: color identification Munsell color, extended practice

TITLE: An Investigation of Alternative Methods of Visual Cueing

DATE: May 1971

ABSTRACT: Three methods of visual cueing (conventional, color, or spatial) were studied to determine which has the greatest effect on reducing operator reaction time when applied to a visual control panel. The panel was 37 by 58½ inches and had six buttons, one in each corner, and the other two in the middle. All buttons were located near the edge of the panel. The conventional cueing used a light right next to the button. The color cueing used six lights randomly arranged in the middle that correspond to the color block the button was in. The spatial cueing used six lights in the middle arranged in the same order as the buttons. The mean reaction times for the 12 subjects were 11.69 for conventional, 12.06 for spatial, and 15.61 for color. Performance with color was likely degraded because of the almost complete inverse in the order to lights to that of the corresponding colored block the button was in. Statistical results as well as practical considerations indicate that conventional cueing techniques should be used for displays of limited size with no primary loading task.

Laboratory and/or Contractor: USAMC Intern Training Center
USALMC
Red River Army Depot
Texarkana, Texas 75501

Principal Investigator(s)/Monitor: Michael E. Harvey

Identification: AD No.: 739583, 31 pp.

Key Words: visual cueing, reaction time, control panel, conventional cueing, color cueing, spatial cueing

TITLE: NAVSHIPS Display Illumination Design Guide
Section II: Human Factors

DATE: July 1973

ABSTRACT: The brief review chapter on color concentrates on color anomolies, describing the color perception of normal and visually abnormal observers. Psychophysical aspects of color such as radiance, luminance and brightness are briefly defined. The chapter on coding examines the following questions: when is coding required, what are the advantages and disadvantages of available codes, what codes are best in given situations and what improvement in performance is provided by coding? Coding is useful in dense, complex displays. Color is the best code when searching or locating is most important. The number of colors which can be used is limited by the capacity of the display system, the size of symbols used, ambient lighting conditions and color vision defects. Both chapters provide numerous summary tables.

Laboratory and/or Contractor: Naval Electronics Laboratory Center
San Diego, California 95152

Principal Investigator(s)/Monitor: H. J. Heglin

Identification: Project No.: NELC N514
AD No.: 770 478, 282 pp.

Key Words: color vision, CRT displays

TITLE: Color Perception in the Transitional Zones of Tricolor Glide Slope Indicators (GSIs)

DATE: November 1973

ABSTRACT: This report describes an investigation of color perception in the transitional zones of tricolor glide slope indicators (GSIs) designed to aid helicopter night approaches to non-aviation ships. Fifteen subjects viewed the GSI lights at night over distances from two to four miles and reported the color observed. In GSIs with color arranged from top to bottom: yellow, green, red (YGR), an anomalous (false) yellow or white appears in the transitional zones between the green and red color regions. It was determined that the anomalous color zone occurs over an angular extent of at least 0.319° in the GSI unit tested. For a similar GSI with the color arrangement, from top to bottom, green, yellow, red (GYR), color mixing occurs in transitional zones but appears as a gradual change in color with no unusual color effects. A physical analysis of the optical design of the GSI units predicts the angular extent of the anomalous color zone in good agreement with the experimental findings.

Laboratory and/or Contractor: Recovery and Guidance, NE-7
Naval Air Engineering Center
Department of the Navy
Philadelphia, Pennsylvania 19112

Principal Investigator(s)/Monitor: Robert T. Hennessy and
Gail J. Bordon
Human Factors Research, Inc.
Santa Barbara Research Park
Goleta, California 93017

Identification: Contract No.: N00156-73-C-1008
Report No.: 1751
AD No.: 771422, 58 pp.

Key Words: color coding, color perception, glide slope indicators, landing aids, visual landing aids

TITLE: An Evaluation of Five Different Abstract Coding Methods - Experiment IV

DATE: July 1961

ABSTRACT: The purpose of this study was to ascertain the relative effectiveness of selected abstract coding methods, based upon their effects on various operator tasks. Five different coding methods were selected: numeral, letter, geometric shape, color, and configuration. Secondary variables included in the study were target density, number of code levels, and operator task. Ten subjects searched multi-celled visual displays, one code per display, for specified targets under conditions of from two to eight code levels with low to high density of symbols. It was found that numeral coding and color coding are the two superior coding methods. If greater emphasis is to be placed on identifying symbols, numeral coding is superior to color coding. No significant differences were found, however, between numeral coding and color coding for the remaining operator tasks: locating, counting, comparing, and verifying.

Laboratory and/or Contractor: U.S. Air Force

Principal Investigator(s)/Monitor: William D. Hitt
Battelle Memorial Institute
Columbus, Ohio

Identification: Contract No.: AF 30(602) - 2078
Human Factors, Vol. 3, No. 2
July 1961, pp. 120-130

Key Words: color coding, shape coding, configuration coding, alphanumeric coding, search time

TITLE: Color Coding

DATE: December 1962

ABSTRACT: Research published in the last decade on color as a coding device is discussed. The method of absolute judgment yielded similar findings with respect to identifications of surface and luminous hues. These findings suggest that a reliable unidimensional hue code should not contain more than about eight optimally spaced stimuli. Variations in purity and luminance in addition to wavelength can significantly increase the number of usable code categories. However, criteria for code selection in a given situation should depend not only upon the number of visual objects to be differentially identified but also upon the type of task for which the code functions. In particular, color codes do not appear to be suited for situations that demand rapid and precise identification, whereas they are valuable in decreasing search-time with locate-type tasks.

Principal Investigator(s)/Monitor: M. R. Jones

Identification: Human Factors, Volume 4
December 1962, pp. 355-365

Key Words: color coding, color identification

TITLE: Predictive Validities of Several Clinical Color Vision Tests for Aviation Signal Light Gun Performance

DATE: January 1975

ABSTRACT: The purpose of this study was to compare several tests of color vision. Scores on the American Optical Company (AOC) test (1965 edition), Dvorine test, Farnsworth Lantern test, Color Threshold Tester, Farnsworth-Munsell 100-Hue test, Farnsworth Panel D-15 test, and Schmidt-Haensch Anomaloscope were obtained from 137 men with color-defective vision and 128 men with normal color vision. The validity of each of these tests in predicting scores on the aviation signal light gun was assessed by using daytime and nighttime administrations of the light gun as the criteria. Two 'best sets' of plates from the AOC and Dvorine tests were selected by calculating a multiple regression equation in a stepwise manner with the nighttime and then the daytime administration of the signal light gun test as the criteria. Based on a graphic presentation of the miss and false alarm rates for each test at various possible cut scores, suggestions were made regarding the use of each test and the selection of optimal pass/fail scores.

Laboratory and/or Contractor: Federal Aviation Administration
Washington, D.C., Office of Aviation Medicine (264320)

Principal Investigator(s)/Monitor: Karen N. Jones, Jo Ann Steen, and William E. Collins

Identification: Report No.: FAA-AM-75-1
AD 006 792/6ST, 12 pp.

Key Words: color vision, night vision, visual perception, thresholds, signal lights, validation, test methods

TITLE: Redundant Color Coding and Keeping-Track Performance

DATE: 1971

ABSTRACT: An investigation was conducted to determine if performance on a keeping-track task could be enhanced by redundantly coding the displayed information channels that were being updated. At set intervals, the subject was interrogated about the status of any one of the information channels. The information consisted of numbers, colors, or numbers on a colored background, the last being the redundantly coded material. The three variables studied were channel value, payoff ratio, and coding condition. Results indicated that redundant coding did not aid performance; rather, it provided the subjects extra cues and increased the number of strategies that were used. As in previous studies, selective attention to the high-valued channels was a function of channel value and payoff ratio.

Principal Investigator(s)/Monitor: A.F. Kanarick and R.C. Petersen
Honeywell Inc.
Minneapolis, Minnesota

Identification: Human Factors,
Vol. 13, 1971, pp. 183-188

Key Words: color coding, display monitoring

TITLE: The Comparative Effectiveness of Color in a Search Task

DATE: January 1969

ABSTRACT: An experiment was performed to assess the comparative effectiveness of colors as used in a target search task. Using a color CRT, two types of target symbols were set against a constant gray surround. "V" Type symbols were designated as the desired target, and "O" Type symbols served as the background targets to provide a clutter context. Six colors were used for both "V's" and "O's", and varying numbers of these symbols (a total of 48 combinations) were displayed to the subject. Thirty-six subjects were used to obtain over 3,500 measures of these experimental conditions. The performance measures were time to count targets and counting errors. The experiment clearly demonstrated the utility of color as a target coding technique, and a search speed superiority for the various colors was found. The search speed order, from best to worst, was: red, blue, yellow, green, black and white. This order was maintained irrespective of the background target colors.

Laboratory and/or Contractor: Honeywell Inc.
Marine Systems Center
West Covina, California

Principal Investigator(s)/Monitor: D. M. Lee

Identification: Honeywell Inc. Human Factors Technical Report No.: 69-1

Key Words: visual search, color coding

TITLE: Effects of Color, Relative Position and the Onset or Offset of Signals in a Watchkeeping Task

DATE: 1967

ABSTRACT: The present study was designed to isolate the relative effects of three stimulus parameters on performance in a one-hour watchkeeping task. The task required the observer to monitor a display consisting of a red and a green light mounted one above the other. One of the lights was normally on (offset was the critical signal), and the other was normally off (onset critical). A total of 128 subjects served in four groups that permitted all factorial combinations of color (red or green), spatial position (top or bottom light of the display), and direction of energy change (stimulus onset or offset). Response times were found to be more rapid for signal offset than for onset, and for the bottom as compared to the top light of the display. No significant effect was noted for color or for any of the interactions.

Principal Investigator(s)/Monitor: M. Loeb, J. S. Warm, and E. A. Alluisi

Identification: Psychonomic Science, Volume 9, 1967, pp. 95-96

Key Words: target detection, color signals, watchkeeping

TITLE: Brightness Contrast, Color Contrast, and Legibility

DATE: December 1965

ABSTRACT: An experimental study was conducted investigating the effects of color and brightness contrast, direction of contrast, and six contrast values upon the legibility of a circular dial. The brightness of four chromatic hues was matched with four achromatic hues. Hues were combined in all possible combinations (excluding chromatic with achromatic) resulting in six contrast values. For both dark on light and light on dark contrast directions, the contrast values were equal. Half of the twenty-four subjects had pilot training and half did not. A Dodge-type tachistoscope was used to present the stimulus conditions. Reading time results indicated that the addition of color contrast to a dial of a given achromatic brightness contrast value, with a light on dark contrast direction, will not degrade and may improve the legibility of that dial. Legibility was also found to increase as contrast value increased. The study indicates that the use of color should be reconsidered in its application as a coding technique in complex system displays.

Principal Investigator(s)/Monitor: M. V. McLean

Identification: Human Factors, Volume 7
December 1965
pp. 521-526

Key Words: color contrast, brightness contrast, legibility, dial reading

TITLE: Target Recognition Performance with Chromatic and Achromatic Displays

DATE: January 1972

ABSTRACT: The purpose of this study was to compare target recognition performance of color (chromatic) and black and white (achromatic) real-world imagery. Performance was measured for identical samples of chromatic and achromatic imagery that were equivalent with respect to luminance contrast. The targets consisted of tanks, jeeps, or soldiers embedded in real-world backgrounds. The targets subtended visual angles of 160, 80 and 40 minutes of arc. Four resolution levels were studied for each image. Time from stimulus onset to target recognition was the primary dependent variable. Data on 48 subjects indicated that colored imagery resulted in significantly faster recognition times than did comparable black and white scenes. This effect was most pronounced as the resolution decreased.

Laboratory and/or Contractor: Honeywell
Systems & Research Division
Research Department
Minneapolis, Minnesota 55413

Principal Investigator(s)/Monitor: J. I. Markoff

Identification: Honeywell Document SRM-148, 16 pp.

Key Words: resolution, chromatic displays, achromatic displays, real-world imagery

TITLE: Efficiency of Verbal versus Motor Responses in Handling Information Encoded by Means of Color and Light Patterns

DATE: December 1955

ABSTRACT: The objectives of this study were 1) to compare the relative compatability of verbal vs motor responses to different types of visual stimuli and 2) to determine the effect of verbalization as a factor affecting the ability to transfer from one type of response to the other. Reaction time data and data on information handling rates are reported for four experimental and four control groups that made verbal (number-naming) and motor (key pressing) responses to spatial and to color symbols. The major findings were as follows: 1) Performance with ten lights as symbols was greatly superior to performance with ten color symbols, 2) With color symbols, verbal and motor responses were equally compatible, and 3) With spatial symbols, motor responses were superior. These results are discussed in relation to the general concept of stimulus-response compatibility and several hypotheses concerning the results are advanced.

Laboratory and/or Contractor: Wright Air Development Center
Wright-Patterson AFB, Ohio

Principal Investigator(s)/Monitor: P. F. Muller, Jr.

Identification: WADC Technical Report No.: 55-472

Key Words: color coding, spatial coding, stimulus-response compatibility

TITLE: Effect of Wavelength on Foveal Grating Acuity

DATE: March 1968

ABSTRACT: Acuity-luminance relations for a grating test object were determined with red, yellow, green, and blue narrow-band chromatic illuminants for five subjects. At intermediate and high luminance levels, acuities for blue were lower than for the other chromatic illuminants in four of the five subjects. One of these subjects also showed lower asymptotic acuity for red at high luminances. The fifth subject, who did not show lower blue acuity, exhibited lower asymptotic acuities than the other subjects. The low blue acuities observed in four of the five subjects are attributed to neural rather than dioptric factors.

Laboratory and/or Contractor: Columbia University
New York, New York

Principal Investigator(s)/Monitor: J. Pokorny, C. H. Graham
and R. N. Lanson

Identification: Contract No.: Nonr-266(46)
Project No.: NR-142-404
Report No.: TR-40
Journal of the Optical Society of America,
Vol. 58, No. 10, Oct. 1968, pp. 1410-1414

Key Words: color vision, visual acuity, optical filters,
illumination

TITLE: Reaction Time to Different Wavelengths at Various Luminances

DATE: 1968

ABSTRACT: This investigation was concerned with determining whether or not differences in reaction times exist in a human subject's responses to six different wavelengths equated at five levels of luminance. The heterochromatic matching was done by the method of flicker photometry and checked by the method of direct comparison. Simple reaction time, the time interval starting with the presentation of a visual stimulus and terminating in a manual response, was used as the method of determining the latencies for the establishment or equal sensory effects for the different wavelengths. Monocular viewing of the stimuli was used by two subjects and reaction times were determined over a luminance range of 5.2 log units around a central value of 1 millilambert. The results indicated that simple reaction time is the same for the different wavelengths at the four highest luminance levels; at the lowest luminance level, the wavelengths fan out in a manner that is in line with the classical data of vision. In other words, the visual functions obtained with simple reaction time parallel certain well known visual functions in intensity discrimination, flicker and visual acuity. The results may be accounted for by the Duplicity Theory of vision.

Laborabory and/or Contractor: Army, Lexington Signal Depot KY

Principal Investigator(s)/Monitor: Joan Diehl Pollack

Identification:
Contract No.: Nonr-266(46)
Report No.: TR-38
AD No.: 677-627
Project No.: NR-142-404
Perception and Psychophysics, Vol. 3, No. 1A, 1968, pp. 17-24

Key Words: color vision, psychophysics, reaction time, adaptation, illumination, visual perception

TITLE: Color Coding Effects in Compatible and Noncompatible Display-Control Arrangements

DATE: 1969

ABSTRACT: An experiment was designed to assess the effect of color coding in compatible and noncompatible display-control arrangements. Forty subjects viewed four arrangements of display-control panels with color coding or no color coding, and with displays and controls arranged in either a compatible or noncompatible arrangement. The subject's task was to shut off the display as fast as possible for 80 trials. Color coding was more effective when displays and controls were arranged in a noncompatible fashion, and had no effect when display and control were arranged in a compatible manner. The results support the importance of compatibility in display-control location.

Principal Investigator(s)/Monitor: G. K. Poock

Identification: Journal of Applied Psychology
1969, Vol. 53, pp. 301-303

Key Words: color coding, display-control compatibility

TITLE: The Speed and Accuracy of Discriminating Differences in Hue, Brilliance, Area, and Shape

DATE: September 1951

ABSTRACT: Two experiments are reported which are concerned with the relative effectiveness of four common visual discrimination factors. The first experiment addressed the question of which of the four discriminable aspects of vision (hue, brilliance, area or shape) can be discriminated most accurately. In the second experiment, the functional relationship between magnitude of stimulus difference and speed of discrimination was examined for each of the four variables. Subjects were asked to sort cards in a wooden box for both experiments.

Results of these experiments led to the following conclusions:

1. People can discriminate differences in hue and in shape faster and more accurately than differences in area or in brilliance.
2. On any visual display, therefore, the most important symbols should differ in hue or in shape.
3. As the difference between two areas or two hues is increased, discrimination time is decreased. At some point, increasing the difference between two hues or two areas has no effect on discrimination time. That is, this time gradually approaches a constant discrimination time for both aspects.
4. This constant discrimination time seems to be the same whether we are discriminating hue differences or shape differences. Therefore, we think that the time required to discriminate very large stimulus differences may be the same no matter what aspect we are looking at.

Laboratory and/or Contractor: U. S. Naval Special Devices Center
Port Washington, New York

Principal Investigator(s)/Monitor: J. B. Reed

Identification: Special Devices Center Report
No.: 131-1-2
AD No.: 639143

Key Words: hue discrimination, size discrimination, shape discrimination, brilliance discrimination

TITLE: Detection and Recognition of Colored Signal Lights

DATE: 1972

ABSTRACT: Two experiments were designed to determine effective colors for stimulus lights as measured by speed of detection and accuracy of identification. Additionally, the nature of the interactions between stimulus color, background color, and amount of ambient illumination were assessed. Responses to four stimulus lights (red, green, yellow, and white) were evaluated against four colored backgrounds, (copper, tan, blue, and green) under two levels of ambient illumination. Responses of 144 subjects were evaluated. It was found that to choose the most effective signal color in a specific situation, stimulus color, background, and amount of ambient illumination must all be considered. The overall ordering of stimulus colors as measured by speed of responding was, from fastest to slowest: red, green, yellow, and white. For errors in color naming, the order from least to most was: green, red, white, and yellow. Detection and identification were more difficult under bright ambient illumination. The addition of an identification task added about 0.25 sec. to the response times for each color.

Principal Investigator(s)/Monitor: R. E. Reynolds, R. M. White, and R. L. Hilgendorf

Identification: Human Factors
1972, Vol. 14
pp. 227-236

Key Words: color coding, target detection, target identification

TITLE: Color Specification for Additive Color Group Displays

DATE: August 1965

ABSTRACT: Nine pairs of dichroic filters were used in a xenon-source additive color projector to determine their effects upon observer performance in a search-and-discrimination task with seven color codes. The objective was to define performance parameters preliminary to setting filter specifications. Results indicated that a blue filter reflecting wavelengths well into the green region facilitated performance in the majority of color codes. A red filter close to the infrared in reflectance reduced performance in most codes. The most efficient color code, regardless of filter, was red. Green, blue and cyan were least efficient. Recommendations were made suggesting a blue filter of approximately 516 mμ cutoff and a red filter with a cutoff between 581 and 595 mμ for optimum observer performance in the context of a seven-color code. Performance criteria were compared and an alternate filter option was described. Further examination of the areas around the most adequate cutoff points and alternate filter arrangements were proposed as the next step toward setting firm specifications.

Laboratory and/or Contractor: Rome Air Development Center
Griffiss AFB, New York

Principal Investigator(s)/Monitor: E. F. Rizy

Identification: Technical Report No.: RADC-TR-65-278

Key Words: color filter, color coding, visual search, visual discrimination

TITLE: Dichroic Filter Specification for Color Additive Displays: II. Further Exploration of Tolerance Stress and the Influence of Other Display Variables

DATE: September 1967

ABSTRACT: Specification of primaries for seven-color display generation was examined under a wide range of conditions, including modifications to the equipment, manipulation of environmental variables, and control of response variables. The basic purpose of this series of studies was to increase the precision of previously determined specifications for dichroic filters to be employed in additive multicolored large-scale displays. The upper tolerance limit for the blue dichroic filter was determined to a high degree of precision. In addition, questions of filter order, character size, and brightness contrast were examined experimentally to determine their influence on filter specification.

As a summary contribution, an "ideal" seven-color additive system is outlined. Finally, recommendations are provided for situations wherein physical restrictions militate against the employment of the full seven color system approach.

Laboratory and/or Contractor: Rome Air Development Center
United States Air Force

Principal Investigator(s)/Monitor: E. F. Rizy

Identification: Report No.: RADC-TR-67-513
AD No.: 659-346

Key Words: color displays, dichroic filters

TITLE: On the Course of Perceived Shape at Twilight Luminances: II. Blue, Red, Green Spots in Extrafoveal Vision

DATE: July 1961

ABSTRACT: The threshold of perception of a small circular patch viewed, in extrafoveal vision, for a brief time, upon a background of mesopic (twilight) luminance, implies the transition from the perception of the circular patch as such to a vague light sensation; the intermediate patterns consist of a small point (as if the circle would be concentrated in its center), or of a thin streak, or of an irregular figure with fuzzy contours. Sometimes the said figures are seen to move across the background, and often they are seen as decentered, in spite of the fact that they are actually steady and projected just in the center of the background. Last, the stimulus sometimes appears as consisting of two patterns well separated in space, in spite of the singleness of the physical stimulation. The above reported effects do not differ substantially when the spectral composition of light is changed from red to blue. As differences of higher order, we might emphasize that the frequency of occurrence of the illusory motion for green light is slightly greater than for the other two colors (steadiest patterns are seen under blue stimulation); in addition, the percent number of double responses is slightly greater for blue than for green, while red stimulation is in an intermediate position.

Laboratory and/or Contractor: Institute Nazionale D Ottica
Florence, Italy

Principal Investigator(s)/Monitor: Lucia Ronchi

Identification: Contract No.: AF 61(052)-80
AD No.: 631889
Atti Della Fondazione Giorgio Ronchi
Vol. 16, No. 4, July-Aug. 1961, pp. 388-394

Key Words: color vision, illusions, extrafoveal vision

TITLE: Shape and Color as Dimensions of a Visual Redundant Code

DATE: 1974

ABSTRACT: Studies have been conducted which indicate that redundant coding is effective in facilitating the locating of a target among other objects. This study examined that hypothesis for a range of shape and color variables. All possible combinations of four shapes and four colors were used as targets in the experiment. The times to locate six each of the targets among 36 background objects for 16 displays in each of three coding conditions of the experiment were determined for 24 subjects. The targets could be differentiated from the background objects on the basis of color only, shape only, and redundant color/shape. The results indicate a difference among the coding conditions, the colors, and the shapes, and in the code-by-shape and code-by-color interactions. An important finding is that the redundant code and the color code conditions did not differ, but the shape code was worse. The data were examined for possible explanations of this result and some implications were suggested.

Laboratory and/or Contractor: Georgia Institute of Technology
Atlanta, Georgia

Principal Investigator(s)/Monitor: Norman E. Saenz and
Charles V. Riche, Jr.

Identification: Human Factors
1974, 16(3), pp. 308-313

Key Words: redundant coding, shape coding, color coding, search time

TITLE: Analysis of Human Factors Data for Electronic Flight Display Systems

DATE: April 1971

ABSTRACT: This report presents the results of a review of 1178 technical documents dealing with human factors considerations in electronic flight display systems. Design-oriented human factors data are presented for the following families of design considerations: display size, information coding, alphanumerics, scale legibility, visual acuity, display system resolution, flicker, contrast ratio requirements, and environmental variables including ambient illumination, vibration and acceleration. The section on color coding noted the absence of CRT studies relevant to the utility of color. The number of hues which can be used in coding depended on such factors as illumination levels and individual differences but is probably between 4 and 12. The use of color increased the speed of processing displays when studied under low and steady light levels. The demonstrated utility of color codes was maximal in large, complex, cluttered and unstructured displays. Such characteristics are not typical of most airborne displays.

Laboratory and/or Contractor: Air Force Flight Dynamics Laboratory
Air Force Systems Command
Wright-Patterson AFB, Ohio

Principal Investigator(s)/Monitor: Clarence A. Semple, Jr.
Raymond J. Heapy
Ernst J. Conway, Jr.
Manned Systems Sciences, Inc.
Keith T. Burnette, 1Lt./USAF
Air Force Flight Dynamics Lab

Identification: USAF Contract No.: F33615-70-C-1132
Technical Report AFFDL-TR-70-174
Task No.: 6190-07-005, 570 pp.

Key Words: chromaticity, cockpit displays, color coding, information coding, target detection, visual acuity

TITLE: A Study of Visual Search Using Eye Movement Recordings; Color Coding for Information Location

DATE: December 1968

ABSTRACT: It was determined experimentally that relatively large numbers of colors could be used effectively to code the location of classes of information on aeronautical charts. Three groups of 11 subjects each were presented with sketches of terrain (ground) including a check point whose color code was provided and asked to locate the checkpoint on a chart (map). The maps were areas from Sectional Aeronautical charts which were either as is, color coded or achromatic with color coding added. All colors were highly discriminable in peripheral vision. The presentation of the color code of the check point removed the limitations of long term memory from the decoding process. The ground/map coordination task was accomplished in significantly shorter time with coded as opposed to uncoded maps. The color-coding system could be superimposed on terrain elevation color codes on charts without seriously degrading performance.

Laboratory and/or Contractor: Engineering Psychology Programs Office
Office of Naval Research
Washington, D.C.

Principal Investigator(s)/Monitor: W. D. Shontz, G. A. Trumm,
L. G. Williams
Honeywell, Inc.
Roseville, Minnesota

Identification: Contract No.: NONR 4774 (00)
Project No.: RR006-09-01
Contract Authority No.: NR 196-045
Report No.: 12009-FR1, 48 pp.

Key Words: color coding, maps

TITLE: Color Coding for Information Location

DATE: 1971

ABSTRACT: Visual search performance was investigated as a function of color-coded and uncoded information location, number of categories coded, number of objects per category, and background clutter. Thirty-three subjects searched 12 areas of modified sectional aeronautical charts for a total of 48 checkpoints. Identification of checkpoints was established with labels plus geographical context information. Color served as a partially redundant code for information location. In general, the findings indicate that color coding for information location is most effective when: (1) many categories of information can or must be coded, (2) colors highly discriminable in peripheral vision are used, and (3) the number of objects per category is kept reasonably small.

Laboratory and/or Contractor: Honeywell Inc.
Systems and Research Center
Minneapolis, Minnesota 55413

Principal Investigator(s)/Monitor: William D. Shontz, Gerald A. Trumm and Leon G. Williams

Identification: Human Factors
1971, 13(3), 11. 237-246

Key Words: color coding, maps

TITLE: Color Name as a Function of Surround Luminance and Stimulus Duration

DATE: 1971

ABSTRACT: The purpose of this study was to attempt a systematic investigation of the effects of both exposure duration and surround luminance upon color naming. Subjects were instructed to respond verbally to the stimulus with one of 10 color categories; red, yellow-red, yellow, green-yellow, green, blue-green, blue, blue-red, white or gray, and "not sure." A session consisted of four mixed-order presentations of the 28 wavelengths at one time-luminance combination. Each subject had three 50-minute sessions for each of the nine conditions. The conditions were presented in a different random order to each subject. The results showed a tendency for increased response uncertainty when surround luminance increased and stimulus brightness therefore decreased, and a similar increase in response uncertainty with briefer stimulus exposures. No presence of a Bezold-Brucke shift or tritanopia were found.

Laboratory and/or Contractor: Albion College
Albion, Michigan 49224

Principal Investigator(s)/Monitor: Michael H. Siegel and
Anne B. Siegel

Identification: Perception and Psychophysics
1971, Vol. 9 (2A), pp. 140-144

Key Words: surround luminance, color naming, exposure duration

TITLE: Color Coding and Visual Search

DATE: 1962

ABSTRACT: This experiment looked at the effectiveness of color as a coding dimension for information transmission in visual displays. Twelve subjects each viewed a series of 300 displays, which varied in display density, in number of colors used, in the particular color of the target, with either a white or black background, under conditions where subject either knew the color of the target in advance, or did not. Neither the particular color of the target used, nor the display background had any significant effect on search time. Search time increased regularly with increasing display density. For multicolored displays, when the color of the target was known in advance, search times were considerably shorter than when the target color was unknown. When the color of the target was unknown, search times were not significantly different than those for single-colored displays. Therefore, color can be useful for coding when it is known what color to look for, and what colors to ignore, and even when it is not known what color to look for, multicolored displays do not decrease performance below that found with single-colored displays.

Laboratory and/or Contractor: Department of the Air Force

Principal Investigator(s)/Monitor: Sidney L. Smith
The MITRE Corporation
Bedford, Massachusetts

Identification: Contract No.: AF-33(600)39852
Journal of Experimental Psychology
Vol. 64, No. 5, 1962, pp. 434-440

Key Words: colored displays, search time, color coding, visual search, multicolored displays, single-colored displays, display density

TITLE: Color Coding and Visual Separability in Information Displays

DATE: 1963

ABSTRACT: The purpose of this study was to investigate the value of color coding in a combat display and to get a measure of any improvement in performance that is due to color coding. Twelve experimental subjects performed both visual search and class counting tasks, viewing displays containing 20, 60 or 100 items. Each item consisted of a vector, letter, and three-digit number grouped together, and was presented as white-on-black in some displays, or in one of five colors. The color code was redundant with the five class-designator letters that were used. Average search and counting time, and counting errors, increased with increasing display density (number of items). None of these measures varied significantly among the five different target colors. Addition of the redundant color code resulted in an average time reduction of 65% in the visual search task and 69% in the counting task, with a reduction of 76% in counting errors. Since the task in this study approximates those found in actual man-machine systems, the data can be used to estimate the improvement in performance when color coding is added to the displays.

Laboratory and/or Contractor: Air Force Electronic Systems Division
Air Force Systems Command

Principal Investigator(s)/Monitor: Sidney L. Smith
MITRE Corporation
Bedford, Massachusetts

Identification: Contract No.: AF-19(628)2390
Journal of Applied Psychology
Vol. 47, No. 6, 1963, pp. 358-364

Key Words: color coding, visual separability, display density

TITLE: Legibility of Overprinted Symbols in Multicolored Displays

DATE: 1963

ABSTRACT: This experiment studied the effects of using different colors in order to increase the legibility of a display. Six experimental subjects viewed a series of displays of overprinted colored numbers, and in each case counted the occurrences of a particular target digit which varied from trial to trial. Five degrees of symbol overprinting were used for displays representing each of the 15 possible pairings of five symbol colors. Counting time and errors were interpreted as inverse measures of symbol legibility. Legibility decreased regularly as degree of symbol overprinting was increased, compared with conditions of no overprinting, trials with full symbol overlap required twice as much counting time and resulted in five times as many counting errors.

The over-all legibility of symbols was not greatly influenced by the particular pair of colors involved in the overprinting, when targets of both colors had to be counted. However, when targets of just one color were counted, a clearly defined ordering of the colors in terms of their visual dominance was apparent.

White numbers were the most legible under these conditions, followed by orange, red, green and blue numbers, in that order. Under conditions of full overprinting, only 1 percent of trials involving white targets were in error, whereas the corresponding error frequency for blue targets was 50 percent. In addition counting time for blue symbols was four times as great. Although overprinting is not recommended, the suggestions presented should help increase legibility in cases where overprinting is necessary.

Laboratory and/or Contractor: The MITRE Corporation
Bedford, Massachusetts

Principal Investigator(s)/Monitor: Sidney L. Smith

Identification: Contract No.: AF 19(628)-2390
Journal of Engineering Psychology
Vol. 2, 1963, pp. 82-96

Key Words: overprinting, color displays, legibility, symbol overlap

TITLE: Color Coding in Formatted Displays

DATE: 1965

ABSTRACT: An experiment was designed to assess and compare the effects of symbolic, numeric, and color coding in formatted displays. Twelve subjects viewed displays in which 2-digit entries were arranged in tabular matrix format. Displays differed in density, structure, and auxiliary coding. Subjects performed row-comparison and item-counting tasks, providing time and error measures. Auxiliary color coding resulted in better performance than superscript or underline codes for both tasks. Color coding was relatively more effective for item counting than for row comparison where the display format was related to the task. The value of a display code appears to be dependent upon the joint interaction of the format in which it is displayed and the task to which it is applied.

Principal Investigator(s)/Monitor: S. L. Smith, B. B. Farquhar, and D. W. Thomas

Identification: Journal of Applied Psychology
1965, Vol. 49, pp. 393-398

Key Words: color coding, symbolic coding, numeric coding

TITLE: Color Versus Shape Coding in Information Displays

DATE: June 1964

ABSTRACT: The purpose of this experiment was to compare color coding and shape coding in a simple counting task. Eight subjects counted objects of a specified color or shape on displays of 20, 60, or 100 items. Counting time and errors increased with increasing display density. Counting based on a 5-valued color code was two to eight times faster and 20 percent to 50 percent more accurate than counting using any of three shape codes. Color counting was not affected by the particular shape code on which the colors were superimposed. Shape counting was somewhat faster and/or more accurate when color did not vary on the display, and vice versa. Differences in counting performance appeared among the three shape codes and among certain of the symbols within shape codes, and small differences were confirmed among the particular code colors used, with green being the most difficult, followed by blue, with white, red, and yellow being equivalent in terms of counting time. The overall results of this study explicitly confirm the effectiveness of color coding for a counting task. Color is particularly useful when one has a small number of display categories, and/or small symbol size.

Laboratory and/or Contractor: Air Force Electronic Systems Division
Air Force Systems Command

Principal Investigator(s)/Monitor: Sidney L. Smith and
Donald W. Thomas
MITRE Corporation
Bedford, Massachusetts

Identification: Contract No.: AF 19(628)2390
Report No.: 63-483
Journal of Applied Psychology, Vol. 48, No. 3, June 1964, pp. 137-146

Key Words: color coding, shape coding, information displays

TITLE: Color Coding in Formatted Displays

DATE: 1965

ABSTRACT: An experiment was designed to assess and compare the effects of symbolic, numeric, and color coding in formatted displays. Twelve subjects viewed displays in which two-digit entries were arranged in tabular matrix format. Displays differed in density, structure, and auxiliary coding. Subjects performed row-comparison and item-counting tasks, providing time and error measures. Auxiliary color coding resulted in better performance than superscript or underline codes for both tasks. Color coding was relatively more effective for item counting than for row comparison where the display format was related to the task. The value of a display code appears to be dependent upon the joint interaction of the format in which it is displayed and the task to which it is applied.

Laboratory and/or Contractor: Air Force Electronic Systems Division
Air Force Systems Command

Principal Investigator(s)/Monitor: Sidney L. Smith
Barbara B. Farquhar
The MITRE Corporation
Bedford, Massachusetts
and Donald W. Thomas
Tufts University

Identification: ESD-TR-65-125
Contract No.: AF19(62)2390
Journal of Applied Psychology
Vol. 49, No. 6, 1965, pp. 393-398

Key Words: *color coding, display density*

TITLE: Symbol Identification as a Function of Misregistration in Color Additive Displays

DATE: 1966

ABSTRACT: The effect of misregistration in color additive projection displays on speed and accuracy of symbol identification was investigated. Registration may be defined as the superimposition of homomorphic images of primary colors to form a single image of a secondary color. Departure from the perfect registration is typically measured in degrees of misregistration. Subjects viewed 36 letters and numbers, presented simultaneously, in seven colors (white, red, green, blue, yellow, magenta, cyan), under seven conditions of misregistration (0 to 200 percent). Performance seriously deteriorated from 67 to 200 percent misregistration, but a misregistration as high as 100 percent was necessary to produce a level of performance which was significantly lower than that obtained under perfect registration conditions. Under misregistration conditions, red and blue were the most efficient color codes, while cyan and white were the least efficient. It was concluded that (1) future studies might profitably investigate misregistrations of smaller increments lying between 67 and 100 percent misregistration, and (2) the relative tolerance of individual colors to deleterious misregistration effects should be taken into consideration when color codes are assigned to critical information categories.

Laboratory and/or Contractor: Displays Techniques Branch
Rome Air Development Center
Griffis AFB, New York

Principal Investigator(s)/Monitor: Alvin M. Snadowsky, Edward F. Rizy, and Merrill F. Elias

Identification: Perceptual and Motor Skills
1966, Vol. 22, pp. 951-960

Key Words: color displays, registration, misregistration, symbol identification

TITLE: Intensity-Time Relationship at Threshold for Spectral Stimuli in Human Vision

DATE: February 1965

ABSTRACT: The intensity-time relationship at threshold of the human eye was investigated with special attention to temporal-summation effects and Bloch's Law. The four parameters selected for this study include (a) narrow-band spectral stimuli of different dominant wavelengths, (b) foveal and peripheral retinal locations, (c) several stimulus sizes, and (d) light versus dark surrounds. The results, obtained with three subjects, show that the intensity-time relationship is dependent upon the wavelength of the spectral stimulus when a large (45 min arc) foveal stimulus is employed. No significant wavelength dependency was found for smaller (4.5 min arc) foveal stimuli and varying stimulus diameters in the periphery. Data taken with a dark surround exhibited more temporal summation than that taken with a light surround. Results are discussed in relation to evidence for differently sized receptive fields for the red and blue cones and for the rod receptors. It was found that there are larger receptive fields for blue than for red foveal receptors.

Laboratory and/or Contractor: National Science Foundation

Principal Investigator(s)/Monitor: H. G. Sperling and
C. L. Joliffe
Honeywell Inc.
Military Products Group
Research Laboratory
St. Paul, Minnesota 55113

Identification: Contract No.: NSF-C253
Journal of the Optical Society of America
Feb. 1965, Vol. 55, No. 2, pp. 191-199

Key Words: foveal receptors, human vision, intensity-time relationship, spectral stimuli

TITLE: Target Detection with Color Versus Black and White Television

DATE: April 1975

ABSTRACT: An experiment was conducted to investigate target detection performance on color and black and white TV. Green, brown, and gray model tank targets were viewed under 25, 35, and 300 TV lines resolution against a green and a brown background on a terrain model. Target-to-background luminance contrasts studied were positive (targets lighter than the surround), negative (targets darker than the surround), and zero. Color provided a slightly higher percentage of target detection than did black and white TV (74 versus 69 percent). Background color did not significantly affect performance, although it figured prominently in several interaction effects. Gray targets were more detectable than either brown or green targets. Higher resolution improved performance about equally for both color and black and white TV, and targets lighter than the background were detected more easily than either negative or zero contrast targets.

Laboratory and/or Contractor: Naval Weapons Center
China Lake, California

Principal Investigator(s)/Monitor: Dan W. Wagner

Identification: Report No.: NWC TP5731
Project/Task No.: 62755N-F55-525-402

Key Words: target detection, color TV, black and white TV, target color, background color, contrast, resolution

TITLE: Target Acquisition with Color versus Black and White Television

DATE: October 1975

ABSTRACT: Two simulator experiments, differing only in field of view (FOV), were conducted to investigate air-to-ground target acquisition with color and black and white television. A television camera obliquely viewed a terrain model from a simulated altitude of 4,000 feet with two FOVs: 4.5 and 3.25 degrees. Subjects searched for green, olive, brown, and earth-colored tanks and trucks as the camera "flew" over the terrain. It was found that (1) color TV was not generally superior to black and white TV; (2) the earth-colored targets provided more correct detections at faster response times than the other colors; (3) tanks were detected, but not identified, slightly faster than trucks; (4) target detection and identification was affected by the background; and (5) the smaller FOV more than doubled correct target detections (41 versus 86 percent).

Laboratory and/or Contractor: Naval Weapons Center
China Lake, California

Principal Investigator(s)/Monitor: Dan W. Wagner

Identification: Report No.: NWC TP5800
Project/Task No.: 62755N-F55-525-402

Key Words: target detection, target identification, color TV, black and white TV, target color, field of view

TITLE: An Investigation of Target Enhancement Using Colored Backgrounds on a Simulated Radar Display

DATE: September 1971

ABSTRACT: This study investigated the hypothesis that sequential changes of background color on a simulated radar display enhances target detectability. Two experiments were conducted wherein target detectability was assessed in terms of the accuracy in which subjects determined the presence of a randomly appearing target symbol imbedded in visual noise. The first experiment tested 30 subjects to determine the relative detectability of targets among display backgrounds of homogeneous color and backgrounds presenting abrupt changes of color. The second experiment tested 24 subjects to determine if the speed and/or sequence of background color change affected target detectability. Results of the study showed that homogeneous green or blue backgrounds significantly enhanced target detectability when compared to the sequentially changing colored background, and that speed and sequence of background color change have little effect. The study also showed colored backgrounds to enhance target detectability when compared to the conventional method of radar display.

Laboratory and/or Contractor: Naval Postgraduate School
Monterey, California

Principal Investigator(s)/Monitor: W. J. Wallace, Jr.

Identification: Masters Thesis
AD 733-182

Key Words: color coding, target detection, radar displays, background color

TITLE: Relative Yellow-Blue Sensitivity as a Function of Retinal Position and Luminance Level

DATE: August 1974

ABSTRACT: Relative sensitivity for yellow and blue was determined by hue cancellation, using the method of constant stimuli. Measurements were made with a one-degree stimulus at the fovea, two degrees above the fovea, and every four degrees along the upper vertical meridian out to eighteen degrees at three luminance levels (0.5, 0.1, and 0.01 ft-L). Relative yellow-blue sensitivity remained much the same from fovea to periphery for the two highest light levels. At the lowest luminance level there was a slight increase in relative blue sensitivity in the near periphery and a progressive decrease in relative yellow sensitivity as the peripheral angle increased. The variability of color discrimination increased greatly as luminance decreased and the peripheral angle increased.

Laboratory and/or Contractor: Naval Submarine Medical Center
Groton Conn
Medical Research Lab

Principal Investigator(s)/Monitor: Seymour Weissman and
JoAnn S. Kinney

Identification: Report No.: 447, Vol. 24/No.3
Project No.: MR005 14
Task No.: MR005 14 1001
AD No.: 618 594
Journal of the Optical Society of America
Vol. 55, No. 1, pp. 74-77, Jan. 1965

Key Words: color vision, luminance, retinal position, yellow-blue sensitivity

SECTION III

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