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TECHNICAL INFORMATION

TOWARD THE QUANTIFICATION OF VISIBILITY

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE / Public Health Service
Center For Disease Control / National Institute For Occupational Safety And Health

TOWARD THE QUANTIFICATION OF VISIBILITY

An Annotated Bibliography

by

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HEW Contract Number
210-76-0116

Report for

U.S. Department of Health, Education, & Welfare
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Division of Physical Sciences and Engineering
Cincinnati, Ohio 45226

January, 1977

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

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HEW Publication No. 77-202

PREFACE

The purpose of this project was to conduct a literature search in the general area of visibility (when "visibility" is used in warning against stationary or moving hazards) and specifically to review the literature in order to establish the extent of research conducted to date on the subject of the Visibility Index.

The Visibility Index will provide the method for examining the effective value of color, texture, pattern, contrast, and other variables used in warning devices, signs, labels, and markings for the purpose of enhancing safety by better visibility. Subsequent to the literature search being conducted in this project, research will be conducted in order to evaluate the use of visible means as effective methods to avoid or reduce the likelihood of a worker being struck or injured by any hazard because of insufficient visiblity.

ABSTRACT

This document reports the results of a state-of-the-art survey on visibility comprising an assessment of the literature on existing standards as well as the various design and environmental variables associated with the concept of visibility. The report also includes an evaluation of future research needs and trends into the development of a general visibility index for the reliable assessment of the visibility of stationary and moving objects. Some of the topics included are: camouflage, pattern recognition, color contrast, luminance contrast, reflectivity, illumination, background, lighting types, distance, and moving objects. The conclusions of this report include a suggested outline of a comprehensive program of study into the visibility concept. The research outline highlights those areas believed to have the greatest near-term potential as well as those requiring longer lead times.

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ACKNOWLEDGMENTS

We wish to express our gratitude to the following persons from Science Information Services, FIRL, for their contributions during the program: Samuel Enion, for administrative assistance; Pearl Stark, Lydia Erdelyi, Audrey Waltner, and Herbert Schwartz for library services; Edith Navé of our Munich office; Yoshihiro Ota and Shigeharu Wada of our Tokyo office for searches in their respective areas. From the Transportation Sciences Laboratory we would like to thank Larry Decina for his help in cataloguing and reproduction and Norma Poindexter and Jill Rose for the preparation of the draft report.

INTRODUCTION

This report provides information on over 300 published manuscripts which address several aspects of the general notion "visibility". The visual mechanism of the eye is complex and only partially understood. Since "seeing" is a sensation having physical, psychological, and cognitive features, it is not surprising that it represents the most intensely studied area in the field of psychophysics. The literature search presented in this report is believed to be thorough, but by no means exhaustive. Given the real limitations of time, budget, and talent, it is not possible to cover each of the conceptual subdivisions outlined in the Table of Contents with equal intensity and detail. We are certain that much significant research has been overlooked. We are equally certain, however, that the material reported on here gives the reader a solid background and some insight into the question of the quantification of seeing or visibility.

The authors feel that after a careful review of these pages, certain key elements will become apparent. These will focus on the fact that most solutions to visibility problems (either through successful design, standard, or concensus) have evolved through trial and error on a rather unsatisfactory scientific basis. This is true because there is so much to be known about the physics of light and color; normal and aberrant viewer capabilities; learning, fatigue, and attitudes effects; time sharing and scanning behavior; as well as the directional reflectance properties of materials that a meaningful coalescence of basic research has occured in very few areas.

VISIBILITY METRIC

The need for a general visibility index for the reliable assessment of the visibility of objects is a long standing one. Two such indices have recently been developed: The Equivalent Sphere Illumination (ESI) system is currently seeing application in office and school settings, while the Visibility Index for roadlighting applications is currently undergoing review by the international lighting community. The need to describe and quantify visibility is well recognized, especially by professional lighting engineers and those interested in human visual performance in various visual environments.

Much effort has been focused recently in the development of a visibility metric with application to the nighttime roadway environment. This activity represents a continuing effort to reduce the extraordinary hazards to pedestrians and drivers at night by designing and evaluating roadway lighting so as to satisfy the true visibility needs of motorists. The nightime roadway provides conditions of wide ranging visual complexity.

This complexity arises from the extremes of the luminance distribution, including glare sources, and the wide range of activities and objects for which adequate visibility must be provided. The roadway visibility problem was addressed by relying on well-founded psychophysical principles of contrast quantification, knowledge of the relationship between adaptation level and contrast sensitivity, and the visual degradation caused by glare sources.

The key factors in a model of visibility for roadway applications can be expected to be the key factors in a more general model as well. Some of these factors are well known to researchers and students of visual perception, others may only be identified through a review of **recently related** research and technical discussions.

FACTORS INFLUENCING THE VISIBILITY OF OBJECTS

The wealth of research literature relative to visual perception permits the identification of the following items as the key factors in the determination of object visibility.

- Luminance Contrast
- Adaptation Level of the Eye
- Object Size
- Time Available for Detection
- Color

These factors are fundamental, of course. Additional factors related to detection of objects in the real-world include:

- Camouflage Effect (similarity of internal pattern, or color, of object and its surround)
- Visual Noise
- Glare
- Atmospheric Distortion
- Expectancy (i.e., psychological set)
- Ophthalmological Characteristics of the Observers (e.g., age, acuity, etc.)
- Time-shared Activities (i.e., spare capacity)
- Dynamic Setting

These latter items are typically the most difficult to deal with when designing objects to be used under a multitude of background conditions as well as a wide range of lighting conditions. The full spectrum for background conditions includes at least the following, and in many cases some of these broad descriptors occur simultaneously in varying degrees.

- Uniform (the least common in natural settings) or Non-Uniform
- Glaring (e.g., water or snow) or Diffuse
- High Luminance (i.e., high photometric brightness) or Low Luminance
- Moving or Stationary
- Polychromatic or Monochromatic

The diversity of lighting conditions is itself quite broad and includes:

Diffuse lighting conditions: sunlight, moonlight, shadow, and artifical lighting, including broad spectrum and monochromatic.

Direct lighting conditions: primarily artificial, such as area lighting and automobile headlights.

Atmospheric attenuation conditions: chiefly fog, snow, and haze.

LITERATURE REVIEW

The following chapters will provide the reader with a wide-reaching view of the visibility issue. The discussion to follow traces the status of visibility research from extant standards and codes through research into light properties, object properties, and viewer capabilities.

EXISTING STANDARDS FOR VISIBILITY

Standards from the viewpoint of visibility have been very limited in areas other than lighting levels for transportation and industry. Most standards reported in the literature deal with lighting levels that are believed to be necessary for good visibility in various situations (i.e., office lighting, roadway lighting, instrument panel lighting). Other standards have been outlined in the literature which pertain to: color schemes for survival clothing, building construction, traffic signs, warning signs, as well as dimensional standards for presentation of other visual media.

UNITED STATES STANDARDS AND CODES

The following standards were identified through a retrospective literature survey. The source of these standards were the U.S. Department of Labor, U.S. Department of Transportation, ANSI, and ASTM.

1. Department of Labor, Occupational Safety and Health Administration, "Occupational Safety and Health Standards," Federal Register, 39(125), 1974.

Standard Title and Number --

1910.37(g) Means of Egress, Exit Marking
This standard specifies the use and design of exit signs for buildings. Illumination (5 foot-candles) as well as that size and color should provide contrast with interior finishes.

1910.144 Safety Color Code for Marking Physical Hazards
Color codes are specified which include: red (fire equipment, danger, stop), orange (dangerous parts of machines), yellow (caution), green (safety), blue (caution for equipment under repair), purple (radiation), and black or white combinations (traffic and housekeeping markings).

1910.145 Specifications for Accident Prevention Signs
This standard specifies the design, application, and use of safety signs (other than those designed for traffic or navigation) to designate specific hazards that may lead to accidents, for example: caution, danger, and radiation signs. The standard suggests colors of letters as well as background color.

2. Department of Transportation, Materials Transportation Bureau, Marking and Labeling Hazardous Materials, Subpart 4, Federal Register, 32(5606), 1967.

Standard Title and Number--

173.404 Labels
Caution labels are described which are diamond shaped to be used in the transportation of explosive or hazardous materials.

173.405 Explosive Labels
Labels for explosive materials must have an explanation as to the dangerous nature of the explosive (i.e., Explosive A, B, or C) and must be orange in color with the inscription, border, and symbol in black.

173.406 Non-Flammable Gas
A diamond shaped sign must be used that is green in color with an appropriate symbol in black.

173.407-409 Flammable Gas-Liquid
A diamond shaped sign is used that is red in color and the symbol is black.

173.413 Oxidizing Material Label
A diamond shaped sign is used that is yellow in color and the symbol is black.

173.414 Poisonous Material Label
A diamond shaped sign is used that is red in color with a skull and crossbones symbol in black.

172.5 List of Hazardous Materials
A list of every possible hazardous material that is transported and an explanation of the appropriate symbol that is to be used is provided.

3. Federal Standard No. 313, Symbols for Packages and Containers for Hazardous Industrial Chemicals and Materials, July 23, 1971.
This standard provides uniform symbols for packages and shipping containers for hazardous materials shipped to and by government activities.

4. American National Standards Institute, American National Standard Specifications for Accident Prevention Signs, ANSI Z35.1 — 1972.
Sign classifications are defined with specifications as to design and color. Letter signs are specified in terms of viewing distance and the sign size is dependent on the message length and letter size. Suggestions as to placement and illumination are also included.

5. American Society for Testing and Materials, Standard Methods of Test for Night Visibility of Traffic Paints, ASTM-D-1011, 1974.
This standard method covers the testing of traffic paint surfaces for luminous directional reflectances using viewing directions similar to those of night traffic.

6. "American National Standard of Office Lighting" Journal of the Illuminating Engineering Society 3(1), 1973, 3-40.
Standards designed to provide efficient and comfortable visibility for office tasks are outlined. Included are the quantity and levels of illumination, luminance ratios, veiling reflection, glare and contrast loss, and system design.

7. Department of Transportation, "Federal Motor Vehicle Safety Standards: Republication of Lighting Standards," Federal Register, 41(35522-35530), 1976.
This standard specified requirements for original lamps, reflective devices, and equipment for signaling for use on motor vehicles during darkness and conditions of reduced visibility.

FOREIGN STANDARDS AND CODES

This section has two parts: European standards and codes and Asian standards and codes. International standards can be found under a separate heading.

European Standards and Codes

The standards contained in this section were obtained through a retrospective search conducted in Munich, West Germany and are exclusively West Germany DIN's.

8. DIN 4818, Safety Colors, September, 1965.
   This standard corresponds to national and international regulations specifying red (danger, stop), yellow (warning against hidden dangers), yellow and black stripes (danger of falling or bumping into a object) and blue (for safety rules that are symbolized or spelled out).

9. DIN 4819, Safety Symbols and Safety Signs, September, 1965.
   The safety symbols standardized here comply with International Standards Org. (ISO) recommendation #507 for safety colors and #734 for symbols.

10. DIN 4844, Safety Marking; Principle, February, 1975.
    This standard addresses safety signs in industrial plants, department stores, shopping centers, schools, sports centers, escape routes, airports, and seaports. It does not apply to traffic. A white circle framed in red with a red bar is a prohibitory sign; a yellow triangle framed in black is a warning sign; a blue circle is a mandatory sign; and green square is a rescue sign.

11. DIN 5381, Identification Colors, September, 1976.
    The identification colors in this standard are designed to be used as surface colors for the identification of signs, labels, containers, machines, tools, etc.

12. DIN 6163, Colors and Color Limits for Signal Lights; General Rules, August, 1975.
    Colors and color limits in this standard pertain to traffic signal lights. For a high probability of recognition, the colors Red B, Yellow **B**, and Green B to D are to be used.

13. DIN 6171, Surface Colors for Traffic Signs; Colors and Color Boundaries for Illumination by Daylight, June, 1970.
    Tables are presented for colors and color boundaries for danger signs, directional signs, and regulating signs in traffic.

14. DIN 16954, Coating Fabrics Manufactured With Plastics and Used for Warning Clothing; Requirements; Test Methods, September, 1975.
The warning clothing must be coated with a fluorescent orange-red synthetic layer of plastic. Testing conditions concerning wear, weather resistance, and bending are also given.

15. DIN 25400, Warning Symbol for Ionizing Radiation, May, 1966.
The symbol consists of a yellow triangle with a black frame and a black symbol in the center and must be attached to containers and tool areas where ionizing radiation occurs.

16. DIN 30710, Safety Markings for Vehicles and Gears, November, 1973.
This standard states that safety markings to indicate construction work should be applied in colors of retroreflecting white and fluorescent red. It consists of white/red oblique stripes (45 degrees).

17. DIN 30711, Warning Clothing, December 1974.
This standard states that warning clothing must be visible in day or night and must be colored fluorescent red-orange.

18. DIN 67521, Photometric Evaluation of Traffic Sign Lighting, March, 1967.
A standardized method that measures the luminous density of illuminated traffic signs is described.

19. Arbeitsstaenttenverordnung, Code Concerning Working Places In Industry, May, 1976.
This code stipulates that all danger areas must be clearly marked and that there should be sufficient lighting to prevent accidents. A minimum level of illumination is specified to be 15 lux.

Asian Standards

The standards and codes presented here were obtained primarily from the Japanese Standards Association and the Japanese Traffic Safety Association.

20. JIS-Z-8721, Japanese Industrial Standard, Specification of Colors According to their Three Attributes, Japanese Standards Association, 1964.
This JIS describes a method for the specification of surface colors according to hue, brightness, and saturation. Colors of materials that exhibit fluorescent are excluded.

21. JIS-Z-8722, Japanese Industrial Standard, Methods of Measurement for Color of Materials Based on the CIE 1931 Standard Colorimetric System, Japanese Standards Association, 1971.
This standard specifices that color measurement should be based on the 2 degree visual field system outlined by CIE 1931 (Standard Colorimetric System).

22. JIS-Z-8723, Japanese Industrial Standard, Method of Comparison for Surface Colors, Japanese Standards Association, 1961.
This standard specifies a method for the comparison of surface colors based on background, mesh, illumination, and viewing direction.

23. Japanese Traffic Safety Association, Road and Traffic Signs Handbook, 1972.
Specifications are given concerning the design materials, demarcation, and marking of road signs, as well as methods of installation and location of road signs.

24. Japanese Standards Association, JIS-Z-9106, General Code of Fluorescent Safety Color, 1972.
The five fluorescent safety colors are fluorescent red, yellowish red, yellow, green, and reddish violet, whose uses for various safety signs are similar to those specified in JIS-Z-19101.

25. Japanese Standards Association, JIS-Z-9107, Safety Signs, 1967, (Reaffirmed 1970).
This supplements JIS-Z-9103 for color, design, and dimensional specifications of the safety signs such as Fire Prevention, Danger, Caution, Relief (First Aid), Prohibition, etc.

26. Japanese Standards Association, JIS-Z-9108, Fluorescent Safety Signs, 1964 (Reaffirmed 1976).
This standard applies when fluorescent colors are used on safety signs specified in JIS-Z-9107. The coloring agents allowed are fluorescent red, yellowish red, yellow, and green, as well as the color paints specified in JIS-Z-9107 (red, yellowish red, yellow, green, blue, reddish violet, white, and black).

27. Japanese Standards Association, JIS-Z-9109, Lantern-Type Safety Signs, 1966 (Reaffirmed 1971).
Colors of lantern-type safety signs are red for Stop, Fire Prevention, Danger, and Emergency Signs; yellow for Caution signs, Green for Safety, Go, and Relief signs; bluish violet for Guide or Induction signs; and white and black for supplemental colors. The standard chromaticity range and diffusive transmittivity (%) for each color are given. A lantern-type safety sign which is normally lighted must be lighted so that the content of the sign will be clearly distinguishable by a person with normal sight from 30 meters away when the ambient illumination is 10 to 30 lux.

28. Japanese Standards Association, JIS-Z-9101, General Code of Safety Color, 1972.
Eight colors (red, yellowish red, yellow, green, blue, reddish violet, white, and black) are designated as safety colors. For example, the red should be the basic color for indication of "Fire Prevention," "Stop," "Prohibition," and "High-Altitude Danger."

29. Japanese Standards Association, JIS-Z-9103, Safety Signs, 1967. Colors, Markings, Letters, and other design specifications of various safety signs, including fire prevention signs, prohibition signs, danger signs, caution signs, medical relief signs, warning signs, etc., are set forth in this standard.

30. Japanese Standards Association, JIS-Z-9104, General Rules of Colored Light for Safety, 1959. Five colors are designated for colored light. They are red, yellow, green, bluish violet, and white: the red for stop, fire prevention, danger and emergency signs; the yellow for caution signs; the green for "go", safety, and relief (first aid) signs; the bluish violet for guide or induction signs; the white as a supplementary color where letters and arrow markings are written.

31. Japanese Standards Association, JIS-Z-9105, Reflective Safety Signs, 1976. The colors (red, yellowish red, yellow, green , blue, white, and black) allowed for use on reflective safety signs are further specified by the criteria determined for hue, brightness, and saturation of each color. The reflective performance of the signs is specified in terms of a partial reflective light flux ratio (%) at zero angle of incidence; for example, 3.1 in case of red or yellowish red, 3.6 in case of yellow, 1.8 in case of green, etc.

32. Japanese Standards Association, JIS-Z-9110, Recommended Levels of Illumination, 1975. Level of illumination is broken down into 15 ranks ranging from 0.5 representing the 0.7-0.3 lux level to 20,000 representing the 30,000-15,000 lux level. Levels of illumination represented by the respective ranks are assigned to provide required level of illumination according to location and type of work. Tables specifying required levels of illumination for lighting of an office, factory, school, hospital, retail store/department store, museum and public hall, restaurant, etc., are included in this standard.

INTERNATIONAL STANDARDS

Only one international standard in a related field has been identified through the retrospective search.

33. International Organization for Standardization, Symbols, Dimensions, and Layout for Safety Signs, 150/R 557-1967(E). This standard applies to the dimensions, symbolizations, and layout of safety signs. The area, S, of a sign is equal to or greater than $L^2 / 2000$ where L is the viewing distance. Dimensions of essential details of the symbols are to be 1/1000 of the viewing distance. A list of symbols and diagrams of recommended layouts for signs are included.

CURRENT PRACTICES

The application of research related to visibility can be broken down into five distinct categories. These categories include applications in air and ground transportation, safety clothing, underwater visiblity, visibility measurement, and occupational and industrial applications.

The majority of reported visibility research has been applied to transportation facilities (both air and ground). Lighting and signing are the most obvious uses of visibility research, but the use of color is also gaining application in many transportation systems. Accident reduction has been the primary goal in the development of reflective and phosphorescent safety clothing which seems to have unlimited application for fire, police, industrial, and highway personnel. Defense and oceanography have profited from visibility research in underwater applications particular in regard to camouflage and color contrast. Visibility measurement encompasses the prediction and measurement of the majority of design and environment factors. And, occupational and industrial applications of visibility research have been in computer graphics, plant layout, and color coding.

These categories will be grouped under separate sections and all research related to the topic is annotated.

AIR AND GROUND TRANSPORTATION RESEARCH

The following list of reports and publications is primarily made up of research that deals with highway lighting, highway signing, and traffic safety applications. Some of the reports in this section pertain to applications of visibility research for airports, particularly in regard to taxiways and runways, as well as atmospheric visibility conditions.

34. Adams, G. H., Highway Markings (A Bibliography with Abstracts), National Technical Information Service, Springfield, Va., April, 1976.
Information is given on painting, striping, and marking of traffic lanes and road edges. Discussions are made of retro-reflectors, bar patterns, wet road conditions, night visibility, pavement reflectance, and weathering.

35. Alexander, G. J.; King, G. F.; Warshaw, M. S.; McGlammery, D., "Development of Information Requirements and Transmission Techniques for Highway Users," TTI, Report No. RR-606-1, July, 1970.
Discussion of a primary concept of information needs in the design of highway information systems particularly in regard to trip planning and signing.

36. American Institute of Graphic Arts, New York, "Symbol Signs. The Development of Passenger/Pedestrian Oriented Symbols for Use in Transportation Related Facilities," Contract No., DOT-OS-40192, November, 1974.
The intent of this project was to produce a consistent and interrelated group of symbols to bridge the language barrier and simplify basic messages at domestic and international travel facilities.

37. Arndt, J. F., "Safety Signs for Agricultural, Earth Moving and Forestry Machines," SAE Paper, No. 710 707 for meeting September 13-16, 1971.
Suggestions were given that symbols should be standard and should indicate the degree of personal injury involved.

38. Bleyl, R. K.; and Boutwell, H. B., "Computer Program for Guide Sign Designing and Drafting," Traffic Engineering, 38(6), 1968, 22-6.
The program developed makes it possible to handle upper-case, lower-case, and capital letters and numerals of any standard size ranging from 4 to 30 inches in height for highway signing.

39. Bodmann, H. W., "Visibility Assessment in Lighting Engineering," Journal of the Illuminating Engineering Society, V. 2, 1973, 437-444.
A Review of CIE publication No. 19, "A Unified Framework of Methods for Evaluating Performance Aspects of Lighting."

40. Bureau of Public Roads, Washington. D.C., "Improvement of Transportation Graphics and Communications," Proceedings of a Seminar, April 11-12, 1968, by FHWA Task Force on Highway Transportation Graphics and Communication.
This report records initial efforts to improve the total information system available to highway users.

41. Bresnahan, T. F.; and Bryk, J. A., "The Hazard Association Values of Accident-Prevention Signs," Professional Safety, 20(1), 1975, 17-25.
The study investigates the effectiveness of color coding and signal words as visual hazard alert cues in accident prevention signs.

42. Council, F. M.; and Hunter, W. W., "Implementation of Proven Technology in Making the Highway Environment Safe," Highway Safety Research Center, Chapel Hill, N.C., August, 1975.
An effort to identify factors limiting the application of known technology for making highways safer and to develop strategies for achieving greater application was discussed.

43. Dudek, C. L.; Huchingson, R.; Dale, R.; Ritch, G. P., "Evaluation of a Prototype Safety Warning System on the Gulf Freeway," TTI-2-18-72-165-13, July, 1974.
An evaluation of a real-time system that warns approaching motorists of stoppages downstream of crest type vertical curves.

44. Eriksson, B., "Studies on Polarizing Filters and Light Sources for Polarized Headlight Systems," Institute of Optical Research, Stockholm, Sweden, June, 1968.
Measurements were made on polarizing filters and light sources aimed at the development of a usable polarized headlight system.

45. Gates. R. F.; Phillips. C. B., "Evaluation of Taxiway Guidance Systems," Federal Aviation Administration, Contract No. FAA-RD-69-60, January, 1970.
Retro-reflective taxiway guidance signs of red, yellow, and green colors were evaluated for color coded applications at airports.

46. Harmon, C. G., "Highway Signing Research: A Survey of Materials and Research Needs Relating to Their Use," Southwest Research Institute, San Antonio, Project No. SWRI-07-1650, July, 1965.
The objective of this study was to evaluate and identify qualities for optimum sign effectiveness with emphasis on night and adverse weather conditions.

47. Illuminating Engineering Society, "IES Guide for Photometric Measurements of Roadway Sign Installation," Journal of the Illuminating Engineering Society, 5, 1976, 244-247.
Uniform test procedures for determining and reporting the illumination and luminance characteristics of roadway sign installations.

48. Klotz, R. C., "Evaluation of a Field Testing Device for Flashing Barricade Warning Lights," PennDOT, FHWA, Contract No. PennDOT-74-7, June, 1975
The report evaluates a portable field testing device used to test and determine the photometric characteristics of Flashing Barricade Warning Lights.

49. Kunzman, W., "Irradiation and Halation," Traffic Engineering, 39(3), 1968, 45, 47-8.
This study considers the effects of irradiation and halation in traffic signing.

50. Lane, F. D.; and Pfau, J. L., "Speed Advisory Information for Reduced Visibility Conditions," Oregon State Highway Division, Salem, FHWA, Contract No. FH-11-7950, May, 1975.
This study develops design specifications for a speed advisory system in reduced visibility conditions which includes fog, rain, snow,and nighttime driving.

51. McGill, W. A.; and Cameron, C., "Comparative Evaluation of Speed Control Signs," Australian Road Research, 3(8), 1968, 3-11.
Experiments were performed to compare the effectiveness of different types of road signs used for the imposition of minimum and maximum speeds.

52. National Academy of Sciences, National Research Council, Washington, D.C., "Visual Factors in Transportation Systems," Proceedings of Spring Meeting 1969, NSS-NRC Committee Vision.
Visual problems are discussed on automobile driving signs and marking, highway lighting, airline pilots, and air traffic control.

53. "Experiment in Roadside Sign Location," Public Works, 99(5), 1968, 78-9.
Advantages of placing signs 30 feet or more from the roadside edge are discussed.

54. Roberts, A. W.; Reilly, E. F.; and Jogannath, M. V., "Freeway Style Diagrammatic Signs in New Jersey," N.J. DOT, Trenton, Bureau of Operations Research, August, 1974.
Diagrammatic and conventional signs were evaluated for their potential effectiveness according to existing situations.

55. Seymour, W. M., "Traffic Controls for Maintenance on High Speed Highways," Kentucky Dept. of Highways, Lexington, Report No. RR-327, May, 1972.
The results of this study support the adoption of orange as the standard color for signing construction and maintenance sites.

56. Srinivason, N. S.; and Lal, J., "Design of Uniform Road Signs," Indian Roads Congress Road Research Bulletin, 11, 1967, 79-104.
This paper deals with the designing of a uniform system of road signs for different traffic and road conditions in India.

57. Street, R. L.; Mayyasi, A. M.; and Berngen, F. E., "Annotated Bibliography and Summary of Research Needs in the Human Factors Aspects of Driver Visual Communications," TTI, Contract No. FH-11-7031, July, 1970.
This effort covers two main areas: (1) visual input requirements in the driving task, and (2) human information-processing capability in complex tasks.

58. Van Bommel, W. J., "Optimization of the Quality of Roadway Lighting Installations — Especially Under Adverse Weather Conditions," Journal of the Illuminating Engineering Society, 5(2), 1976, 99-106.
The parameters affecting driver visibility are discussed, including those due to luminaires, road surfaces, and luminaire arrangement.

59. Walton, N. E., "Visibility and Driver Information," HRB Record, 440, 1973.
The report deals with street lighting, signs, and delineation necessary for better visibility.

60. Woo, J. C., "System Study, Design, Test, and Evaluation of Concepts for Marking of Low Visibility Aviation Obstructions," Mount Auburn Research Associates, Cambridge, Mass., Contract No. FA-67-WA-1718, June, 1968.
This study determined the requirements for effective marking of overhead obstructions of low visibility that are potential aviation hazards.

61. Jaster, K., "Influence of Crosswalk Lighting on Accidents at Zebra Crossings in Hanover," Lichtechnik, 25(4), 1973, 183-6.
This study shows that the installation of low pressure sodium lamps at crosswalk areas had a positive influence on the number of pedestrian accidents.

62. Bauer, H., "Color and Light, Aids in the Combat Against Traffic Hazards," Sicher Ist Sicher, 25(7/8), 1974, 318-327.
Based on present day knowledge of light and color, recommendations for improving the existing warning devices in traffic are presented.

63. Japan Automobile Manufacturers Assoc., "Hints to the Use of Color Systems for Traffic Control," Traffic Safety Study Committee, 1975. A color system is described for application to signs for bicycle and bus lanes, as well as guides to highway entrances.

64. Traffic Safety Study Committee, "Actual Examples of Recent Color Utilization for Road Traffic Control," Japan Automobile Manufacturers Assoc., 1975.
Examples are given for the use of color marking for steep grades, high accident areas, pedestrian crossing, etc.

65. Osanami. T., "Fundamental Problems of Visiblity in Road Traffic," Journal of the Illuminating Engineering Institute of Japan, 55(12), 1971, 4-9.
This study suggests the use of a contrast vision chart for driver examinations.

66. Kabayama, H., "A Study on the Visibility of Lantern-Type Lighted Signs," Journal of the Illuminating Engineering Institute of Japan, 55(12), 1971, 23-28.
Suggestions are given for the luminance level of lantern-type road signs which have a white background.

67. Kawakami, M., et al., "Studies on the Visibility of Traffic Signs," Journal of the Illuminating Engineering Society of Japan, 55(12), 1971, 29-34.
A series of experiments were made on the visibility of traffic signs where background, color, and distance were varied.

SAFETY CLOTHING

The design of safety clothing has widespread applications, particularly where there is an increased risk of accidents. The publications included in this section are essentially a description of the various uses of safety and clothing and of their fabrication.

68. Farr, M.; and Constable, C., "The Thinking That Gets a Garment Right," Industrial Safety, 14(10), 1968, 9-10, 29.
An Ergonomics company discusses clothing to increase the safety, visibility, and movement of the wearer at work.

69. Griep, D. J., "Safety Clothing for Work on the Road," Institute for Road Safety Research, Voorburg, Netherlands, 1970.
Tests were carried out on safety clothing to assess the visibility of this clothing for road users and its acceptance to wearers.

70. Michon, J. A.; Ernst, J. T.; and Koutstaal, G. A., "Safety Clothing for Human Traffic Obstacles," Ergonomics, 12(1), 1969, 61-70.
Several fluorescent and non-fluorescent colors are compared to determine which to recommend for people who work on or near roadways.

71. "Protective Clothing and Ergonomics," National Safety News, 99, 1969, 150.
A description of protective clothing designed to provide high visibility for construction workers.

72. Warren Spring Lab, Stevenage, England, Ergonomics Abstracts, 48347-48982, August, 1967.
Contents include discussions on the design of high visibility clothing and personal equipment.

UNDERWATER VISIBILITY

Since the basic problem of visibility underwater is in the transmissivity of light through water, much of the current research has concentrated on color or luminous contrast decrements. This research has led to some recommendations that state the use of fluorescent-colored paints and artificial light to counterbalance the color and luminous contrast decrements.

73. Kent, P. R., "Vision Underwater," American Journal of Optometry and Archives of American Academy of Optometry, 43(9), 1966, 553-65.
This study was a comparison of the visual resolution capacity in air and water, and concluded that both size and distance are overestimated underwater but that visual resolution of Landolt rings in clear water at short distance was better than in air.

74. Kinney, J. S.; Luria, S. M.; and Weitzman, D.O., "Visibility of Colors Underwater Using Artificial Illumination," Journal of the Optical Society of America, 59(5), 1969, 624-8.
Scuba divers observed colors under mercury vapor and incandescent light sources in clear and turbid water, and defined optimum combinations of type of water, light source, color, and fluorescence for underwater visibility.

75. Kinney, J. S.; Luria, S. M.; and Weitzman, D. O., "Visibility of Colors Underwater," Journal of the Optical Society of America, 57(6), 1967, 802-9.
This study experimented with horizontal and vertical viewing angles to determine relative visibility of colors in four types of water.

76. Muntz, W. R.; Baddeley, A. D.; and Lythgoe, J. N., "Visual Resolution Underwater," Aerospace Medicine, 45, 1974, 61-66.
The range that divers could resolve grating test objects underwater was measured and a plot was made of threshold contrast vs. spatial frequency of the grating (a modulation transfer function). Results indicate that performance underwater can be predicted in the laboratory if contrast reduction due to the water is allowed for.

VISIBILITY MEASUREMENT

A variety of visibility meters have been developed that are based primarily on the measurement of luminous contrast. These meters have been used to measure nighttime roadway lighting **and instrument panel lighting,** as well as natural daylight.

77. Finch, D. M.; and Palmer, J. D., "Assessment of Nighttime Roadway Visibility," Highway Research Board Bulletin, 163, 1957, 1-16.
This paper discusses the variety of visibility meters in use, as well as description of the University of California instrument that evaluates uniform and non-uniform lighting conditions at night.

78. Blackwell, O. M.; and Blackwell, H. R., "Assessment of Night Visibility and Visual Performance Under Different Systems of Fixed Roadway Lighting," Institute for Research in Vision, Ohio State University, Columbus, Ohio, 1975.
This report summarizes the development and use of the Blackwell Task Evaluator and also suggests future applications to roadway lighting problems.

79. Kerchaert, R. B.; and Sauter, J. L., "A Procedure for Measuring Instrument Panel Visibility," SAE Paper, 720232, for meeting January 10-14, 1972, 865-873.
This paper suggests the use of the Luckiesh-Moss visibility meter in the measurement of instrument panels.

80. Yamaji, R., "Study of the Motor Car-Road System Based on Visual Function," Acta Society of Opthamology, Japan, 74(9), 1970, 1164-68.
The visibility of objects was examined for road surfaces which had imbalanced luminance distributions,concluding that visibility is a function of luminance contrast as well as distance.

81. Moore, J. D.; and William, T., "Measurement and Evaluation of Sign Reflectivity," IEEE Southeast Congress Proceedings, Paper 0-6, 1973.
A discussion of some of the various methods for measuring sign reflectivity.

82. Martin, M., "Standardization of Visual Tasks and Measures," U.S. Army Human Engineering Laboratory, Arberdeen Provision Ground, Maryland, March, 1973.
This report discusses the application of the Visual Task Evaluator for a variety of field test visibility studies for military research.

83. Brown, J. L., "Visual Sensitivity," Physiology Program, Office of Naval Research, Contract No. NONR-N00014-67-A-0398-0007, May, 1975.
A concise review of the literature on visual sensitivity from 1969 through 1971.

84. Takei, T., "A Trial for the Measurement of Visibility," 15th Meeting of the Japanese Society of Human Engineering, May, 1974.
A discussion of the design of a visibility meter which is made of a scattering type polarizing plate and uses polaroid film to allow changes in polarization.

85. Ito, K. "Review of Visibility Evaluation and Measuring Methods," Annual Meeting of the Architectural Institute of Japan, October, 1968.
Visibility evaluation/measurement procedures were reviewed, including the Delos method and Blackwell's VTE, as well as methods used by Eastman, Simpson and Finch, and Cottrel.

INDUSTRIAL AND OCCUPATIONAL APPLICATIONS

Industrial and occupational applications of visibility research have been in glare control, color coding, and signing. Reductions of light source glare has shown reduced eye fatigue in work related tasks and color coding has proved to be an effective accident reduction technique in hazardous work areas. Standardization of safety symbols and signs has also facilitated overall industrial safety practices.

86. Knave, B., "Lighting: Applications of Vision Physiology in Occupational Hygiene," Nordica Hygiene, 54(2), 1973, 55-67.
A discussion of the physics of light and its effect on the physiology of the eye. Emphasis is placed on glare and its generation of eye strain and visual fatigue.

87. "Color - It Reduces Eye Fatigue," Occupational Hazards, 17, 46-49.
A general discussion of the causes of eye fatigue (glare, excessive contrast, constant distance and light adjustments, and peripheral brightness and motion) and recommendations for the use of color in industry to reduce eye fatigue.

88. Ferguson, D. A.; Major, G.; and Keldoulis, T.; "Vision at Work: Visual Defect and the Visual Demand of Tasks," Applied Ergonomics, 5(2), 1974, 84-93.
A review of several studies on visual fatigue and inefficiency applied to communications, and a program to facilitate visual tasks is outlined.

89. Gengler, P. G., "For the Sake of Safety and Efficiency - Mark Those Pipes," Plant Engineering, 29(15), 1975, 81-82.
A system for marking pipes that increases safety and efficiency in industrial settings is described.

90. Azuma, T.; and Takhashi, S., "Illumination and Coloration in Industry," Safety Digest (Japan) 20(1), 1974, 4-12.
A discussion of new illumination standards for Japanese industries that account for reductions in production costs and eye fatigue.

91. Samukawa, S., "Keeping Things in Order by Color Management," Safety (Japan), 26(4), 1975, 53-57.
The author discusses a system of colors for signs, markings, and protective paint that promotes occupational safety.

DESIGN FACTORS

The design variables that affect the visibility of an object can be subdivided into the following groups:

- camouflage
- pattern
- color contrast
- luminance contrast
- area (target size)
- reflectivity

CAMOUFLAGE Most of the research concerned with camouflage has been in the direct field testing of the effects of various colors and backgrounds on target detection. There has been no research reported that deals with the theoretical nature of the causes and effects of camouflage. The camouflage research conducted by the Army was essentially of the trial and error type. (This color does not produce the camouflage effect with that type of scenery, etc.)

PATTERN This design factor is by far the most researched topic in this category. Pattern recognition has been studied in its relation to other factors, such as color contrast, brightness, area or size, as well as its relation to the environmental factors of illumination, background, and distance. Pattern recognition has also been studied from a wide variety of situations or applications, for example, highway road signs, aircraft displays, legibility, and computer graphics. It has also been investigated from numerous standpoints, for example, the physiological studies of pattern recognition measure the evoked cortical potentials of the retina and psychophysical studies employ response times, bisensory signals, and memory, etc., as measures of pattern recognition.

COLOR CONTRAST The discrimation of color can be essentially broken down into two distinct areas of study: the psychophysical processes of color vision and the physical processes of spectral absorption and saturation. Under these two areas, there are a number of studies that employ luminance, contrast, pattern recognition, and field size as independent variables in the discernment of color contrast.

LUMINANCE CONTRAST This category has yielded the most research in attempts to privide a sound physical and psychophysical basis for visibility. Luminance contrast has also been studied, not only under varying conditions such as background, illumination, and distance, but also under design factors such as color contrast, reflectivity, and area.

AREA The influence of area or target size on visibility may be divided into three sections of studies dealing with spatial frequency, apparent size, and visual search as the independent variables.

REFLECTIVITY Most of the research in this section has been applied research dealing with reflective properties of signs and roadways and their. influence on visibility. There have also been some technological research into directional reflectance properties of various metals and other materials (such as clothing and asphalt).

CAMOUFLAGE

The visibility of a camouflaged object is dependent on several factors. Some of the more important object characteristics are the size of the object, its shape, contrast with its background, the illumination level, and the time available for seeing the object. When an object is camouflaged, it is generally considered that the object is relatively small, that the brightness of the background is defined by the environmental conditions and therefore uncontrollable, and the time available to detect the object is essentially infinite. Therefore, camouflage methods have usually concentrated on minimizing the effects of object contrast. In essence, an object which is reduced to threshold contrast levels will be the most difficult to see under normal viewing conditions.

Military Applications

The military necessity of camouflaging personnel as well as vehicles, electronic gear, and other equipment against detection by enemy ground personnel has made the detectability of a target an important design consideration. Traditionally, most of the research on camouflage has been conducted by the military and was usually conducted by placing camouflaged objects in a typical setting and having military personnel look for the objects. The percentage of observers who located the object in these studies defined the detectability of each object. Given the absence of a quantification method for the perceptibility of camouflage, this method probably represents the most valid method of evaluating camouflage from a military point of view.

Research Needs

From the military viewpoint, the ultimate test of camouflage objects must be made with human subjects. Since it is technically feasible to predict the visibility of an object in a particular background by photometric evaluation of factors such as luminance, color, and contrast, the most practical and economical solution to the future study of camouflage should be through photometry. Based on the knowledge gained from past visibility research on contrast, reflectivity, pattern recognition, etc., field factors can be determined for a variety of military objects in any type of environment.

Camouflage Studies

92. Army Test and Evaluation Command, Aberdeen Proving Ground, Md. "Security From Detection," Report No. TOP-1-3-515, October 1972. A method is described for the evaluation of infantry position with audio and visual position disclosing techniques.

93. Anstey, Robert L., "Visibility Measurement in Forrested Areas," Army Natick Labs, Mass Earth Sciences Division, Report No. SR-S-4, November, 1964.
This report summarizes the visibility of objects in any forested area and stresses the need for the Secchi disk (a flat, dull white surface) to be used as a standard target.

94. Dobbins, D. A.;and Gast, M., "Jungle Vision I, Effects of Distance, Horizontal Placement, and Site on Personnel Detection in Semi-deciduous Tropical Forests,"Army Tropic Test Center, Fort Clayton (Canal Zone), No. 4735I, April, 1964.
Detection thresholds were determined to be 100 feet in tropical vegetation.

95. Dobbins, D. A., "Jungle Vision II, Effects of Distance, Horizontal Placement, and Site on Personnel Detection in an Evergreen Rainforest," Army Tropic Test Center, Fort Clayton (Canal Zone), No. 4735H4, November, 1964.
A comparison between detection thresholds for tropical vegetation and evergreen vegetation.

96. Dobbins, D. A., "Jungle Vision IV, A Comparison Between the Detectability of Human Targets and Standard Visibility Objects in an Evergreen Rainforest," Army Tropic Test Center, Fort Clayton (Canal Zone), No. 4493C2, February, 1966.
A reaffirmation of the reduced detectability of the Army's camouflage uniform is discussed, as well as the recommendation that an olive drab silhouette be employed as a standard target.

97. Ramsley, A. O., "Feasibility of Using Fluorescent Colorants to Afford Camouflage Protection Against Photographic Detection," Army Natick Labs, Report No. C/OM-TS-145, October 1966.
Infrared image converters require that the reflectance of objects be relatively low and, therefore, the use of fluorescent colorants will increase reflectivity and decrease detection from infrared photography.

98. Ramsley, A. O., "Modern Counter-Surveillance in Combat Clothing," Army Natick Labs, Report No. A1141J4, 1970.
The report describes a color system for combat clothing that satisfies the reflectance requirements for camouflage protection against all modern surveillance devices.

99. Ramsley, A. O., "Camouflaged Article and Method Of Producing Same," Office of the Secretary of the Army, Report No. C 1682C1, May, 1969.
This report contains a method for camouflaging dyeable materials against daylight or nighttime detection.

100. Sell, R. E., "Camouflage Practices," Nuclear Research Associates, Inc., New Hope Park, N.Y., Report No. NRA-864-1, July, 1967. State-of-the-Art review on camouflage.

101. Young, M. E., Protective Clothing, Part 3, Survival, Aircraft, and Combat Environments, (A Bibliography with Abstracts), National Technical Information Service, Springfield, Va., No. 391-812. The bibliography cites reports on design, testing, and evaluation of protective apparel for survival, aircraft, and combat situations.

PATTERN RECOGNITION

Pattern recognition and its relation to visibility can essentially be treated as a design variable necessary for the prediction of visibility. Some of the characteristics of pattern recognition include form, area, and size perception;and these object factors can be further isolated into components such as number of sides in an object, symmetry, angular variability, color, and spatio-temperal relationships.

These pattern characteristics or cues may appear to increase the complexity of a visual task,but some demarcation is necessary for the perception of objects within the visual field. They help to stabilize the perception of objects in space as well as the viewer's own position and orientation in space,and also to stabilize the motor adjustments of the eyes, such as accomodation and convergence. The perception of object pattern characteristics **is** generally considered to be neural in nature where the detection of the object itself is considered a function of the retinal receptors. Research on pattern recognition and visibility has been studied in its relation to environmental factors such as illumination, background,and distance. Some of the principles of pattern recognition have also been applied to transportation and industrial situations.

Spatial Cues

Some of the spatial characteristics or cues that are considered to be innate mechanisms of the human visual system necessary for visibility include: figure-ground relationships, relative size, linear perspective, accomodation, and aerial perspective. Of the visual cues for space perception, relative size, linear perspective,and accomodation can be specified in quantitative terms. Aerial perspective is also quantifiable through the specification of relative contrast sensitivity which may subsequently address figure-ground relationships.

Since there are various factors involved in spatial perception, research in this area has generally sought to correlate spatial cues with gradients of light or shadow,as well as gradients of hue in chromatic objects.

Visual Complexities

The simple perception of size or shape characteristics in objects may be further influenced by visual complexities of the object as well as its background. The visual complexity of an object may be influenced by the viewer's orientation to the object, the ambiguity of the object, and the viewer's cognitive set. These factors have been experimentally shown to influence the discrimination of objects to limited degrees, and research in the area of visual displays and control systems has attempted to minimize these effects through the addition of acoustical cues and various global organizations of the spatial cues.

Research Needs

Since pattern recognition forms an integral part of the visibility of an object and spatial characteristics can be specified in quantitative terms similar to luminance intensity, future research should be directed toward the quantification of the psychological dimension of complexity. This may be accomplished through the measurement of weighted combinations of angular variability, symmetry or the number of sides, etc.

Pattern Recognition Studies

102. Bateman, R. P., "An Investigation of Pattern Recognition of Air-Craft Attitudes Indicator Displays," Masters Thesis, Air Force Int. of Technology, Wright-Patterson AFB, Report No. FA/EE/73-3, June, 1973.
    This report proposes an algorithm for separating patterns in aircraft indicators. Theories are proposed on spatial disorientation accident statistics.

103. Burton, G. J., "Visual Detection of Patterns Periodic in Two Dimensions," Vision Research, V. 16, 1976, 991-998.
    Single models proposed in earlier investigations of visual contrast detection of linear patterns are extended to apply to two-dimensional space. Evidence reported indicates that two-dimensional space has no effect on accurate predictions of contrast threshold values of the pattern, but it is suggested that detection mechanisms are size-tuned in both dimensions.

104. Caelli, T. M.; and Umansky, J., "Interpolation in the Visual System," Vision Research, V. 16, 1976, 1055-1060.
    This paper emphasises the differences between pattern detection and recognition, and proposes a model for the latter process. The model is based on a concept of interpolation where the visual system constructs a shape representation by encoding rates of change of spatial parameters with respect to distance.

105. Clouser, D. C., The Effects of Corrosion on the Recognition Threshold of Symbols Stamped into Steel Surfaces, Masters Thesis, Texas A & M University, May, 1972.
This report consisted of an experimental determination of the effects of corrosion on the recognition of symbols. The conclusions reported were that (1) even a small amount of corrosion is detrimental to recognition; (2) removal of corrosion becomes less effective to recognition as the degree of corrosion increases; and (3) viewing angle is relatively unimportant.

106. Copping, B.; Alexander, V. D.; and Hunter, J. J., "Human Factor Assessment of the Legibility of Five Numeric Visual Displays," Applied Ergonomics, 4(3), September, 1973, 144-149.
The experiments described were aimed at discovering which of five numerical displays was most suitable to telephonists with a display behind the keyshelf. The results are generally applicable to other office functions. The numerical displays eliminated perceptual confusions of form (0 to o or B and 8) and acoustic confusions in memory of names (B, C, D, and E) within a larger set of symbols.

107. Cosgrove, M. P.; Kohl, G. A.; Schmidt, M. J.; and Brown, D. R., "Chromatic Substitution with Stabilized Images: Evidence for Chromatic Specific Pattern Processing in the Human Visual System," Vision Research, 14(1), 23-30.
This report shows that adaptation to colored luminance borders decreases the visibility of stabilized lines of the same color but does not affect the visibility of luminance borders of a different color. The interocular transfer of this color and pattern specific adaptation suggests that cortical analytic mechanisms specific to both color and pattern were adapted.

108. Fitts, P. M., "Engineering Psychology and Equipment Design," Handbook of Experimental Psychology, Stevens, S. S., ed., John Wiley and Sons, Inc.: New York, 1951, 1287-1340.
The chapter discusses problems and methods of research on equipment problems, including design of visual displays (Discrimination Processes, Visibility, Pattern Discrimination), design of quantitative displays (Numerical Displays), displays for spatial relations (Cues, Figure-Ground Relations, Set, Ambiguity), and tactual displays (Shape Coding, Size Coding, Color Coding). Some of the other design factors mentioned include auditory displays and the design of control systems.

109. Frith, U., "Lines that Affect Speed of Visual Scanning," Perception, V. 4, 1975, 407-409.
The report shows that scanning from left to right through arrays of shapes is slower with vertical than with horizontal lines.

The reverse is true for scanning from top to bottom, and therefore, lines lying across the direction of scan appear to act as barriers.

110. Gibney, T. K., "Legibility of Segmented Versus Standard Numerals: The Influence of the Observer's Task," Aerospace Medical Research Labs, Wright-Patterson AFB, Ohio, Report No. AMRL-TR-68-124, August, 1968.
Laboratory research has indicated that segmented numerals are not as easy to read as standard Arabic numerals. Research results from this study suggest that the differences disappear in some practical, complex tasks.

111. Gilinsky, A. S., "Orientation Specific Effects of Patterns of Adapting Light on Visual Acuity," Optical Society of America Journal, 58(1), 1968, 13-18.
Experimental evidence in this report shows that adapting flashes of 1 second or longer affect the resolution threshold of line gratings as a function of orientation. Pre-exposure to horizontal gratings gives greater threshold than vertically or obliquely oriented contours, and the differential washing effects are functions of exposure to a light and dark adapting pattern.

112. Glezer, V. D.; Leushiva, L. I.; Nevskaya, A. A.; and Prazdnikova, N. A., "Studies on Visual Pattern Recogntion in Man and Animals," Vision Research, 14(7), 1974, 555-583.
Three types of recognition performance have been isolated. The first type was shown to be controlled by innate mechanisms of the visual system while the second and third types result from learning. Visual images in man are invariant under size transformation and rotation on the vertical axis; the invariance to other types of rotation is a result of training. The invariant nature of the recognition process in the human visual system is determined by the existence of separate channels to process shape and spatial characteristics.

113. Hastings, D. W.; and Evans, S. H., "The Selection of Local Features for Pattern Identification: An Exploratory Study," Texas Christian University, Int. for the Study of Cognitive Systems, Project THEMIS, No. 367, July, 1965.
A feature analytic process is proposed as a basic mechanism in the encoding and storage of visual shapes by humans. These features are stored in memory according to their positional relationships in the pattern.

114. Kolers, P. A.; and Perkins, D. N., "Orientation of Letters and Errors in Their Recognition," Perception and Psychophysics, 5(5), 1969, 265-269.
In this experiment, subjects were asked to name letters that were rotated, reflected, or inverted. Inversions induce more

errors than reflections and reflections induce more errors than rotations. The data suggest an "orientation set" in which the identification of ambiguous characters depends on their orientation.

115. Reed, J. B., "The Speed and Accuracy of Discriminating Differences in Single and Compound Aspects of Vision," Mount Holyoke College, South Hadley, Mass., Psychophysical Research Unit, Contract No. NONR-131(01), September, 1952.
People were found to discriminate compound hue and shape faster than any other compound. Hue and area, and hue and brightness require little more discrimination time than hue and shape.

116. Ward, F.; and Tansley, B. W., "Increment Thresholds Across Minimally Distinct Borders," Journal of the Optical Society of America, 64(6), 760-762.
This work suggests that the increment threshold sensitivity accounts for differences only between achromatic channels and not to relative brightness differences due to chromatic-channel imbalances.

117. Uttal, W. R.. "The Effect of Deviations from Linearity on the Detection of Dotted Line Patterns," Vision Research, 13(11), 1973, 2155-63.
Results of this study indicate that straight lines are more easily recognized than curves or angles in dot configurations. The global organization of the stimulus,therefore, is a strong determinant of the ease of visual pattern recognition. The implications for pattern recognition theory are considered using an optical computer.

118. Vernoy, M. W., "Masking by Pattern in Random-Dot Stereograms," Vision Research, V. 16, 1976, 1183-84.
Techniques such as random-dot stereograms have been used to investigate the time course for perception of a figure in depth. The purpose of this study was to investigate masking by pattern in random-dot stereograms.

COLOR CONTRAST

The perception of chromatic areas is affected markedly by the color of adjacent areas (usually termed surround or background). The effect of this phenomenon is termed color contrast. For example, a central chromatic patch will appear more or less gray if surrounded by a sufficiently large and relatively dark background, but dimmer or more gray if surrounded by a relatively light background. Different juxtapositions of chromatic areas also produce perceived shifts in hue and saturation where hues shift in opposite directions, making them complementary, and saturations shift away from each other, magnifying the difference.

Some of the basic principles of color contrast include the following:

- the smaller the central area in comparison with the surrounding area, the larger the color contrast effect.
- color contrast occurs with spatial separation of two fields, but the contrast effect decreases as separation increases.
- the magnitude of color contrast, measured by the amount of cancellation color (to give white), varies with the area of the surround color.
- color contrast is at a maximum when luminous contrast is absent or reduced to a minimum.

Chromatic Adaptation

Chromatic Adaptation is a process manifested by changes in hue, saturation, or brightness that occur during exposure to a given light and, consequently, these changes may influence the perceived color of a succeeding light. Some of the research related to this topic has considered the effect of adaptation on discrimination of colored cards under a variety of adaptation conditions. Under these conditions it was shown that just-noticeable differences between red, green, and blue colored cards increase as the color temperature of the light source decreases (for example, High Pressure Sodium @ 2100K). Another study kept chromatic adaptation constant and described unit perceptual color attributes of hue, saturation, and lightness for a given color in color space. Research has also been reported on the effects of light adaptation and its saturation effect on color.

Effects of Surround Characteristics

There has been a variety of research topics that sought to isolate some of surround characteristics that affect color contrast. Some of these surround characteristics include distinctness of the border between targets and their background, chromatic borders vs. achromatic borders, and channelization of the two fields.

Other research that was identified on color contrast and the effects of surrounding fields pertained to successive contrast effects of pattern and luminance. Some of these investigations have studied: the effect of reduced luminous contrast on color contrast; the effects of constant luminance on color discrimination; and the variation in pattern as a function of their color.

General Studies

This area is primarily composed of research concerned with color vision and visual displays. Studies which were identified relate to psychophysical, developmental, and defective aspects of color vision.

Research Needs

It is evident, with reference to the visual field, that chromatic adaptation and contrast occur instantaneously, and it is likely that these effects are not confined to just the retina but may also involve the cortex. Despite the lack of knowledge on the physiological effects of color contrast, the psychophysical effects of color contrast are well founded and provide a basis for the quantification of color contrast. The determination of visibility, therefore, should include some estimate of color contrast in addition to luminance contrast.

Color Contrast Studies

119. Christ, R. E.; Stevens, A. L.; and Stevens, D. J., "Color Research for Visual Displays," New Mexico State University, Dept. of Psychology, Report No. NMSU-JANAIR-FR-74-1, July, 1974.
A multiple display-task system was developed for testing the efficacy of color as a coding variable in visual displays.

120. Comerford, J. P., "Stereopsis with Chromatic Contours," Vision Research, 14(10), 1974, 975-982.
Stereopsis occurred for stimuli defined by chromatic contours. A chromatic contour was defined as a spatial chromatic change with minimally distinct borders. Discriminations differed for various targets and background, but was essentially related to the distinctness of the border.

121. Cook, T. C., "Color Coding - A Review of the Literature," Human Engineering Lab, Aberdeen Proving Ground, Md. Report No. HEL-TN-9-74, November, 1974.
This report concentrated on factors directly applicable to visual displays - such as hue, alphabet size, and the general advantages and disadvantages of color codes. Color coding was found to be lacking when operators had to make quick, precise identifications.

122. Crockett, D. W., Color Vision (A Bibliography), National Technical Information Service, Springfield, Va., Report No. PS-76/0059/6ST, February, 1976.
References are presented on defective color vision, genetic characteristics, and the use of optical filters to enhance color images. Color vision requirements from a human engineering viewpoint for various occupations are discussed.

123. DeWeert, C. M.; and Levelt, J., "Dichoptic Brightness Combinations for Unequally Colored Lights," Vision Research, V, 16, 1976, 1077-86.
The relative contributions of left and right eye stimuli to dichoptic brightness impressions were found to be dependent on the wavelength in such a way that middle-wavelength stimuli contribute a larger part than lower or higher wavelength stimuli.

124. Fagan, J. F., "Infant Color Perception," Science, 183(4128), 1974 973-975.

The strength of pattern preference for infants was positively related to a degree of hue difference in checkerboards.

125. Federman, P. J.; and Siegel, A. I., "Aircraft Detectability and Visibility: V. Detectability of Stimuli Coated with Fluorescent and Ordinary Paints; A Further Study," Applied Psychological Services, Wayne, Pa., Contract No. N156-38581, December, 1961.

The detectability of various stimuli were investigated that would provide increased aircraft detectability by visual means. Stimuli studied included fluorescent yellow-orange, fluorescent red-orange, white, and white with a black medial stripe. Results indicated fluorescent yellow-orange was most visible under three sky background conditions.

126. Federman, P. J.; and Siegel, A. I., "Survey of Thin Film Fluorescent Material," Applied Psychological Services, Wayne, Pa., Contract No. DOT-FA73-WA3320, December, 1973.

This study suggests support for the use of thin film fluorescent materials on the basis of conspicuity enhancement, minimum added weight, no drag effect, and a favorable cost/utility ratio.

127. Gummerman, K., "Successive Processing of Color and Form from Brief Visual Displays," Perception and Motor Skills, 40(1), 1975, 31-41.

This study sought to determine the relationship between the visual processing of color and form and to determine the number of perceptual stages operating in the perception of color and form.

128. Judd, D. B.; and Wyszecki, G., "Color in Business, Science and Industry," John Wiley and Sons: New York, 1975.

This book provides a synopsis of basic facts concerning color vision; the chemical, physical, psychological, and psychophysical aspects of color; and the principles behind color matching. The various tools and techniques used in the measurement of color, color difference, and the presentation of color in chromaticity space are also covered.

129. Kaiser, D. K., "Color Names of Very Small Fields Varying in Duration and Luminance," Journal of the Optical Society of America, 58(6), 1968, 849-852.

Experiments showed that normal trichromat observers could name colors consistently when retinal illuminance time was constant; and as the total retinal illuminance diminished, degree of artificial tritanaopia increased.

130. Kato, H., "Experimental Studies of Color Vision with Mixture of Colored Lights. Report I. Color Vision of Normal Subjects (Japanese)," Acta Society of Ophthamology, Japan, 77(9), 1973, 1350-58.

Color matching tests with standard color lights were given to subjects to see how color discrimination ability changes with age. Results indicated a significant decrease with age for red-green, green-blue, and yellow-blue discrimination. Brightness sensitivity was also found to decrease for subjects over 50 years.

131. Krantz, D. H., "Small-Step and Large-Step Color Differences for monochromatic Stimuli of Constant Brightness," Journal of the Optical Society of America, 57(11), 1967, 1304-16.

An experimental study of color-difference judgments by methods of triads, consisting of standard stimulus and two comparison stimuli. Results are represented by a unified model for metric space, which combines discriminability with supraliminal similarity.

132. Massof, R. W., "Probability Summation Model for Heterochromatic Luminance Addivity Failure of Absolute Visual Threshold," Perception and Psychophysics, 13(2), 1973, 349-355.

A probability summation model which includes the revised zone fluctuation theory and Abney's Law (an addivity model) was developed that could account for individual differences in color vision.

133. Mikaelcan, H. H., "Interocular Generalization of Orientation Specific Color Aftereffects," Vision Research, 15(6), 1975, 661-63.

McCollough effects (variations in width and position of mach bands as a function of luminance) were generated by exposure to red vertical and green horizontal gratings observed with achromatic gratings forming concentric bands.

134. Pointer, M. R., "Color Discriminations as a Function of Observer Adaptation," Journal of the Optical Society of America, 64(6), 1974, 750-59.

A colorimeter was constructed to measure the size of color differences as a function of adaptation. Nine different adaptations were used: dark adaptation, five white-light sources with color temperatures in the 6500-2000 K range, and adaptation to three colors, red, green, and blue. Results indicate an increase in color differences with decreasing color temperatures.

135. Ramsay, J. O., "Economical Method of Analyzing Perceived Color Differences," Journal of the Optical Society of America, 58(1), 1968, 19-22.

A series of experiments on the perception of color differences were conducted where 20 subjects estimated ratios of each of the possible differences in a set of 21 colors compared to a standard difference.

136. Reynolds, R. E.; White, R. M.; and Hilgendorf, R. L., "Detection and Recognition of Colored Signal Lights," Human Factors, 14(3), 1972, 227-236.

Two experiments were designed to determine effective colors for stimulus lights as measured by the speed of detection and accuracy of identification. Additionally, the nature of the interactions between stimulus color, background color, and the amount of ambient illumination were assessed.

137. Valberg, A., "Light Adaptation and the Saturation of Colors," Vision Research, 15(3), 1975, 401-404.

The effect of the luminance of an achromatic surround on the saturation of central color stimuli was measured by means of a color matching method. It was found that the opponent purity of the matching varied according to a power function of the luminance of the surround. A saturation index is defined as a measure of the variation of saturation with adaptation luminance.

138. Volz, H. G., "Optical Properties of Pigments: Objective Methods for Testing and Evaluation," Angew.Chem. 14(10), 1975, 688-98.

Colorimetry and color-order systems based on the perception of color are described and are followed by a discussion of the theories of light absorption and light scattering.

139. Von Grunau, M. W., "The Fluttering Heart and Spatio-Temperal Characteristics of Color Processing, II. Lateral Interactions Across the Chromatic Border," Vision Research, 15(3), 1975, 437-440.

Two experiments are reported that investigate the hypothesis that lateral interactions between color processing mechanisms across chromatic borders are involved in the 'fluttering heart' phenomenon. The effect is destroyed by separating the target and background with a black line. The interaction by varying the target width leads to the same result.

140. Ward, F.; and Tansley, B. W., "Increment Thresholds Across Minimally Distinct Borders," Journal of the Optical Society of America, V. 64, 1974, 760-762.

This work suggests that the increment threshold technique is sensitive only to differences between achromatic channels, and not to relative brightness differences due to chromatic-channel inbalance.

141. Witzel, R. F.; Burnham, R. W.; and Onley, J. W., "Threshold and Supra-threshold Perceptual Color Differences," Journal of the Optical Society of America, 63, 1973, 615-25.

This study found that it is possible for trained observers in color scaling to abstract color attributes of hue, saturation, and lightness; that a unit suprathreshold perceptual color ellipsoid can be described about a given color in color space; and that the precision of color-difference matching seems to be a function of the size of the perceptual color interval of the reference color.

142. Yonemura, G. T.; and Kasuya, M., "Color Discrimination Under Reduced Angular Subtense and Luminance," Journal of the Optical Society of America, 59(2), 1969, 131-135.

A quantitative, reciprocal relationship was developed for area and luminance under visual conditions of reduced luminance and angular subtense; and quadratic equations were given for the relation between chromaticity discriminability and luminous flux.

143. Zimmerman, W., "Systematic Harmonization of Lighting and Color," Holzindustrie, 21(10), 1968, 281-285.

The author deals with the following points: luminance in the visual field; determination of the color of different work areas; and aesthetic evaluation of colors. Tables are presented for the determination of differential sensitivity and comfort, and the determination of the relationship between luminance and the color of light.

LUMINANCE CONTRAST

Luminance contrast can be described phenomenologically as a prerequisite that enables a person to see an object due to brightness differences between the object being viewed and the background which surrounds the object. Physiologically, there must be a variance in the luminance level of the object and background for the retinal receptors to elicit the appropriate signals to the brain. Luminance contrast can also be described quantitatively as the luminance difference divided by the background luminance and the reciprocal of the minimum contrast which can be detected is known as contrast sensitivity.

The study of luminous contrast as well as contrast sensitivity are an integral part to the measurement and evaluation of visibility. The major divisions of research in this area are applied in nature and include the study of variables such as illumination, adaptation luminance, time, and color contrast,as they affect luminance contrast.

Transportation Research

Highway visibility and street lighting are the two most studied areas in the application of the luminance contrast concept. The contrast sensitivity with any particular background luminance is usually expressed as relative contrast sensitivity (RCS),which is expressed as a percentage of the limiting maximum value. The application of the RCS function has provided the cornerstone for the measurement of visual performance in a driving task by indicating how the amount of light provided by a lighting system affects seeing ability. Various quantification formulas for visibility have been developed from the concept of luminance contrast and usually include the affects of adaptation and disability glare.

Computer Graphics and Symbols

A number of experimental studies have employed luminance contrast techniques to the study of the legibility of dials, symbols, computer scanners, etc. The primary consideration in this type of research has been luminance contrast of the object to be seen, but variables such as color contrast and viewing angle have also been studied to enhance legibility or visibility.

Luminous Contrast Studies

144. Adrian, W., "Method of Calculating the Required Luminances in Tunnel Entrances," Lighting Research and Technology, 8(2), 1976, 103-106.

Equivalent veiling luminance occurs from luminances in a field super-imposed around a fixation point and has the effect of decreasing the contrast of a small target. It was shown

that contrast reduced in such a way always has to be 0.2 to ensure visibility, the required entrance luminances for different veiling luminance, and target contrast levels can be calculated.

145. Allen, T. M.; Smith, G. M.; Janson, M. H.; and Dyer, F. M., "Sign Brightness in Relation to Legibility," Michigan Department of State Highways, Report No. R-581, August, 1966.

Various combinations of letters were tested under different backgrounds and a wide range of ambient lighting conditions to determine the relationship between sign luminance and legibility. Minimum and maximum brightness values are discussed for urban, suburban, and rural ambient illumination conditions.

146. Bell, G. L., "Effects of Symbol Frequency in Legibility Testing," Human Factors, 9(5), 1967, 471-7.

Two fonts were tested at symbol brightnesses of 8, 6, and 5 fL. against a constant background brightness of 1 fL., and each symbol was shown to subjects randomly. Results showed that subjects' performances were better when symbols occurred with unequal frequencies.

147. Blackwell, O. M.; and Blackwell, H. R., "Visual Performance Data for 156 Normal Observers of Various Ages," Journal of the Illuminating Engineering Society, 1(1), 1971, 3-13.

The visual performance of subjects ages 23 to 68 was assessed in terms of task visibility measured under reference lighting conditions. Average log threshold contrast was found to increase with age at all background luminances.

148. Borgioli, M., "On the Relationship Between Response Speed and Visibility Level," Atti Fond. Giorgio Ronchi, V. 31, 1976, 249-53.

The visuo-motor reaction time was recorded by flashing a 4 in. test spot on a 35 nit background. Visibility level varied from 16 to 1 (contrast threshold).

149. Boynton, R. M.; and Boss, D. E., "The Effect of Background Luminance and Contrast Upon Visual Search Performance," Project 63, Illuminating Engineering Research Institute, April 1971, 173-186.

Luminance, contrast, and target size were varied in a visual search and recognition task. Results indicate that visual performance was found to be maximal at the highest contrast and luminance.

150. Eastmann, A. A., "New Contrast Threshold Visibility Meter," Illuminating Engineering, 63(1), 1968, 37-40.

A portable visibility meter is described which uses the contrast reduction principle and does not require an internal light source for providing veiling luminance. Veiling luminance is provided by either task background or a standard reflecting surface placed beside the task.

151. Eastman, A. A., "Color Contrast vs. Luminance Contrast," Illuminating Engineering, 63(11), 1968, 613-20.

This study reports that when luminance contrast of a 10-minute disk against its background is greater than 0.65, color contrast is of little importance in the visibility of the disk, regardless of the combination of colors. Differences in the visibility of colored targets or neutral targets probably will be less than 0.5%, even with luninance contrasts as low as 0.40.

152. Frisby, J. P.; and Clatworthy, J. L., "Illusory Contours: Curious Cases of Simultaneous Brightness Contrast," Perception, 4, 1975, 349-357.

It is suggested that simultaneous brightness contrast, mediated by lateral inhibition, plays an important role in illusory contours. These contours may reflect another way in which lateral inhibition serves to clarify and sharpen retinal images.

153. Gallagher, V. P., "Visibility Metric for Safe Lighting of City Streets," Journal of the Illuminating Engineering Society, 5(2), 1976, 85-91.

The relationship between an empirical measure of driver visual performance and a method for the quantification of visibility is explored in an effort to develop roadway lighting specifications based on visibility needs.

154. Guth, S. K.; Eastman, A. A.; and Rodger, R.C., "Brightness Difference--A Basic Factor in Suprathreshold Seeing," Illuminating Engineering, 48(5), 1953, 233-239.

The four factors of size, contrast, brightness, and time are shown to govern the visibility of an object. The brightness difference or contrast between an object and its background determine the level of illumination necessary for threshold visibility.

155. Illuminating Engineering Subcommittee, "Present Status of Veiling Reflections Know-How," Illuminating Engineering, 63(8), 1968, 433-5.

CRF is the contrast rendition factor-ratio of task contrast to contrast under diffuse illumination measured in terms of flux contrast by photometric means; and PCF is the psychophysical conversion factor which accounts for differences in measuring tasks visually vs. photometrically.

156. Luchiesh, M.; and Moss, F. K., "Brightness Contrasts in Seeing," Transactions of the Illuminating Engineering Society, 34(6), 1939, 571-597.

Brightness and color are shown to be primary factors in perception, and brightness contrast is shown to be of major importance in the recognition of details of objects.

157. Matin, L., "Critical Duration, Differential Luminance Threshold, Critical Flicker Frequency, and Visual Adaptation---Theoretical Treatment," Journal of the Optical Society of America, 58(3), 1968, 404-15.

A quantitative theoretical model analogous to an electric filter containing a cascade of R-C elements with output-controlled variation of a time constant is shown to predict relations between differential luminance threshold, critical duration, flicker frequency, and adapting luminance in human psychophysical data.

158. McLean, M. V., "Brightness Contrast, Color Contrast, and Legibility," Human Factors, 7(12), 1965, 521-26.

An experimental study which investigates the effects of color and brightness contrast, direction of contrast, and six contrast values on the legibility of a circular dial. Results indicate that the addition of color contrast to a dial may improve the legibility of the dial. The study indicates the use of color as a coding technique in complex system displays.

159. Mount, G. E.; and Thomas, J. P., "Relation of Spatially Induced Brightness Changes to Test and Inducing Wavelengths," Journal of the Optical Society of America, 58(1), 1968, 23-7.

An experimental study of spatial induction of brightness change using a chromatic-appearing test disk and inducing rings of nearly equal luminance; evidence that induced brightness change depends only on relative luminances of stimuli.

160. Narisada, K.; and Yoshimura, Y., "Minimum Perceptible Luminance Contrast of Human Eyes Adapted for Given Luminances Other Than Those of the Object Background," National Technical Report, Matsushita Electrical Ind., 20, 1974, 287-295.

Relationships were obtained between the adaptation luminance of the observer and the background luminance of an object. Data was compared with those obtained by Schreuder.

161. Pinegin, N. I.; and Travnikova, N. P., "Probability of Visual Detection of Objects as Function of Angular Dimensions, Contrast, and Searching Time," Soviet Journal of Optical Technology, 38(5), 1971, 257-60.

An exponential distribution of probability for visual detection of objects was found and a method for selecting and training of observers is proposed.

162. Stecher, S., "Discrimination of Luminance Differences Between Temporally Separated Paired Flashes," Journal of the Optical Society of America, 57(10), 1967, 1271-2.

The determination of luminance difference between two successively presented suprathreshold fields as a function of their temporal separation is reported.

163. Williams, C. M., "Legibility of Numbers as a Function of Contrast and Illumination," Human Factors, 9(5), 1967, 455-60.

Various contrast conditions, consisting of black or white lettering on white, black, and gray backgrounds, were compared under 0.60, 0.06, and 6.0 Fc levels of illumination. Significant differences were found in performance under contrast conditions with poor illumination, and varying contrast for tasks of short duration had little effect on performance as long as illumination remained above 0.60 Fc.

AREA (TARGET SIZE)

The visibility of an object is primarily dependent on its luminance and color contrast, but a secondary characteristic, such as the area or size of an object, acts to define the angular subtense of the object. It is generally believed that as the area or size of an object increases, the luminance of the background field that is required for contrast sensitivity is reduced. This is to say that as an object becomes larger, the degradation to contrast sensitivity becomes smaller. In this section, research has been grouped into studies dealing with the actual object size and studies dealing with perceptual phenomena.

Target Size

Most of the early research in regard to area sought to define visual acuity in terms of an area/luminance relationship based on Ricco's law (visual threshold is the product of the stimulus area times its luminance for small areas) and Piper's law (visual threshold is the square root of area and luminance for large areas). These physical laws are still employed by some researchers to study luminances necessary to perceive colors and to determine luminances as a function of the visual angle.

Much of the current research on the subject of target size has dealt with the determination of a representative target size for uniformity of experimental techniques in the measurement of visibility. Some of the recommendations of this type of research state that target size should be based on geometric progressions of the visual angle; reflectance factors; and luminance increment/visual area characteristics.

Perceptual Phenomena

The law of size constancy states that, in a comparison of two objects, the stimulus object will appear to change less (than would be expected on the basis of retinal image theory) while increasing the distance of the standard object. The size constancy effect may be expected to occur when conditions are complex with respect to color and brightness constancy. The apparent size of an object has been studied by varying these two conditions for the purpose of predicting the luminance and color contrast conditions that may enhance the size constancy effect.

Studies on Target Area

164. Nikitina, E. A., "Raschat Raspredeleniua Yarhosti po Rel'efnomu," Svetoteknika, 10(10), 1967, 24-8.

    A theoretical study giving equations for brightness as a function of size as well as the reflection factors of objects and background.

165. Connors, M. M., "Luminance Requirements for Hue Perception in Small Targets," Journal of the Optical Society of America, 58(2), 1968, 258-63.

    An experimental study of the luminances necessary to perceive red, green, and blue light at various visual angles and target area.

166. Hill, A. E., "Towards a Psychophysical Scale of Visibility," American Journal of Optometry and Archives of the American Academy of Optometry, 47(1), 1970, 36-44.

    The author derived a sensory mode scale, "ease of seeing", which is a power function of visual acuity measured with equivalent stimulus values. Findings suggest that if visual acuity measurements are to be representative of the sensation "ease of seeing", then the size of visual test charts must be graded in a geometric progression of the visual angle.

167. Hills, B. L., "Visibility Under Night Driving Conditions: Measurements Using Disc Obstacles and a Pedestrian Dummy," Lighting Research and Technology, 7(4), 1975, 251-8.

The visibility of disc objects and a pedestrian dummy were described by a standard luminous increment-visual area characteristic.

168. Judd, D. B.; and Eastman, A. A., "Prediction of Target Visibility from Colors of Target and Surround," Illumination Engineering, 66(4), 1971, 256-66.

Some 263 combinations of target and surround colors were measured for visibility with a contrast threshold visibility meter. The report shows the proportional variations due to modifications of external and spectral distributions, as well as chromatic aberations.

169. Mansfield, J. R., "Brightness Function: Effect of Area and Duration," Journal of the Optical Society of America, 63(8), 1973, 913-20.

The dependence of perceived brightness on flash luminance was determined for dark-adapted observers varying target size, retinal location, and wavelength.

170. Schoonard, J. W.; and Gould, J. D., "Field of View and Target Uncertainty in Visual Search and Inspection," Human Factors, 15(1), 1973, 33-42.

An attempt to understand visual inspection of miniature computer components. Results indicate that time increases of 1 to 2 minutes do not improve detection performance, and restricting the field of view to small areas of the stimulus does not enhance detection.

171. Shapley, R., "Goussian Bars and Rectangular Bars: The Influence of Width and Gradient on Visibility," Vision Research, 14(12), 1974, 1457-62.

Evidence is presented that shows the visibility of bars is dependent on their width.

172. Virsu, V.; and Haapasolo, S., "Relationships Between Channels for Color and Spatial Frequency in Human Vision," Perception, 2(1), 1973, 31-40.

A discussion of the psychophysical structure that is required for the capacity of simultaneous integration and differentiation in the perception of size and color in visual objects is discussed.

173. Weale, R. A., "Apparent Size and Contrast," Vision Research, 15(8), 1975, 949-55.

Measurements were made of the apparent size of a square as a function of its contrast at a constant mean luminance. Evidence is presented that at low contrasts a darker target will appear to be larger than a light target. Data also reveals a significant asymmetry where the eye distinguishes between light-dark and dark-light contrasts.

REFLECTIVITY

There exists much basic research dealing with the reflective properties of flat, curved, regular, and uniform surfaces. This research finds its application in mirrors, telescopes, and a host of other optical devices; satellite and meteorological device detection; lasers; and glazing. Knowledge gained from these areas is of little help when one is dealing with fabric, paints, or other materials having irregular surfaces.

Highway Signing and Delineation

Much of the current research on the subject of reflectivity has focused on specifying retro-reflective properties of paints and beads for signing and delineation systems on highways. These studies essentially are applied research for specific problem areas and their relationship to the broader concept of visibility is based solely on the idea that vehicle headlights are retro-reflected in the bead or paint and therefore allows the driver to see the material.

Other Surfaces

Some recent studies which have a direct application have dealt with the determination of the reflective properties of roadway surfacing materials, as well as the reflectivity of sunlight on various automobile components.

Reflectance Measurement

The measurement of reflectivity in the past has been limited to the use of a goniometer, a photometric device which requires a stage for holding the sample to be studied, a calibrated light source, and a photometer. It also requires a frame or gantry which permits the control of the angular relationships of the stage, the light source, and the photometer.

An instrument has been reported on for use *in situ* that is independent of ambient light and capable of measuring the relative reflectance of any object or surface. The instrument employs a light sensor which is color corrected for human sensitivity and is modulated by an internal beam of light directed toward the object to be measured.

Research Needs

Much research remains to be done on the reflective properties of paints and other wall surface materials as well as paper, pasteboard, printing inks, and paints and metals used for tag and sign manufacture. The reflective properties of even the most common materials: vinyls, synthetic and natural fibres, latex, rubber, etc., has scarcely been reported on. Of particular importance are those fabrics for which reflectorization through the various processes available is possible and which are already available on the commercial market.

Reflective Studies

174. Colorado State Department of Highways, Reflective Traffic Bead Study, Planning and Research Division, Interim Report No. 2, November 1967.

A report on the performance of different types of reflective glass beads in roadway paint for concrete or bituminous surfaces. Bead types varied in gradation and were either of low (1.55+) or high (1.65+) index of refraction.

175. Egan, W. G.; and Hilgeman, T., "Retro-Reflectance Measurement of Photo-metric Standards and Coatings," Applied Optics, 5, 1976, 1845-49.

The opposition effect (brightening in the retro-reflection direction) has been measured for MgCO3, $BaSO_4$ paint, and sulfur in the visual region with incandescent illumination and found to be 1.3, 1.5, and 1.3, respectively. The opposition effects in photometric standards can lead to calibration errors at opposition with such materials.

176. King, L. E., "Measurement of Directional Reflectance of Pavement Surfaces and Development of Computer Techniques for Calculating Luminance," Journal of the Illuminating Engineering Society, 5(2), 1976, 118-126.

A directional reflectance goniometer was developed and used to measure the directional reflectances of 11 concrete and asphalt pavement samples. An electronic data processing program, known as HILITES, was developed to handle the data. The program combines lamp and luminaire candlepower arrays with reflectance data to calculate illumination pavement luminance, and glare.

177. Lowden, P. R.; and Stoker, J. R., "The Relative Effect of Dew on Three Reflective Sign Materials," California State Division of Highways, Materials and Research Division, Report No. M/R-636469, June 1971.

Still and motion pictures recorded the effects of simulated dew (steam), as well as the actual dew formation in the field, on reflective sign materials.

178. Lozano, R. D., "Measurement Standards for Retro-reflective Materials Used in Road Signs," Lighting Research and Technology, V.8, 1976, 107-112.

Different standards on the angular requirements for measuring the coefficient of luminous intensity of retro-reflective materials used in road signs are analyzed. It was found that of the many different types of measurement required by the CIE and the U.S., there are only four that satisfy practical needs.

179. Mason, M. T.; and Coleman, I., "Study of the Surface Emissivity of Textile Fabrics and Materials in the 1 to 15 MU Range," Black Engineering, Inc., Cambridge, Mass., March 1967.

Laboratory measurements of the total and spectral infrared radiation from textile materials and the effects of changes in environmental parameters, such as background temperature, fabric temperature, and humidity, were studied. It was found that the weave of a fabric tends to mask any spectral detail. Further masking of detail is done by reflected background radiation. Temperature or humidity may also change the spectral characteristics of fabrics.

180. Nimeroff, I.; and Hall, W. A., "Instrumental Colorimetry of Retro-reflective Sign Materials," National Bureau of Standards, Report No. NBSIR-74 518, January 1975.

The colorimetric properties of 126 samples of retro-reflective materials of 7 different colors were measured in simulated nighttime conditions. On the basis of the color measurements and their variability, tentative recommendations for color boundaries were prepared.

181. Robertson, R. N.; and Shelor, J. D., "The Applicability of High Intensity Sheeting on Overhead Highway Signs," Virginia Highway and Transportation Research Council, Report No. VHTRC-76-R3, August, 1975.

A survey was conducted to determine the percentage of signs that could be refurbished with high intensity reflective sheeting and thus eliminate the need for illumination. Benefits were anticipated including energy and cost savings, as well as improved services to motorists.

182. Robertson, R. N., "Evaluation of High Intensity Sheeting for Overhead Highway Signs," Virginia Highway and Transportation Research Council, Report No. VHTRC-75-R24, December 1974.

The purpose of this report was to determine the feasibility of using high intensity reflective material on overhead highway signs. Luminance measurements were made of the illuminated versus non-illuminated reflective signs.

183. Saur, R. L., "Influence of Luminance and Geometry on Glare Impression," Optical Society of America, 58(6), 1968, 847-849.

A study of sunlight reflected by automotive trim items using a glare comparator. The experiments show how glare from bright surfaces can be reduced by increasing surface curvature instead of adopting matte surface finish.

184. Spencer, D. E.; and Gaston, E. A., "Current Definitions of Reflectance," Journal of the Optical Society of America, 65(10), 1975, 1129-32.

Eight definitions of reflectance are compared with experimental results presented in an earlier paper. Two types of reflection, diffuse and specular, usually take place simultaneously at all incidence and viewing angles. Half of the definitions apply only for purely diffuse reflection (i.e., reflection devoid of any specular component).

185. Tooke, W. R.; and Hurst, D. R., "Wet Night Visibility Study," Georgia Department of Transportation, Project No. GDOT-6701, HPR, July 1975.

Laboratory and field tests are reported on 11 retro-reflective systems for delineation. Both visual effectiveness and maintenance studies were performed.

186. Williams, T., "Reflectivity Instrumentation Design," Louisiana Tech. Univ., Ruston, Division of Engineering Research, Report No. PB-250 964/4 WT, December 1974.

A reflectometer was constructed and used during both daylight and night hours to make field reflectivity measurements of highway signs. A human eye corrected light sensor collected the modulated light reflected from a two degree spot on the sign and the receiver measures the average value of the resulting amplified A.C. voltage (i.e., relative reflectance). Field measurements are discussed as well as other possible uses of the instrument.

ENVIRONMENTAL VARIABLES

Research that related to Environmental factors that affect visibility were broken down into the five following categories:

- illumination
- background (contrast)
- type of lighting
- distance
- velocity of moving targets

Illumination The research related to illumination can be broken down into two distinct divisions: interior and exterior illumination levels. Under these two divisions, research has primarily been concerned with illumination levels as they relate to performance and safety. Other research has been in the psychophysiological effects of illumination levels on photopic, mesopic, and scotopic vision, as well as the retinal and cortical effects of illumination on pattern recognition.

Background The effect of background on visibility has been studied primarily in its relationship to visibility and performance. Numerous studies have concentrated on the effects of disability and discomfort glare on the surround brightness and the resulting performance decrement. Other studies have looked at the effects of background and its relationship to adaptation.

Aside from the performance criteria in studies related to background, there has also been research related to color saturation and spectral content of the background, and their effects on visibility.

Type of Lighting Of the many types of lighting systems in use today, there is little supportive information in regard to how they affect visibility. There has been some research dealing with natural daylighting and its effects on the work environment, but the majority of research in this category has been theoretical treatises on achromatic, monochromatic, and herterochromatic relationships to visibility. There has also been some technological research into the color temperature scales and ratings for various lamps, but the effect of color temperature on visibility has not been reported.

Distance The relationship between distance and visibility has been reported by most of the research in this area to be dependent on visual acuity, visual field size, background, target, and adaptation brightness. Aside from this descriptive type of research, there have been no studies that sought to determine or quantify distances necessary for visibility under various background, target, and adaptation luminances.

Velocity of a Moving Target Dynamic visibility has been studied to a limited extent, but the perception of moving objects depends on the rate of motion and tracking time of an object. These two factors along with color of the moving object have been the primary areas of study.

ILLUMINATION

Illumination is defined as the density or amount of luminous flux that falls on a surface. The relationship between illumination and visibility is circuitous due to the fact that the viewer does not necessarily see as a result of illumination, but he sees an object that is reflecting the illumination (luminance).

Since all objects vary in the amount of light that they reflect, some objects may appear the same under different levels of illumination. The basic problem in specifying illumination levels for visibility can be explained in terms of brightness constancy. For example, a black object that reflects only half of the light that a white object reflects will require 50% more illumination to make both objects equally bright. Thus, an increase in illumination increases the intensity of the object as well as increases the intensity of the surrounding field which may act to reduce contrast sensitivity.

Illumination and Contrast The effect of illumination on contrast sensitivity is the predominant source of study in the determination and specification of internal and external illumination levels for visibility. The basic trend, therefore, has been toward the specification of how much light is reflected from an object (luminance), and away from the specification of how much light is falling on an object (illumination).

Illumination Studies

187. Blackwell, H. R.; and Blackwell, O. M., "Effect of Illumination Quantity Upon Performance of Different Visual Tasks," Illuminating Engineering, 64(4), 1968, 143-52.

The effects of illumination are examined and two classes of tasks are identified---contrast discrimination and visual acuity. Contrast discrimination is expressed in terms of contrast sensitivity plotted against background luminance. Results show visual acuity increases progressively with luminance.

188. Blackwell, H. R., "A More Complete Quantitative Method for Specification of Interior Illumination Levels on the Basis of Performance Data," Illuminating Engineering, 64(4), 1968, 289-295.

A method is described which depends on a standard curve relating task difficulty to task luminance required for performance, and use of a standard instrument for visual task evaluation. The method takes into account: angle from which work is viewed, information requirements, reflectivity, disability glare, and transient adaptational effects.

189. Crockett, P. W., "Night Vision and Dark Adaptation," NTIS/PS-76/0133/9ST, March 1976. Research reports are cited on the physiological aspects of night vision under low intensity illumination as applied to human engineering for vehicle operation, pilots, and military personnel.

190. Lewin, I., "Effect of Illumination Systems Upon Visual Performance," National Bureau of Standards, Special Publication 1(361), 1972, 483-490.

Visual performance is discussed in its relation to the speed and accuracy of vision, and a concept entitled "Contrast Rendition Factor" is developed. CRF relates to the amount of contrast produced on a written task by any given illumination system evaluated in its relation to a reference standard.

191. Kabayama, H., "Studies on Illumination Method of Signs for Better Visibility," Safety Digest, Japan, 18(2), 1972, 81-84.

Various lighted road signs, including reflective, internally, and externally illuminated, were tested for visibility in respect to vehicle speed and color.

192. Blackwell, H. R., "Analysis of Individual Differences in Visual Performance to be Expected with the Current IES Method for Prescribing Illumination," Journal of the Illuminating Engineering Society, 6(1), 1976, 3-9.

This article discusses the methods of analysis involved in contrast sensitivity as a prescription of visual performance in comparison to the IES prescription of illumination.

BACKGROUND

As stated previously, contrast can be described as a relationship between neighboring regions of the visual field which have various luminous values. Background luminances may have different effects, depending on the areas involved, their location with respect to the line of sight, and their actual luminances compared with that of the object being viewed. These luminances may produce a decrement in visual ability of discomfort through glare, or they may enhance the visibility of an object through increased contrast sensitivity. Ideally, the best conditions for visibility are achieved when the whole field of view is uniform, but, in actuality, this rarely seems to occur. Of particular interest to the study of luminance background fields is the quantification and measurement of the visual performance affects of glare and adaptation.

Glare

Glare is believed to affect the performance of visual tasks on two different levels, usually expressed in terms of discomfort glare and disability glare. Discomfort glare is caused by a luminous source more intense than the background which causes annoyance to the viewer but does not necessarily impair his visual perception. Disability glare, on the other hand, is caused by light within the immediate background area of a task under consideration which impairs the viewers' perceptual ability to detect objects, essentially, by decreasing the threshold sensitivity of the retina. Thus, the most obvious effect of glare is the increase in background luminances and the subsequent reduction in contrast sensitivity. The majority of research in this area has sought to define the effects of glare, in addition to background luminance, on the viewers' visual performance.

Adaptation and Background Fields

Adaptation can be described as the process by which the retina becomes accustomed to more or less light than it was exposed to during a preceding period, and, essentially, results in some form of change in the sensitivity of the eye. The viewers' state of adaptation is affected primarily by the combined luminances in his visual field which is generally regarded as background luminance and also, adaptation may be influenced by luminous sources of glare anywhere in his visual field. The viewers' adaptational state as well as any decrement due to glare have been shown to be necessary components in the quantification of visibility.

The majority of research concerned with adaptation and the content of the background field varied background field characteristics such as size, luminance, and color with the intent to measure their effects on contrast sensitivity and form recognition.

Background Studies

193. Brown, B., "Effect of Background Constraint on Visual Search Times," Ergonomics, 19, 1976, 441-9.

     In this study, a prescription is proposed for a uniformity of background conditions in the study of visual search tasks.

194. Ireland, F. H.; Kinslow, W.; Levin, E.; and Page, D., "Experimental Study of the Effects of Surround Brightness and Size on Visual Performance," USAF, AMRL Technical Report, No. 67-102, VI, 1967.

     An attempt to determine quantitatively the degradation in visibility due to high surround brightness, and to provide useful data for the display system designer.

195. Longobardi, G., "On the Dependence of Estimate of DGF on the Equivalent Veiling Luminance," Atti Fond. G Ponchi (Firenzi), 28(2), 1973, 324-328.

A Study in which the Disability Glare Factor (DGF) was calculated as a function of age.

196. Narisada, K.; and Yoshimura, Y., "Minimum Perceptable Luminance Contrast of Human Eyes Adapted for Given Luminances Other than those of the Object Background," National Technical Report, Matsushita Ele. Ind., 20(3), 1974, 287-295.

An experimental study to determine the relationships between the adaptation luminance of observers and the background luminance of the object necessary for the detection of the object with various luminance contrasts.

197. Pitt, I. T.; and Winter, L. M., "Effect of Surround on Perceived Saturation," Journal of the Optical Society of America, 64(10), 1974, 1328-31.
This investigation examines the effects of having a light or dark surround around a color. Results show that a dark surround increased apparent brightness of a color but reduced apparent saturation.

198. Sampson, F. K., "Field Evaluation of Reflected Glare," Illuminating Engineering, 58(10), 1963, 250-261.

The measurement of reflected glare on performance in a classroom by observation of a difficult task is discussed and an apparatus for measuring the luminance of the task and background from a chosen angle is described.

199. Hormon, M. H., "Visibility of Light Sources Against a Background of Uniform Luminance," Journal of the Optical Society of America, 52(12), 1967, 1516-21.

A nomogram is described, based on Blackwell's data on contrast threshold of the human eye, for determining whether a light source can be detected against a uniform background luminance.

200. Zabelina, I. A.; and Gavilov, V. A., "Effect of the Spectral Content of the Background on the Visibility of a Point Source," Soviet Journal of Optical Technology, 39(12), 1972, 779-80.

Results indicate the independence of the spectral content of the background to visibility and the color of the background or a point source account for very small differences in visibility.

201. Boynton, R. M.; and Moss, D. E., "The Effect of Background Luminance and Contrast on Visual Search Performance," Illuminating Engineering, 66(4), 1971, 173-186.

A visual search task that involved both central and peripheral vision was used to assess visual performance. Results indicate maximal visual performance with the highest contrast and luminance used.

202. Jainski, P.; and Schmidt-Clausen, H. J., "Visual Acuity in Separate Fields of Adaptation of Inhomogenous Luminances," Optik, 31, 1970, 410-425.

This study measures the effects of separate fields of adaptation of inhomogenous luminance of Landalt rings with special attention paid to the dependence of visual acuity on adaptation luminance, viewing time, and distances.

203. Fisher, A. J.; and Christie, A. W., "A Note on Disability Glare," Vision Research, 5, 1965, 565-571.

An experimental study showing that threshold luminance differences change when a glare source is introduced into the field of view. A quantitative formula for disability glare is proposed that accounts for the effects of age.

204. Fry, G. A.; and Alpern, M., "The Effect of a Peripheral Glare Source Upon the Apparent Brightness of an Object," Journal of the Optical Society of America, 41, 3, March 1953, 189-195.

This study shows that changes occuring before and after the onset of glare source can be accounted for in terms veiling luminance produced by stray light falling on the fovea.

TYPES OF LIGHTING

It is evident that, with inadequate lighting or the wrong type of lighting, seeing may become inefficient, uncomfortable, and even hazardous. Various factors must be considered when trying to define which type of lighting may best suit visibility requirements of the viewer. Visual demands may range from difficult tasks that involve prolonged eye contact within a confined or a constantly changing visual field, to only casual glances of the visual environment. The time that is available to the viewer may also be long or short, and the objects that must be viewed may require color discrimination or simply detection of black, gray, or white.

Except for natural daylight, the spectral characteristics of light will vary with the light source. Light sources are generally rated in terms of their luminous and spectral efficiency, where the former is defined as the ratio of total luminous flux emitted to power consumed, and the latter is defined as the ratio of the spectral content of one visible wavelength to the spectral content of the maximum visible wavelength. But these two characteristics of light sources rarely are found to be maximum in artificial lighting because, as one efficiency rating of a particular light source increases, the other rating will usually decrease. The ultimate decision, then, is to determine the visibility needs of the viewer's task based on design considerations such as luminous contrast or color contrast, glare, and economics.

Research and Application

Experiments have shown that as the luminous efficiency of a light source approaches maximum (e.g., low-pressure sodium), the luminous contrast or contrast sensitivity of the viewer will also be heightened. This may be due to the fact that subtle differences between an object and its background are intensified when a high luminous efficient source is capable of covering all surfaces with a blanket of light.

The spectral efficiency of a light source, comparatively, will act to enhance the color properties of objects and their color contrast. Research in this area argues that the spectral efficiency is necessary for all aspects of visual sensitivity and not only color contrast. Whether or not monochromatic or chromatic light increases visibility still remains to be studied, but for present purposes, light source types should be evaluated on the basis of the visual task.

Studies of Lighting

205. Dziegelewaki, T., "Natural Lighting and Colour Schemes in Work Premises," <u>Ochrona Pracy</u>, 26(2), 1972, 15-18.

    Physical color characteristics of natural lighting are exploited to correct lighting conditions and to facilitate visual perception in industrial premises.

206. Hietbrink, G.; and Quaedflieg, N. J., "Occurrence of Glare and Choice of Proper Light Color," <u>Electro-Techniek</u>, 46(21), 448-54.

    Recommendations for the choice of proper light color and the effects of light color on glare are suggested.

207. Henderson, S. T.; and Marsden, A. M., "Lamps and Lighting," Arnold Publishers, London, 2nd Ed., 1972.

    This manual contains contributions from 34 different authors containing information on the fundamentals of light, lamp types, and color rendering properties, luminances, and circuits and general lighting specifications.

208. Holmes, J. G., "Essays on Lighting," A. Hilger, London, 1975.

Topics dealt with in this book include color and color rendition, lamps and luminaires, natural and artificial lighting of interiors, and road lighting.

209. Hubble, L., "Standardized Visual Assessment of Color: A Progress Report," Paint Manufacturers, 45(9), 1975, 10-12.

This study examines the effects of artificial and natural illumination on the assessment of color and suggests requirements for artificial light in the assessment of paint colors.

210. Adema, A.; and Krochman, J., "The Influence of Spectral Energy Distribution on Visual Acuity," Optik, 44(2), 1976, 173-181.

An expansion of previous studies that involved monochromatic radiation with consideration of chromatic aberations.

211. Mahr, K., "Correlation Between Color Rendition, Efficiency of a Luminous Source, and Visual Efficiency of Modern Light Sources," Lichttechnik, 22(9), 1970, 441-443.

Based on the fact that a small correlation exists between efficiency and color rendition for modern light sources, evidence is presented that indicates a much higher correlation between color rendition and visual efficiency (i.e., the higher the visual efficiency, the lower the color rendition).

212. Matsuura, "On the Relation of Visibility to Changes in Colored Visual Objects Under Lighting Using Sodium Lamps," J. of the Illuminating Engineering Institute of Japan, 55(12), 1971, 19-21.

Evidence is presented for limited use of sodium lamps for roadways due to differences found in contrast sensitivity.

213. Yurov, S. G., "Photopic, Mesopic, and Scotopic Vision," Applied Optics, 6(11), 1967, 1877-83.

Physiological characteristics of the spectral sensitivity of the eye are examined, as well as the spectral efficiency of light in regard to work related tasks.

214. Thornton, W. A., "The Commercial Prime Color Fluorescent Lamp," Lighting Design and Application, 6, 1976, 46-47.

A description of the spectral power distribution of the commercial fluorescent lamp.

DISTANCE

As stated previously, size constancy is a fundamental law of the human perceptual mechanism which permits the appreciation of object size regardless of distance. The fact that some studies of the effects of distance on visibility do not consider object size appears to confuse the issue of size/distance effects. Distance parameters have been studied and quantified on the basis of the principles of stereoscopic vision, and have resulted in analytical formulas that consider size as well as distance. Other studies that have considered distance effects on visibility are applied in nature and have considered the atmospheric effects on visibility distances in conjunction with other visibility parameters such as the object, the background, and adaptation.

Research Needs

Apart from the consideration of object size in the study of visibility distances, distance parameters should not be considered an isolated or separate factor necessary for visibility, but must be embodied into research which considers other design variables such as luminance and color contrast.

Distance Studies

215. Cavonius, C. R.; and Hilz, R., "Invariance of Visual Receptive-Field Size and Visual Acuity with Viewing Distance," Journal of the Optical Society of America, 63(8), 1973, 929-933.

The size of the human visual receptive field was measured by two methods while an observer accommodated on near and distant targets. The two methods were measuring the modulation-sensitivity function of the visual system, and the estimation of the receptive field by determining the size of a superimposed background that effectively masks a small test flash. Results indicate that viewing distance does not influence receptive-field size and that size constancy is not considered a result of changes in the receptive field.

216. Chapanis, A.; and Scarpa, L.C., "Readability of Dials at Different Distances with Constant Visual Angle," Human Factors, 9(5), 1967, 419-425.

Five dials, sizes, and markings at a constant viewing angle were tested at distances from 14 to 224 in. using response times, errors of estimation, and questionnaires. Results showed significant effect of distance on readability.

217. Cohen, A., "Horizontal Visibility and the Measurement of Atmospheric Optical Depth of Lidar," Applied Optics, 14(12), 1975, 2878-2882.

In this paper, a generalized treatment is described of the atmospheric visibility distances for a variety of atmospheric conditions. A quantitative formula is developed for visibility distance and the use of a dye-laser radar system is discussed for the remote sensing of visibility distances.

218. Cohen, R. W.; Gorog, I., "Visual Capacity - An Image Quality Descriptor for Display Evaluation," RCA Engineering, 20(3), 1974, 72-79.

A quantitative descriptor that can be used to compare human appreciation of different displays at any viewing distance is described. This quantity, called visual capacity, can be thought of as the total number of edges that can be perceived by an observer located at a given distance from a display.

219. Hoffman, H. E., "Review of the Most Important and Well-Founded Knowledge About the Visibility of Aircraft," Deutsche Luft- und Raumfahrt Witt, 74(33), 1974.

In field experiments it was determined in what manner the maximum detection distance depends on horizontal visibility, type of aircraft, background, adaptation brightness, and the observer himself.

220. Yanagawa, K., "Human Engineering and Design of Indication-Controlling Equipment in Centralized Controlling Systems," Signalling (Japan), 28(11), 1973, 12-16.

A review of the ergonomic aspects in the design of controls as they relate to visibility factors such as distance, size, and shape.

221. Bonvallet, G. G., et al., "Visibility Distance as Affected by Roadway Lighting Parameters," Illuminating Engineering, 60(5) 1965, 355-363.

This study sought to determine the variations in visibility distances as affected by color, size, contrast, illumination, and viewing time under different street lighting systems.

MOVING TARGETS

The perception of movement, in effect, is the interaction of temporally and spatially distributed retinal stimulations. This can be explained by the fact that the eyes are never motionless and, consequently, the retinal image of a moving object affects different patterns of receptors from one moment to the next. Retinal receptors define the apparent speed or motion of an object through the successive stimulation of individual receptors which enable the determination of a time interval between stimulations.

The spatial stimulation involved in the perception of a moving target is somewhat more complex since it involves simultaneous inhibition and facilitation which is dependent on the time interval. Experiments have shown that the stimulation of a point "A" will set up a momentary inhibitory effect in an adjacent area of the retina so that when the moving object reaches point "B" it may arouse excitatory effects against a background of inhibition. Research has also indicated that the perception of moving targets is affected by luminous contrast in such a way that a moving target creates a contrast wave across the retina. The contrast wave effect of a moving target may reduce visibility to a certain degree because retinal stimulation of the leading edge acts in the same way as a stationary target, but as the object passes, the continued stimulation of the receptors that were activated by the leading edge will act to reduce the stimulation of the trailing edge. In essense, the trailing edge may be more indistinct or less sharpened by contrast than the leading edge.

Much of the research that has dealt with the visibility of moving targets has been concerned with effects of variables such as color, angular changes or eye movements, background, and illumination on the perception of a moving target. Other research, which has been more applied in nature, has focused on the aeronautical and traffic applications of the perception of moving objects from an aircraft or vehicle that is also in motion.

Factors Affecting the Perception of Moving Targets

As evidenced in the previous section, luminous contrast has been shown to greatly affect the visibility of a moving target due to its inhibitory actions on the retina, but further research has shown that the reginal receptors which are tuned to spectral wavelength (color) may act to reduce the motion aftereffects of a moving target. Increased levels of illumination and the possible increase in contrast sensitivity have also been shown to reduce the retinal inhibitory action of a moving target.

Moving Targets Studies

222. Goodwin, A. W., "The Effect of Color on Time Delays in the Human Oculomotor System," Vision Research, 13(7), 1973, 1395-98.

This study suggests some of the influences that target color has on tracking random motions and saccadic reaction times.

223. Koztrkova, M. G., "Study of the Dynamic Acuity of Vision," U.S. Army Foreign Science and Technology Center, Washington, D.C. Jan. 1972.

It is suggested that dynamic visual acuity is dependent on the rate of motion and tracking time of an object. A test procedure was developed to measure dynamic visual acuity.

224. Murthy, D. N.; and Deekskatulu, B.L., "New Model for Control Mechanism of the Human Eye," International Journal of Control, 6(3), 1967, 263-74.

Discussion of a quantification model to describe the action of a control system for directing human gaze at a moving target.

225. Robinson, D. A., "Oculomotor Control System," Proceedings of IEEE, 56(6), 1968, 1032-49.

A review of the literature on eye movements from the standpoint of automatic control systems.

226. Tynan, P.; and Sekuler, R., "Simultaneous Motion Contrast: Velocity, Sensitivity, and Depth Response," Vision Research, 15(11), 1975, 1231-38.

A study which measured the effects of surround motion on a target's perceived velocity, perceived depth, and visibility. Surround speed had no effect on luminance threshold of the target.

227. Over, R.; and Lovegrove, W., "Color Selectivity in Simultaneous Motion Contrast," Perception and Psychophysics, 14(3), 1973, 445-48.

This study experimented with the apparent motion of static vertical lines viewed against a background of moving vertical lines. Motion contrast was found to be reduced when surround differed in color from the target and motion aftereffects were attributed to inhibitory interaction among neural detectors tuned to wavelength and direction of target motion.

228. Azuma, T.; and Takahashi, S., "Illumination and Coloration in Industry," Safety Digest, (Japan), 20(1), 1974, 4-12.

This study was primarily concerned with color coding in industry, but further research cited in this report relates to the visibility of moving targets. The visibility of a moving target is dependent on how fast the visual angle of the eye has to be changed. Also, in higher angle change speeds where visual sensitivity decreases, the effect of illumination on visibility becomes greater.

229. Bossler, F. B., "Visual Image Stabilization Measurements and Specifications," Applied Optics, 7(6), 1968, 1155-8.

Requirements given for stabilizing visual images in a vibrating environment are defined by the results of measuring tolerance to target vibrations. This study pertains to the visibility of objects from moving vehicles.

CONCLUSIONS AND RECOMMENDATIONS

The review of the preceding material permits some general observations. The areas of study which embrace the quantification of the visibility of simple targets against uniform backgrounds is well developed in theory. As its application proliferates, it will be receiving real-world validation. This area of study includes that of Blackwell, Fry, Hills, Adrian, and Gallagher, as referenced in the section of this report entitled Luminance Contrast. This general area might be termed (perhaps too narrowly) the study of Stable Targets.

It has been the feeling of this writer that the notion of visibility or conspicuity has two major subdivisions. The first division serves to define (quantify) visibility for those applications where the objects are fixed in space and therefore have fixed backgrounds and relatively fixed lighting conditions. These objects can be classed as "Stable Targets" or "External Contrast Targets." The use of the word "External" is based on the idea that the background for these targets is a true background and not part of the target itself. This type of target lends itself nicely to quantification through knowledge of contrast, contrast sensitivity, and glare a la Blackwell and the others mentioned. The basic limitation on this system at the moment is a lack of knowledge of the effects of: (a) a moving target and (b) a moving observer. That is, as yet we know little about "Dynamic Visibility". This method, however, which is quantifiable through available photometric equipment and techniques, is ideally suited to the Stable Contrast cases such as signs and labels.

The second of the two major subdivisions includes those targets for which neither a true background nor specific lighting conditions can be specified. In the interest of providing a parallel discussion, these could be termed: "Instable Targets" or "Internal Contrast Targets." The visibility of these targets is less easily quantified for obvious reasons. The term internal is used advisedly in this case since the visibility of these objects cannot rely solely on the relationship between the object luminance and the luminance of a true background. It must rely, instead, on the internal contrast within a pattern of luminances on the object itself. The application of highly reflective materials to work clothing has as its major aim the enhancement of internal contrast.

The use of international orange or other fluorescent colors for such garments attempts to convert an Instable Contrast case into a Stable Contrast case, and in many applications is a highly desirable design solution. This approach has obvious limitations however, as "errors of scale" can develop through widespread application of a single color choice.

VISIBILITY RESEARCH REQUIREMENTS

As mentioned following the description of Stable Contrast targets, the limitation of this fairly well-established method is the failure to account for target or observer movement. We can expect publications this year (1977) on the effects of movement on adaptation and on target contrast by the movement of vehicle mounted lighting. Little change is expected, however, in the state of knowledge of moving targets (e.g., pedestrian or workman) of even the simplest stable contrast cases.

The vast majority of real-world seeing problems, however, are of the Instable Contrast type,and here we venture into areas where experimental control is difficult and,consequently,little research is conducted.

In order to grasp exactly what we are dealing with, it might help to use an illustration of an everyday occurence. Picture a workman running through a work site at dusk being approached by a large truck. The workman is wearing a white hard-hat, a fluorescent vest, brown pants, and boots.

The quantification of this mundane scene requires the following, presently unavailable, information:

- Area averaged values for luminance and color of the profile provided by the workman
- Area averaged values for luminance and color of the work site area as seen from the elevated perspective of the truck driver
- Time averaged values for luminance and color contrast for the workman and his varied background
- Time averaged values for changes in the angular size of the workman's profile as the driver approaches
- Time averaged values of luminance exposure (i.e., adaptation level) of the driver

This scene serves to illustrate that the visibility community cannot yet deal with

- Complex targets
- Complex backgrounds
- Dynamic situations
- Color vs. luminance contrast relationships

The three interrelated areas of study from which some of these answers can be expected to emerge are: camouflage, pattern recognition,and color perception. Much information is known about these areas if viewed in isolation. The basic problem develops when one attempts an integration and extension of this knowledge to particular applications problems. Adding dynamic elements serves only to further confuse the issue.

Two areas which require further study, but are essentially ready for inclusion in an all-encompassing model of visibility, are: the reflectivity of materials and the color rendering properties of available light sources. The former is a simple matter technologically, but little interest has been directed in that area historically. The latter is an area where the work has largely been done and what is required is dissemination alone.

VISIBILITY RESEARCH PRIORITIES - NIOSH

It is possible, based on the information collected through this project, to outline a program of research priorities which will best meet the needs of the Institute.

Since the scope of the project encompassed visibility issues related to signs, labels, and markings, as well as protective clothing, it seems reasonable to recommend research areas which will bear the most immediate benefits. These may not be the areas of maximum safety enhancement or accident reduction, however.

Chart 1 shows the key elements required for the quantification of the visibility of stable contrast cases. As mentioned earlier, this area is fairly well researched and a useable system already exists. The integration of color, however, has not been accomplished and some research attention should be directed into this field.

Chart 2 provides an outline of the key elements in the quantification of visibility for instable contrast cases. Note that here we are dealing with much "softer" data bases. That is, little is known about pattern discrimination that is useful in the real-world. Transient adaptation, which is the effect on contrast sensitivity of non-uniform luminous surrounds, has only recently resulted in a serious research effort and field validation has not yet been accomplished.

The development of a theoretical basis for camouflage is tied to pattern discrimination and its absence indicates that very little is known about the threshold of visibility and invisibility for complex cases. This area would suggest a long term research effort over an extended period of time (5 to 10 years). The most fruitful area for research having an immediate, or at least near-term, impact on the development of a comprehensive visibility model is the study of moving targets. It appears reasonable that movement can be expressed as a function of contrast. The net effect would be the integration of movement effects with the wealth of information extant in the studies of contrast and target size.

Chart 3 illustrates a method (and some informational requirements) for the implementation of the basic research findings which are output from efforts under Charts 1 and 2. The basic steps illustrated under this plan call for field trials of all laboratory generated hypotheses. The

Chart 1

Step-Wise Program of Research Toward Visibility Quantification for Stable Contrast Cases

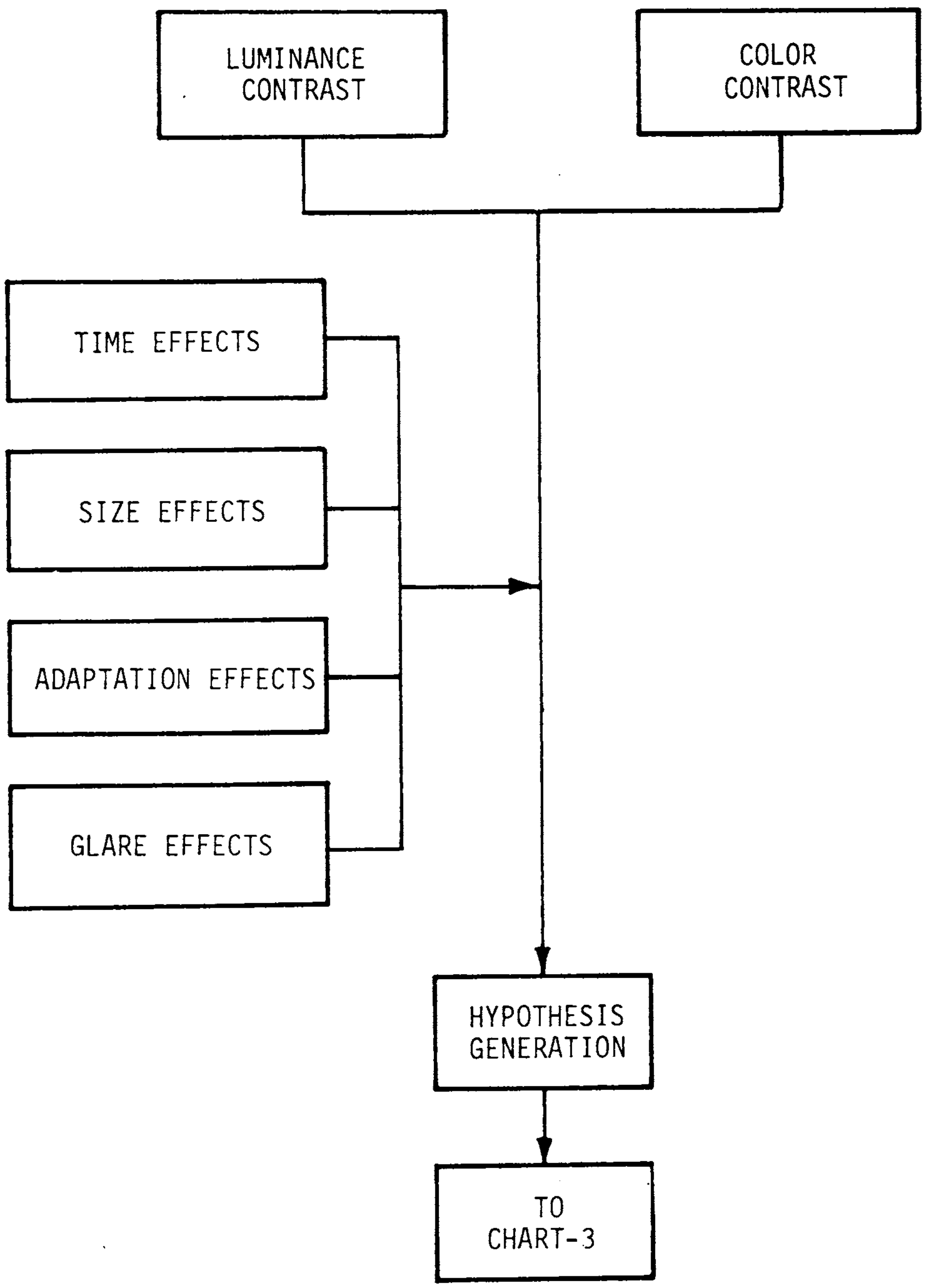


Chart 2

Step-Wise Program of Research Toward Visibility Quantification for Instable Contrast Cases

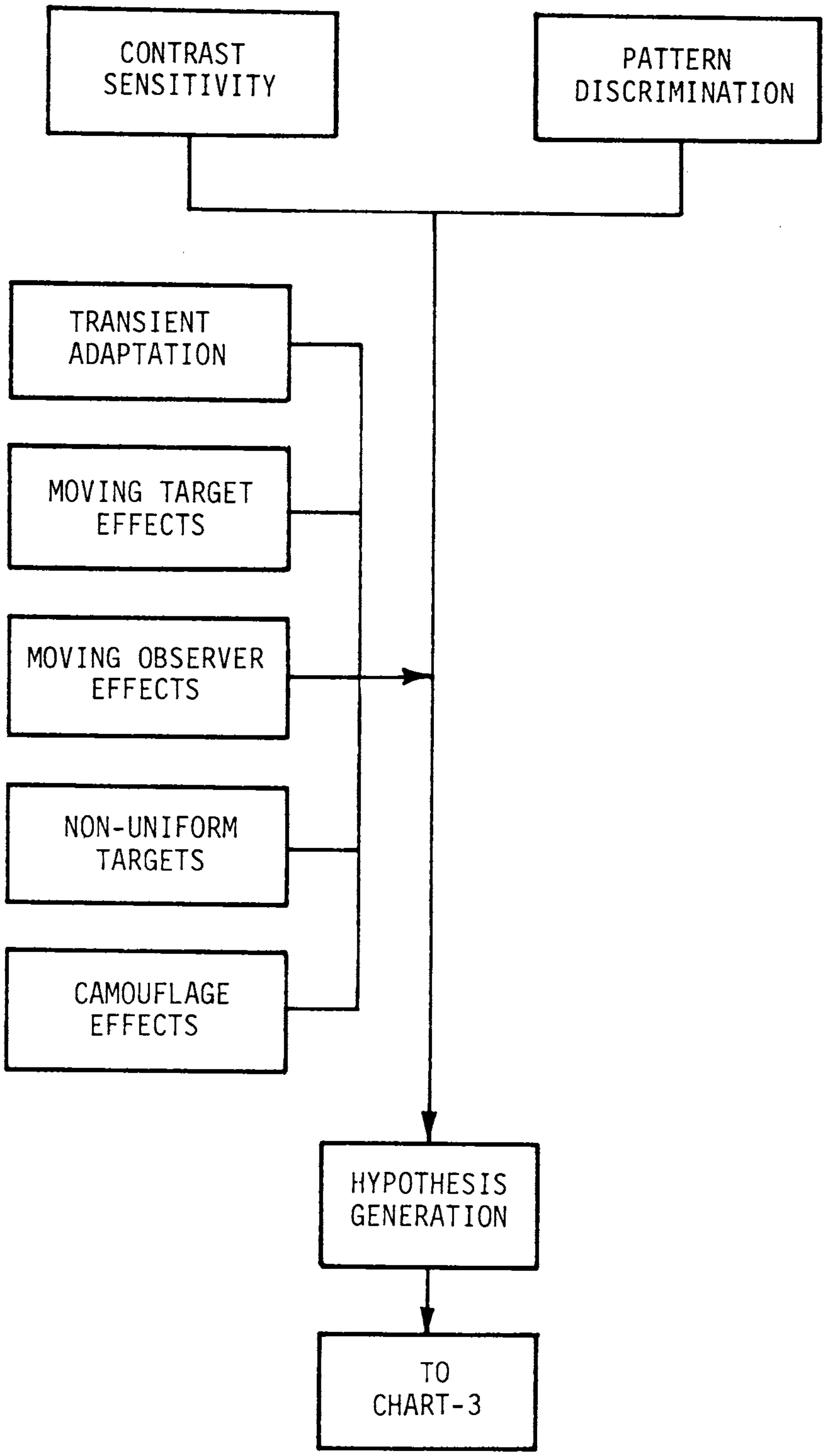
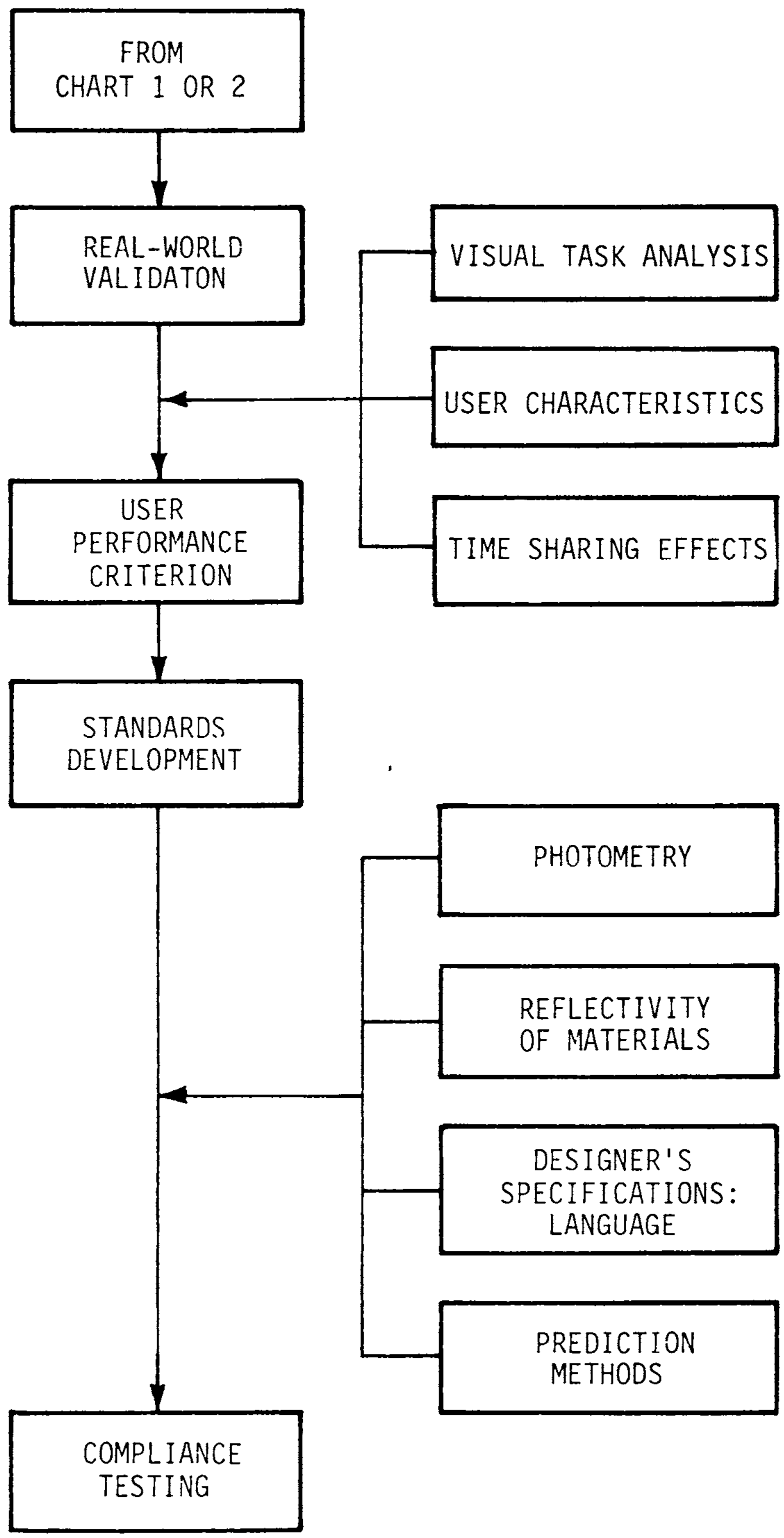


Chart 3

Step-Wise Program for Implementation of Basic Visibility Research



evaluation of these results in terms of the task for which they are applicable, the viewer's capabilites,and other (visual and non-visual) simultaneous task demands on the viewer. These need to be integrated into the selection of User Performance criterion bases on which a visibility standard can be written.

Interjected between the writing of standards and the development of engineering type compliance testing, certain technological areas will need improvement. These include photometry,which is presently geared toward the measurement of light and not visibility. Several modifications to presently available hardware will be required to provide a simplified method of measuring visibility. At present, even for the simpler cases,a technician trained in the theory of contrast and glare is required.

The reflectivity of materials is another area where research effort should be directed. Presently,the technology is available to measure reflectance,but still little is known about commonplace materials such as paper and inks, paints, pasteboard, and plastic films (to name a few), as well as specially designed reflective materials and fluorescents.

As a last step before the development of compliance testing, some effort must be given to the simplification of specifications and the development of a language of visibility which will help to stabilize the concepts. An essential aspect of this process, of course, is the development of reliable prediction methods so that visibility prescriptions (i.e., standards) can be satisfied through a variety of means which do not unnecessarily delimit the designer's prerogatives.

SUPPLEMENTARY BIBLIOGRAPHY

Due to the volume of research that has been conducted on the application as well as the variables involved in visibility, two supplementary categories of research are also submitted. The first category contains a list of delivered publications that have a direct bearing on this survey but time constraints have limited their review. The second category contains a list of books and publications which pertain to factors somewhat tangential to the main interest of this report which were not available to be delivered or reviewed with this report.

ITEMS DELIVERED BUT NOT REVIEWED

The publications listed in this supplementary category contain research that was received too late to be included in the final report or that was tangential to the goals of this research. Some of these publications were received from foreign scientific journals and do not include English abstracts.

230. Adrian, W., "A Method for Rapid Determination of Physiological and Psychological Glare in Street Lighting," text in German, Lichttechnik, 20(10), 1968, 118A-123A.

231. "ADAC Tests Safety Clothing and Accessories for Pedestrians, Pedestrians on the Test Run," ADAC-Motorwelt, 1972(4), 1972, 37-39.

232. Adrian, W., "Fundamentals of Physiological and Psychological Glare and its Numerical Presentation," text in German, Lichttechnik, 27(8), 1975, 312-319.

233. Adrian, W., et al., "Glare Through Street Lighting," text in German, Lichttechnik, 20(1), 1968, 1A-5A.

234. Adrian, W., "On the Influence of the Light Density Distribution of Lamps on the Luminous Density, its Uniformity and Glare in Street Lighting," text in German, Lichttechnik, 20(2), 1968, 15A-20A.

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238. Benz, K., "Studies on Psychological Glare in the Mesopic Range," text in German, Lichttechnik, 21(3), 1969, 29A-32A.

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