FLIGHT SAFETY FOUNDATION
HUMAN FACTORS & AVIATION MEDICINE

Vol. 37 No. 3 | For Everyone Concerned with the Safety of Flight | May/June 1990

Color Vision and Cockpit Operations

It is time to reevaluate the appropriateness of color vision standards that were developed in World War I.

by
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Color vision sensitivity varies qualitatively from individual to individual in somewhat the same way that a full-scale sense of perfect pitch varies from individual to individual. What is seen as a shade of red by one individual may be subjectively perceived as something else by another. Yet, by common agreement, both individuals will label their respective perception as reddish.

Approximately eight percent of human males (and a fraction of one percent of females) in a given population of aircrew training applicants will have some degree of color insensitivity: that is, be unable to discriminate between certain shades of a color and white, or, between shades of colors, or even between certain colors. The insensitivity may range from mild to complete, and should not, in most cases, be referred to as color blindness. The term "color blind" is centuries old and actually refers to the most extreme insensitivities as revealed by mismatching some dyed threads while weaving a pair of kilts or performing some other domestic chore where a break with traditional color patterns is innocently made. The U.S. Federal Aviation Administration (FAA) recognizes that persons with color vision insensitivity can fly safely, and regularly issues waivers in individual cases. Figure 1 gives the numbers by medical certificate class as of early 1989.

In view of the eight percent prevalence of color insensitivity in the male population, the design of instrument displays should have, in addition to any color coding used as a supplementary aid for the viewer, generic non-color dependent visual presentations of analog and digital information. These non-color dependent displays should be readily understood when viewed by a crew member who does not have perfect color vision. Because of the wide range of color vision sensitivity in the human population, initial design criteria for displays should exclude color as the primary transmitter of critical information, with form, stippling, black, shades of gray, and white, used as the primary information-containing modes.

A secondary enhancement of the displays through the use of color is a logical optional add-on, but, these add-on displays should be easily read, not only by persons who have varying sensitivities to color, but also by those who see no colors at all, i.e., just shades of gray and black or white. In fact, some color cathode ray tube (CRT) displays could, during certain component failures, default to a monochrome format, and therefore, must have the critical information fully available in this mode.

Specific Human Color Vision Aspects

Human vision is based on the retina's capacity to detect light wavelengths in a specific range of the electromagnetic spectrum. The fovea of the normal human retina contains concentrations of color detector cells (cones) with primary color (red, green, and blue) visual detector pigments having peak values at wavelengths of 575, 540 and 430 nanometers (nm) respectively. Figure 2 shows the relative distribution by wavelength sensitivity of these color detection pigments in the human retinal cone cells.

The combination of wavelengths and energy levels of electromagnetic energy that stimulate the retina determine the perceived colors of things being viewed. The full spectrum of perceived colors is developed from the light stimulations of the red, green, and blue retinal detector cells (note: color TV is similarly based on red, green, and blue detection and combinations). This system of perceived colors is the additive color detection system, and should not be confused with the subtractive system used for surface absorption of some, and reflection of other, wavelengths (for example, the colors in a picture projected by a color slide use the subtractive system based on magenta, cyan, and yellow, these three being made up from combinations of the primary colors.

Color Vision Waivers
U.S. Active Pilots
1989

Class of Medical Certificate	Active Airmen	Color Vision Waivers	Color Vision Waivers with Operational Restrictions*
First	126,594	1,649	149
Second	188,858	3,568	1,023
Third	348,556	4,915	6,797
Total	664,008	10,132	7,969

Source: Civil Aeromedical Institute
*The term "waiver" is commonly interchanged with "statement of demonstrated ability."

Figure 1

As earlier cited, about eight percent of males have a genetic makeup that gives varying degrees of insensitivity to color detection and far less than one percent of females have similar insensitivity (the shorter male y chromosome cannot make up for a gene on the x chromosome that contains an inherited insensitivity code, but the matching x on the other x of the female can). The scientific community in the 19th and early 20th century developed categories for persons of varying sensitivities to the color spectrum. Before describing these categories, the following specific definitions are necessary:

- *Saturation*. With respect to a given light energy wavelength, the proportion of that wavelength energy within a light signal which is made of different wavelengths.
- *Intensity*. The photon energy content of an electromagnetic energy beam.
- *Hue*. The wavelength of a light signal.
- *Trichromat*. A person who has retinal receptors for red, green and blue.
- *Protanope*. The word is derived from "proto," which stands for "first," and "anope" for "without vision." The visual system of a pure "protan" does not have the red-absorbing cone receptor.
- *Protanomalous*. These trichromates do not lack the red detecting pigment, but their photosensitive red pigment is not as sensitive as in the normal trichromat. The protanomalous pigment reacts to the shorter wavelengths of red than the normal trichromat.
- *Deuteranope*. The visual system of a deutan is insensitive in the green range. The word "deuter" means "second."
- *Deuteranomalous*. A trichromat with abnormal green sensing pigment. The person with this trait has a lower sensitivity to green light and may have some difficulty distinguishing between white and green.
- *Tritanope*. Blue insensitivity: "tri" for "third."
- *Tritanomalous*. A trichromat with abnormal blue sensing pigment, giving a lower sensitivity to blue light.
- *Monochromat*. A person who sees only one color — that is, everything is either black or seen in one or another shade of gray.

Research Accomplished

Mertens has conducted studies of accidents in relation to color vision deficiency (1). He emphasizes in his studies that there is no known case in which an aircraft accident has been attributable to color vision deficiency. He suggests that evaluations of the impact of changes in color in regard to advanced color display technology be made. He also points out that color vision test displays used by aviation medical examiners are often improperly illuminated and this can account for difficulties experienced by some pilots in taking the color vision tests.

Mertens further notes that color vision test displays that have been in use for a number of years change color, and this may cause problems for some people. In addition, he finds that several of the currently accepted color vision screening tests are obsolete and a number of them have not been properly standardized. He states that "plate tests should not be used for second and third class screening." He questions whether or not a specific color vision test should be given to those who will use electronic flight instrument system (EFIS) displays. Of course, the checkout of the pilot who will use the display is the true test of the ability to use it.

Mertens notes that the data have been confused in regard to accident rates in pilots with color vision waivers. He reported that Dille and Booze found that accident rates for pilots with color vision waivers did not differ significantly in comparison with the pilot population at large when recent flying time was compared (2,3). He also notes that no accident has been attributed to color blindness.

A recent publication on effective color vision in the Australian literature found that observers with defective color vision were not disadvantaged by color displays when blue was used as the target feature (4). The study used three groups of six subjects, each with defective color vision, seriously hampering the report's statistical analysis validity in view of the small group of subjects used. In addition, the subjects were not pilots, and this again hampers the development of conclusions in that nonpilots can not be as attuned to flight instrument interpretation as those who use instruments regularly.

For some reason, known only to the authors, the "normal color vision subjects" used a control group that averaged 24 years of age (note: this cohort is likely to be experienced in video games and responses to CRTs) while the test group averaged 41 years of age for six subjects with deuteranomaly, and 30 years of age for six subjects with deuteranopia, and six with protanopia. All of the color defective group members were male, but, also for some reason known only to the authors, the 24 color normal controls were made up of 11 males and 13 females.

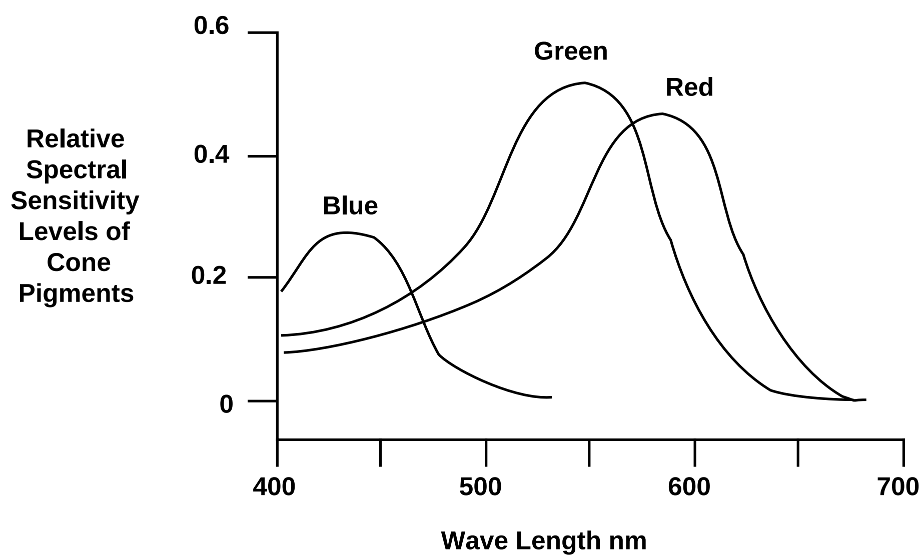
Mixing gender and age is not good science. One wonders what statistical advice was received by the authors in pulling together such a heterogeneous group of differing individuals in regard to these studies, and how, with such tiny experimental group numbers, significant conclusions can be drawn. One can only conclude from this study that all of the subjects could interpret the displays, but some interpreted certain displays somewhat faster than others did (in the millisecond range). But it is not known whether this is of any real safety significance in the flight environment. In fact, some color deficients performed better than the normals in some tests.

Recommendations

Aviation color vision standards are, to a significant degree, a holdover from the World War I era and are based on the perceived requirements of that time.

Studies have not documented an aircraft accident that

Sensitivities of the Three Human Color Detector Pigments Contained in the Cones of the Retina



Source: Best and Taylor, 1973 9th Ed., CH. 8, p. 83, Williams and Wilkins, Baltimore.

Figure 2

was caused by color vision insensitivity.

Recent studies on color vision have been relatively few, due mainly to the low priority color vision actually plays in modern aviation activities. Most laboratory studies have consisted of small number of nonpilot subjects, and the published reports have not been correlated with operational aviation safety experiences. This leads to the conclusion that the World War I basis for color vision screening relative to pilot operations is no longer appropriate. The designers of cockpit instruments should continue to incorporate features that provide for interpretation by viewers irrespective of their genetic color vision sensitivity. ♦

[The medical advisory panel of the Aircraft Owners and Pilots Association, of which the author is a member, has proposed changing the color vision standard for U.S. Federal Aviation Administration (FAA) first-class pilot medical certificates to the lesser standard presently applicable to second-class certificates, and to delete the color vision standard for third-class certificates.—Ed.]

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About the Author

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