Vision Aids for People with ***Impaired Color Perception***

The National Institute for Rehabilitation Engineering (NIRE) is a non-profit organization which operated clinics for the development and dispensing of vision aids from 1967 through 1987. These clinics assisted *hundreds* of people having permanent impairments of vision … or other disabilities. This paper summarizes clinical methods developed, tested and used during this 20-year period for assisting individuals having ***Impaired Color Perception***. Because the NIRE no longer operates these clinics, the information is being made available so that NIRE's data and methods may be used by others to help to functionally or vocationally rehabilitate individuals having Impaired Color Perception or Color Blindness.

INTENDED READERSHIP: This paper was designed to be read and understood by people who have impaired color perception or who are totally color-blind. It is also intended for their families, employers or employment counselors, doctors and therapists.

PURPOSE: The purpose of his paper is to assist interested people in better understanding color-deficient vision, various help options tested or known and the inherent limitations of these modalities. ***NIRE recommends that all vision patients be examined by their own eye doctors before seeking color vision aids.***

"Color Blindness" vs. "Impaired Color Perception"

People are termed: **"Color-Blind"** when there is no color perception, whatsoever. These people see everything in shades of gray. Fortunately, truly "color-blind" people are rare and very few in number. Most color-blind people are born with the disability. Some have normal or near-normal visual acuity. Others, including those with "achromatopsia", may have reduced visual acuity. ***Note: Assuming the patient has been to his or her eye doctor, first, when best corrected visual acuity is 20/100 or worse, the person should also be referred to a local "Low Vision Clinic" for low-vision aids assessment and testing. The Low Vision Clinic should be able to address the color vision issues in addition to the reduced visual acuity problem.***

People are termed: **"Color Perception Impaired"** when they have reduced or abnormal color perception. These situations are most common and are significant when they affect driving or occupational safety, or people's employability at certain occupations. Color perception is partly psychological as well as physical. Often, two people having "normal" color perception will see the same colors differently. For this reason, color perception skills are almost always measured objectively by people's abilities to perform color sorting and color matching tasks with accuracy and repeatability.

Eye Examinations with Color Vision Testing are generally arranged when a person suspects he may have a driving or occupational safety problem relating to color recognition - or when he has difficulty performing the normal and necessary visual functions of his job due to color discrimination difficulties. Such referrals may be made to the person's own eye doctor, or to a vision clinic, for a complete eye examination and thorough color perception testing.

First, complete eye examinations and refractions should be performed to ascertain the person's best corrected visual acuity for each eye, any corrective lens prescriptions needed, the visual fields for each eye, and whether the eyes converge to provide fused binocular vision at all times. The patient should explain to the eye doctor exactly why he is concerned about his color perception being impaired (whether safety or job related). After these steps, the patient is ready for the color perception tests.

The color perception test usually administered is called the "Ishihara Color Perception Test." Developed and perfected years ago, this simple but effective test is still the world standard. The patient observes six or more colored circles and states the number seen in each circle. The numbers spoken aloud are written down by the doctor who immediately knows from the numbers spoken, if the patient has impaired color perception and, if so, the exact type. Depending on the patient's type and degree of impairment, and on the patient's safety, occupational or functional needs, additional color matching tests may be conducted using colored fabric samples or Pantone color strips. After these examinations and tests, the eye doctor will know about all of the patient's vision problems, including those relating to color perception. ***After the examination and tests, the doctor will know which, if any, of the problems may be medically treatable – and will arrange for appropriate treatments and / or functional (optical) aids.***

Types of Assistive Devices for Color Perception Impairment

"Normal" color perception can never be given or restored to people having impaired color perception or total color blindness. At best, specific tools can be given to many such people, for specific functional purposes, i.e. (1) distinguishing red, amber and green traffic signals for safer driving, (2) distinguishing color coded wires or parts when performing factory assembly work, or (3) being able to continue working as an illustrator or painter by correctly matching colors. Briefly described below are different types of assistive devices which may be used, as detailed later in this paper.

1. Eyeglass lens with transparent 3-color strip , high on the lens, for use in knowing with certainty if a traffic signal is red, green or amber, *for safer driving*. This method may be useful to both color-deficient and color-blind people. *Success Rate: high – with minimal training.*

2. Eyeglass lens with transparent 3-color strip , low on the lens, for use in distinguishing wires or parts of different colors while performing *factory assembly work*. This method is often useful to both color-deficient and color-blind people. *Success Rate: high – with intensive job-specific training.*

3. Table-top closed circuit TV (CCTV) image magnifier such as is used by people who have greatly reduced visual acuity. This can be used by a color-deficient person who also has reduced acuity. A color camera and color monitor are used … with the color saturation adjusted to be higher than normal. This enables a person with poor acuity and reduced color perception to compensate both problems. The standard CCTV will not help a totally color-blind person to distinguish colors although it may help the reduced acuity problem. Success Rate: *moderate – with user training.*

4. Eyeglasses (or contact lenses) having one lens red, and the other lens green may help some color-deficient, and even some color-blind people to better distinguish different colors from each other. These lenses never restored even near-normal color perception. However, this method was found in NIRE's clinics to work with only a small percentage of people tested but not with the majority. These major factors were found to affect the usefulness of this method: (1) whether or not the two eyes consistently provided a merged, stereoptic image from the two eyes; (2) the person's ability to mentally switch either eye on or off at will while viewing a scene; (3) the person's awareness, while watching a merged image, of what each eye was seeing. This method was not found to be reliable because it depended too much on psychological factors peculiar to each person. NIRE staff never were able to develop any type of training method for this system that consistently showed any reasonable promise of success. *Success Rate:* *very low.*

5. Personal computer color discrimination systems for graphic artists were found to be useful for many persons employed in the graphics art field who desired to continue their employment after incurring color perception problems. (Our staff recommended against starting work in this field for people already color-blind or severely color perception impaired.)
Success Rate: *moderate – with job-specific training.*

Type of Color Blindness and/or Color Perception Impairment

A. TOTAL Color Blindness. This occurs very rarely and the person sees only in varying shades of gray. The human eye's retina contains two types of cells: "rod" cells in the peripheral areas - which cannot see colors; and "cone" cells in the central or macular areas of the retina - which selectively see and recognize each of three primary colors (red, green & blue). People with total color blindness usually have *reduced visual acuity* at the same time because missing, dead or damaged cone cells result in loss of both acuity and color perception. Total color blindness may be in any one of these categories for any individual: (1) genetic, non-progressive, e.g. "achromatopsia"; (2) genetic, progressive, i.e. certain types of macular degeneration; and (3) acquired, non-genetic (almost always progressive) i.e. macular degeneration, some forms of diabetic retinopathy, or certain types of brain injuries or diseases. Typically, people with total color blindness also have visual acuity best corrected to 20/200, or 20/400 or even worse.

B. Acquired Color Perception Impairments: Only a few conditions cause "acquired" Color Perception Deficiencies. These should be diagnosed and medically treated to slow or stop progression. Acquired Color Perception Deficiencies may be caused by disease of the optic nerve or retina. Acquired color vision problems only affect the eye with the disease and may become progressively worse over time. Patients with a color vision defect caused by disease usually have trouble discriminating blues and yellows. Early macular degeneration and diabetic retinopathy are two examples and there are others. Once under medical treatment, vision aids can be used to the extent that that will be functionally useful for safety or occupational needs.

C. Inherited Color Perception Impairments typically affect many more men than women - although woman may be carriers. As many as 8% of all men, but only 0.5% of all women, have inherited color perception deficiencies. For practical purposes, *most color-deficient individuals have varieties of red-green or green-blue discrimination problems*. Blue-only deficiencies are very rare. Color deficient patients are not completely red- or green- blind. Compared to persons with normal color vision, they have some trouble differentiating between certain colors or shades, but the severity of the color deficiency is variable. *Inherited Male Color Deficiencies are reported to break down roughly as follows: 5% green-insensitive trichromats, 1% red -insensitive trichromats, <1% red-blind and <1% green-blind dichromats.*

1. Terms:

Trichromat sees using all three colors (red/green/blue)
Anomalous Trichromat - reception of one pigment is misaligned

Dichromat - only 2 of the 3 visual pigments exist - red, green or blue is missing.
Protanomaly - reduced red sensitivity in an anomalous trichromat
Deuteranomaly - reduced green sensitivity in an anomalous trichromat

Protanopia - unable to receive first color (red)
Deuteranopia - unable to receive second color (green)
Tritanopia - unable to receive third color (blue)

2. Dynamics: (from generally accepted, published papers)

In an anomalous trichromat, the color reception of the green cones is shifted towards the red end of the spectrum, to a greater or lesser degree; or the reception of the red cones is shifted towards the green part of the spectrum. Hence the range of deficiency varies greatly, according to the degree of shift in wavelength reception.

In a dichromat, either the red or the green reception pigment is totally missing.

In a red-blind dichromat (protanope), there is an additional complication. When the red cones are not there, the overall level of the light received by the eye is reduced, as so many cones are normally tuned to red, and receive the upper wavelengths. This means that colors with a lot of red will seem darker. Therefore, red text on a black background causes particular difficulty. This phenomenon is unusual among women, with about 0.5% of women having any color vision deficiency, and about 0.5% being deuteranomalous (that is, deficient in receiving green).

Only about .005% of the population (male and female) are totally color blind, and 0.003% have tritanopia, or blue-blindness.

Oddly enough, this doesn't simply affect how one perceives red or green, but also colors and shades which vary from each other by the amount of red or green they contain. In addition, because Protanopes are less sensitive to light at the red end of the spectrum (a large proportion of the cones are tuned to the longer wavelengths), colors in this area appear darker to them. *Note: Deuteranopes do not see this luminosity difference, as the other cones and rods can compensate.*

Some Typical Color–Discrimination Optical Aids

FIGURE 1 - Eyeglass lens with transparent 3-color strip , high on the lens, for use in knowing with certainty if a traffic signal is red, green or amber, for safer driving. This method is often useful to both color-deficient and color-blind people. The 3-color filter strip is cemented onto the lens of the better eye, as shown. The driver looks at the traffic light through each of the three filters, red, then amber, then green. The traffic light will be red, amber or green. Its image will be bright through the filter of the same color, and much darker as seen through either of the other two filters. If this is not the case, then the driver is looking at a light that is a color other than red, amber or green.

FIGURE 2 - Eyeglass lens with transparent 3-color strip , low on the lens, for use in distinguishing wires or parts of different colors while performing *factory assembly work* at desktop or lower level. This method is often useful to both color-deficient and color-blind people. A totally color-blind person needs to scan and compare every color and this can be very time consuming. A partially color deficient person will see and recognize

most colors, unaided. He will have to use the "scan and compare" procedure only to verify any of a small number of colors or shades he is uncertain about.

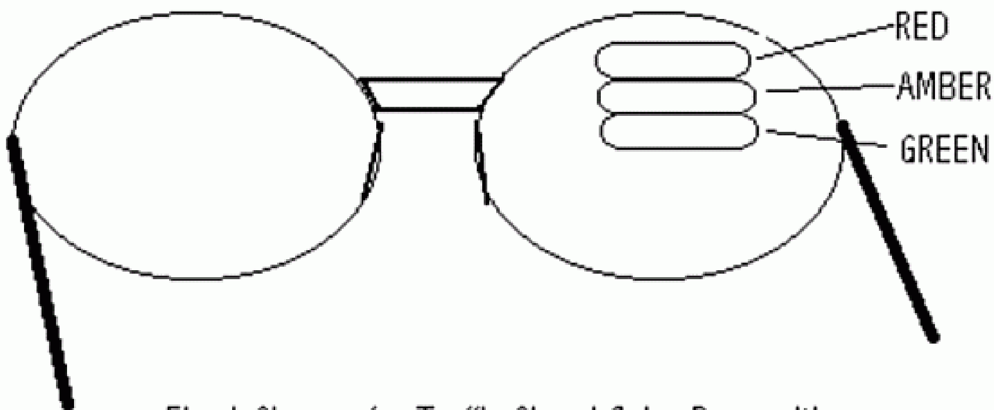

Fig. 1 Glasses for Traffic Signal Color Recognition

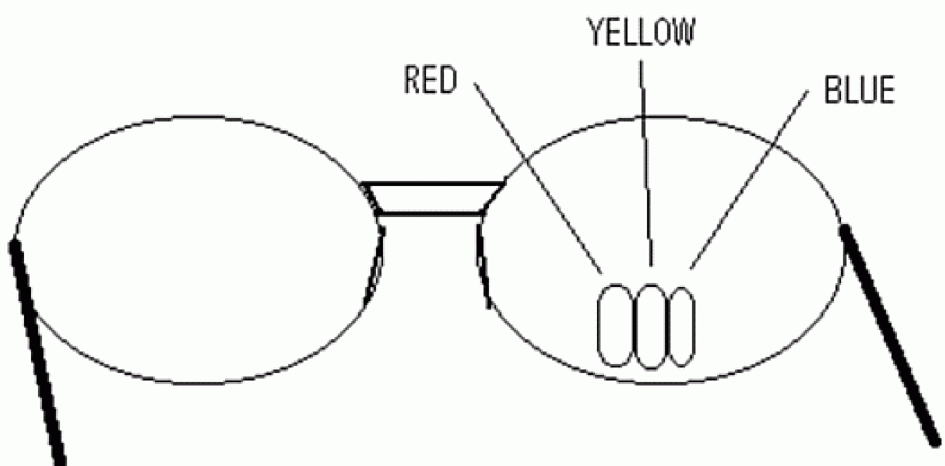

Fig. 2 Glasses for Desktop Color Differentiation

EXAMPLES:

<u>A person unable to distinguish red from green</u> sees red as brightness in the red strip and darkness in the blue strip. He sees green as darkness in the red strip, a brighter image in the blue strip and partial brightness in the yellow strip. Other colors such as orange, purple, etc. may be confusing to the naked eye but become matchable and identifiable with experience when scanned through the filters. *(Some people in this category preferred red, yellow and green filters rather than red, yellow and blue.)*

A person unable to distinguish green from blue (as the only color deficiency) may recognize and discriminate all colors except blue or green without using any optical aids. Such people requiring an optical aid specifically for assembling color coded wires or parts on the job, may do best with filters that are, respectively: blue, green and yellow. With this combination, the person can quickly determine if an object is blue, green or a mixture such as yellow-green (mustard) or blue-green (aqua). People with other color discrimination deficiencies (besides blue & green) will find the blue, green and yellow filter combination inadequate. They will need red, yellow and blue (or green) filters.

To use these glasses, the worker moves his head and eyes to view a wire, component or part that is colored, through each of the three color filters, in this case: red, yellow and blue. He performs this sequence twice: first on the unknown color coded part – and then on known color samples. When the two color samples produce the same results, then they are matched. The reference colors should have written color identification – color name and/or Pantone number.

Closed Circuit TV (CCTV) table-top "image magnifiers," such as used by people who have greatly reduced visual acuity, can be used by partially color-deficient persons who also have reduced acuity. Color cameras and monitors are used … with the color saturation adjusted to higher than normal. *(Note: Some of these systems allow manual adjustment of HUE or color balance; others do not.)* These systems may enable some people with poor acuity and reduced color perception to compensate both problems. However, CCTV systems did *not help totally color-blind* people to distinguish colors.

Eyeglasses (or contact lenses) having one lens red, and the other lens green, may help some color-deficient, and even some color-blind people to better distinguish different colors from each other. These lenses never restored even near-normal color perception. However, this method was found in NIRE's clinics to work with a small percentage of people tested, not with the majority. These major factors were found to affect the usefulness of this method: (1) whether or not the two eyes consistently provided a merged, stereoptic image from the two eyes; (2) the person's ability to mentally switch either eye on or off at will while viewing a scene; (3) the person's awareness, while watching a merged image, of what each eye was seeing. This method was not found to be reliable because it depended too much on psychological factors peculiar to each person. NIRE staff were never able to develop any type of training method for this system that consistently showed any reasonable promise of success.

Color-Tinted Eyeglasses (with both lenses the same color) were found to have benefits for some people with Blue-Green discrimination problems … but not for most other color discrimination problems. Two variations of this method were successfully used by a significant number of patients. These were as follows:

(1) Low-Cost Tinted Sunglasses having “Plano” or non-prescription lenses that were purchased over-the-counter for as little as ten dollars each pair. Generally, they came in each of three colors: Gray (colorless), or Green, or Brown (or Orange). Color discrimination abilities through Gray lenses were the baselines for each person tested. Compared to this were each patient’s color discrimination skills, separately, through Green – and then Brown (or Orange) lenses. Most of these patients had problems with color identification terminology, especially for these colors: green, aqua, turquoise, blue and gray.” Therefore, color-matching tests were done with the person comparing, selecting and matching actual color samples. As previously noted, a high percentage of Blue-Green impaired people performed better with green or brown tinted lenses than with the colorless gray lenses. These uniformly dark lenses were more useful in bright-light areas and less useful in dimly lit areas or at night.

(2) Customized Prescription Sunglasses were found to function the same way but with certain added advantages: A) They provided better vision for many people because the lenses were prescription ground to correct refractive errors. B) They could be made with “Gradient Tinted” lenses, useful indoors or outdoors, in bright or dim light. Because the color density is graduated, users can change the lightness of the view simply by raising the head and lowering the eyes.

Personal Computers for graphic artists with impaired color discrimination were found to be most useful for persons already employed in the graphic arts field, to continue their employment after having incurred color perception problems. (Our staff sometimes recommended against starting work in the graphic arts to people already color-blind or severely color perception impaired or with very low visual acuity.)

Two Types of Color Vision for Graphics Arts Workers

RGB (red-green-blue) vision is what humans use when viewing light waves directly with their eyes. The eye’s retina contains three types of cone cells; some respond to red; others to green; and others to blue. (R + G + B = WHITE) This vision is known as a “color additive system” and it applies to viewing color TV screens, computer monitors, movies, etc. or other forms of projected light. Graphic artists who design colored web pages are using the RGB color vision system. If they use a 256-color computer display standard, then they can assign a number from 1 to 256 to any colors or shades they may use. This is a very convenient color matching system with 100% color repeatability so that it lends itself to use by graphic arts workers who are partially color impaired and even to workers who are totally or near-totally colorblind.

CMYK (cyan-magenta-yellow-black) are the primary colors used in the color printing industry to define the colors that are seen by human beings when reflected back to the eye from printed full-color pages. The CMYK system is a "color subtractive system." The eye still views the colors in its native RGB mode. However, the artist who creates the printed pages must use the CMYK system in mixing his dyes in order for the light reflected back to the viewer's eyes to convey the correct colors in the RGB system.

It is for these reasons that advanced computer applications software for color illustrators and color photo editors often give the user the option to work in RGB mode or in CMYK mode. Generally, because the screen is in RGB mode, the artist works in RGB mode and then converts the images to CMYK mode prior to color printing.

Color illustrations meant for printing may contain any of various numbers of colors. Typically, color modes are available offering 8, 16, 32, 64, 128, 256, etc. up to millions of colors. Only the finest, highest resolution (photo quality or better) images, typically, use more than 256 colors. Based on these numbers, printed-on-paper color matching samples are available. The standard printing industry materials for color matching are called: "Pantone Samples." Each sample card is a single hue, identified by a unique "Pantone number" and on each card are printed a number samples of the same hue but differing in color saturation levels. The color-impaired or color-blind artist can absolutely match and identify the colors he is working with using their Pantone color and saturation level numbers. Using a color scanner, the artist can scan an existing color illustration, see it on the screen and then use special features in the computer program to identify any or all colors selected by Pantone color and saturation numbers.

Our conclusions, based on many years' experience, were and are: "Thanks to modern PC design and the latest graphic arts software application, many people with impaired or even totally absent color perception can learn to function well as graphic arts creators or editors. Innate interest, ability, training and persistence are necessary for success."

For additional information, please email: nire@warwick.net or contact:

The National Institute for Rehabilitation Engineering
Box 1088 – Hewitt, NJ 07421 Tel. (800) 736-2216
