PART 3

VISION AND LIGHT

The Physiology of Sight

Visual Data Collection

Human visual processing occurs in two steps. First the entire field of vision is processed. This is typically an automatic function of the brain, sometimes called *preattentive processing*. Secondly, focus is localized to a specific object in the processed field. Studies at the University of Pennsylvania indicate that segregating specific items from the general field is the foundation of the identification process.

Based on this concept, it is now theorized that various light patterns reaching the eyes are simplified and encoded, as lines, spots, edges, shadows, colors, orientations and referenced locations within the entire field of view. The first step in the subsequent identification process is the comparison of visual data with the long-term memory of previously collected data. Some researchers have suggested that this comparison procedure is a physiological cause of *deja vu*, the uncanny feeling of having seen something before.[8]

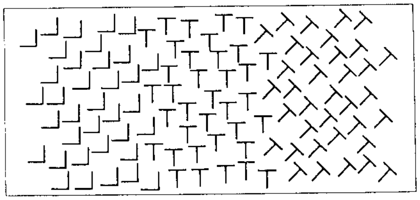
The accumulated data are then processed through a series of specific systems. Certain of our light sensors receive and respond only to certain stimuli and transmit their data to particular areas of the brain for translation. One kind of sensor accepts data on lines and edges; other sensors process only directions of movement or color. Processing of these data discriminates between different complex views by analyzing their various components.[9]

By experiment, it has been shown that these areas of sensitivity have a kind of persistence. This can be illustrated by staring at a lit candle, then diverting the eyes toward a blank wall. For a short time, the image of the candle is retained. The same persistence occurs with motion detection and can be illustrated by staring at a moving object, such as a waterfall, then at a stationary object like the river bank. The bank will seem to flow because the visual memory of motion is still present.

Differentiation in the Field of View

Boundary and edge detection can be illustrated by the pattern changes in Fig. 8. When scanning the figure from left to right, the block of reversed *L*s is difficult to separate from the upright *T*s in the center but the boundary between the normal *T*s and the tilted *T*s is easily apparent. The difficulty in differentiation occurs because horizontal and vertical lines comprise the *L* and upright *T* groups, creating a similarity that the brain momentarily retains as the eye moves from one group to the other. On the other hand, the tilted *T*s share no edge orientations with the upright *T*s, making them stand out in the figure.

FIGURE 8. Pattern changes illustrating boundary and edge detection



Differentiation of colors is more difficult when the different colors are in similarly shaped objects in a pattern. The recognition of geometric similarities tends to overpower the difference in colors, even when colors are the object of interest. Additionally, in a grouping of different shapes of unlike colors, where no one form is dominant, a particular form may hide within the varied field of view. However, if the particular form contains a major color variance, it is very apparent. Experiments have shown that such an object may be detected with as much ease from a field of thirty as it is from a field of three.[10]

Searching the Field of View

The obstacles to differentiation discussed above indicate that similar objects are difficult to identify individually. During preattentive processing, particular objects that share common properties such as length, width, thickness or orientation are not different enough to stand out. If the differences between a target object and the general field is dramatic, then a visual inspector requires little knowledge of what is to be identified. When the target object is similar to the general field, the inspector needs more specific detail about the target. In addition, the time required to detect a target increases linearly with the number of similar objects in its general field.

When an unspecified target is being sought, the entire field must be scrutinized. If the target is known, it has been shown statistically that only about half of the field must be searched.

The differences between a search for simple features and a search for conjunctions or combinations of features can also have implications in nondestructive testing environments. For example, visual inspectors may be required to take more time to check a manufactured component when the possible errors in manufacturing are characterized by combinations of undesired properties. Less time could be taken for a visual test if the manufacturing errors always produced a change in a single property.[11]

Another aspect of searching the field of view addresses the absence of features. The presence of a feature is easier to locate than its absence. For example, if a single letter *O* is introduced to a field of many *Q*s, it is more difficult to detect than a single *Q* in a field of *O*s. The same difficulty is apparent when searching for an open *O* in a field of closed *O*s. In this case statistics show that the apparent similarity in the target objects is greater and even more search time is necessary.

Experimentation in the area of visual search tasks encompasses several tests of many individuals. Such experiments start with studies of those features that should stand out readily, displaying the basic elements of early vision recognition. The experiments cover several categories, including quantitative properties such as length or number. Also included are search tasks concentrating on single lines, orientation, curves, simple forms and ratios of sizes. All these tests verify that visual systems respond more favorably to targets that have something added (*Q* versus *O*) rather than something missing.

In addition, it has been determined that the ability to distinguish differences in intensity becomes more acute with a decreasing field intensity. This is the basis of Weber's law. The features it addresses are those involved in the early visual processes: color, size, contrast, orientation, curvature, lines, borders, movement and stereoscopic depth.

Weber's Law

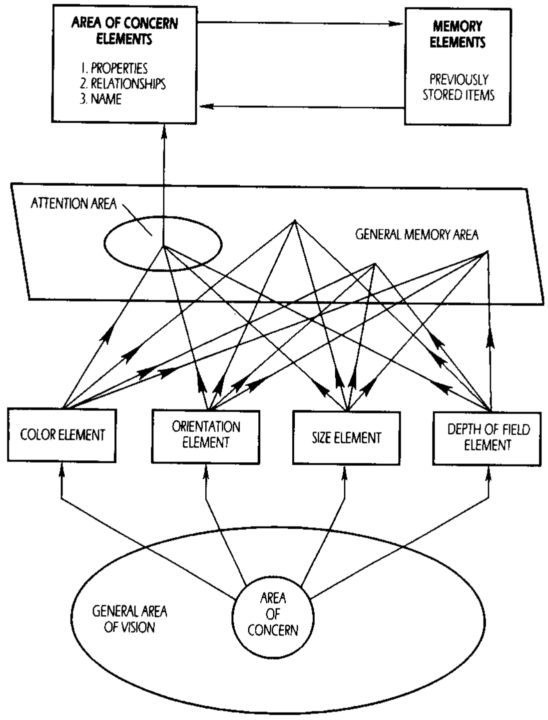
Weber's law is widely used by psychophysicists and entails the following tenets: (1) individual elements such as points or lines are more important singly than their relation to each other and (2) closed forms appear to stand out more readily than open forms. To view a complete picture, the visual system begins by encoding the basic properties that are processed within the brain, including their spatial relationships. Each item in a field of view is stored in a specific zone and is withdrawn when required to form a complete picture. Occasionally, these items are withdrawn and positioned in error. This malfunction in the reassembly process allows the creation of optical illusions, allowing a picture to be misinterpreted.

The diagram in Fig. 9 represents a model of the early stages of visual perception. The encoded properties are maintained in their respective spatial relationships and compared to the general area of vision. The focused attention selects and integrates these properties, forming a specific area of observation. In some cases, as the area changes, the various elements comprising the observance are modified or updated to represent present conditions. During this step, new data are compared to the stored information.

Vision Acuity

Vision acuity encompasses the ability to see and identify what is seen. Two forms of vision acuity are recognized and must be considered when attempting to qualify visual ability. These are known as *near vision* and *far vision*.

FIGURE 9. Stages of visual perception



Components of the Human Eye

The components of the human eye (Fig. 10) are often compared to those of a camera. The lens is used to focus light rays reflected by an object in the field of view. This results in the convergence of the rays on the retina (film), located at the rear of the eyeball. The cornea covers the eye and protects the lens. The quantity of light admitted to the lens is controlled by the contraction of the *iris* (aperture). The lens has the ability to become thicker or thinner, which alters the magnification and the point of impingement of the light rays, changing the focus. Eye muscles aid in the altering of the lens shape as well as controlling the point of aim.

This configuration achieves the best and sharpest image for the entire system. The retina consists of rod and cone nerve endings that lie beneath the surface. They are in groups that represent specific color sensitivities and pattern recognition sections. These areas may be further subdivided into areas that collect data from lines, edges, spots, positions or orientations.

The light energy is received and converted to electrical signals that are moved by way of the optic nerve system to the brain where the data are processed. Because the light is being reflected from an object in a particular color or combination of colors, the individual wavelengths representing each hue also vary. Each wavelength is focused at different depths within the retina, stimulating specific groups of rods and cones (see Figs. 10 and 11). The color sensors are grouped in specific recognition patterns as discussed above.

FIGURE 10. Components of the human eye in cross section

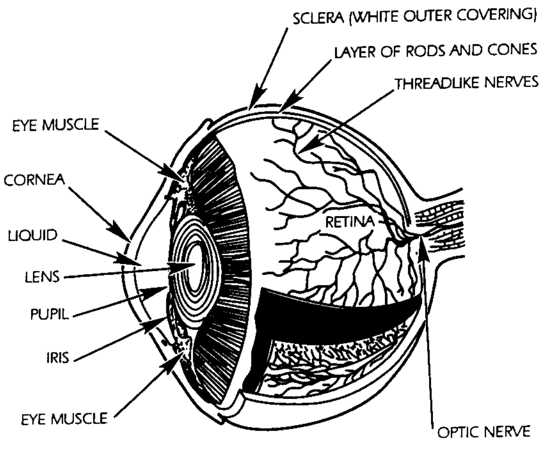
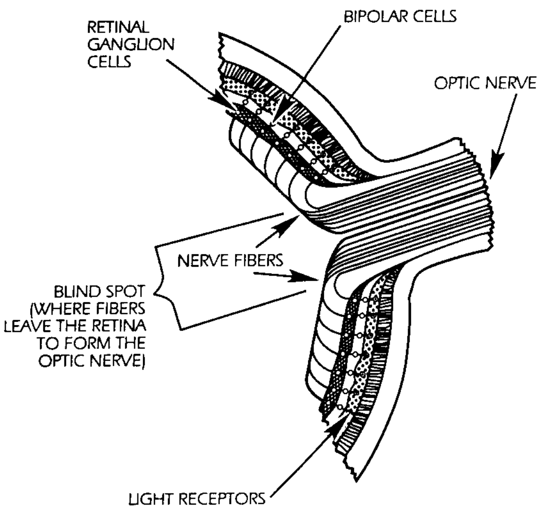


FIGURE 11. Magnified cross section showing the blind spot of the human eye



To ensure reliable observation, the eye must have all the rays of light in focus on the retina. When the point of focus is short or primarily near the inner surface of the retina closest to the lens, a condition known as *nearsightedness* exists. If the focal spot is deeper into the retina, *farsightedness* occurs. These conditions are primarily the result of the eyeball changing from nearly orb shaped to an elliptical or egg shape. In the case of the nearsighted person, the long elliptical diameter is horizontal, If the long diameter is in a vertical direction, farsightedness occurs. These clinical conditions result from a very small shift of the focal spot, on the order of micrometers (ten-thousandths of an inch).

Determining Vision Acuity

The method normally used to determine what the eye can see is based on the average of many measurements. The average eye views a sharp image when the object subtends an arc of five minutes, regardless of the distance the object is from the eye. The variables in this feature are the diameter of the eye lens at the time of observation and the distance from the lens to the retina.

When vision cannot be normally varied to create sharp clear images, then corrective lenses are required to make the adjustment. While the eye lens is about 17 mm (0.7 in.) from the retina, the ideal eyeglass plane is about 21 mm (0.8 in.) from the retina. Differences in facial features must therefore be considered when fitting for eyeglasses. Under various working conditions, the glass lenses may not stay at their ideal location. This can cause slight variations when evaluating minute details and such situations must be individually corrected.

For the majority of visual testing applications, near vision acuity is required. Most visual inspections are performed within arm's length and the inspector's vision should be examined at 400 mm (15.5 in.) distance. Examinations for far vision are done at distances of 6 m (20 ft).

Vision Acuity Examinations

Visual testing may occur once or more during the fabrication or manufacturing cycle to ensure product reliability. For critical products, visual testing may require qualified and certified personnel.

Certification of the visual test itself may also be required to document the condition of the material at the time of testing. In such cases, testing personnel are required to successfully complete vision acuity examinations covering specific areas necessary to ensure product acceptability. For certain critical inspections, it may be required for the eyes of the inspector to be examined as often as twice per year.

Near Vision Examinations

The examination distance should be 400 mm (16 in.) from the eyeglasses or from the eye plane, for tests without glasses. When reading charts are used, they should be in the vertical plane at a height where the eye is on the horizontal plane of the center of the chart. Each eye should be tested independently while the unexamined eye is shielded from reading the chart but not shut off from ambient light.

The Jaeger™ eye chart is widely used in the United States for near vision acuity examinations. The chart is a 125 × 200 mm (5 × 8 in.) off-white or grayish card with an English language text arranged into groups of gradually increasing size. Each group is a few lines long and the lettering is black. In a vision examination using this chart, visual testing personnel may be required to read, for example, the smallest letters at a distance of 300 mm (12 in.). Near vision acuity examinations that are more clinically precise are described below.

Far Vision Examinations

Conditions are the same as those for near vision examinations, except that the chart is placed 6 m (20 ft) from the eye plane. Again, each eye is tested independently.

Grading Vision Acuity

The criterion for grading vision acuity is the ability to see and correctly identify 7 of 10 optotypes of a specific size at a specific distance. The average individual should be able to read six words in four to five seconds, regardless of the letter size being viewed.

The administration of a vision acuity examination does not necessarily require medical personnel, provided the administrator has been trained and qualified to standard and approved methods. In some instances specifications may require the use of medically approved personnel. In these cases, the administrator of the examination may be trained by medically approved personnel for this application. In no instance should any of these administrators try to evaluate the examinations.

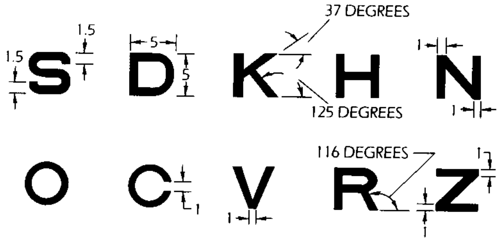
If an applicant does not pass the examination (fails to give the minimum number of correct answers required by specification), the administrator should advise the applicant to seek a professional examination. If the professional responds with corrective lenses or a written evaluation stating the applicant can and does meet the minimum standards, the applicant may be considered acceptable for performance of the job.

Vision Acuity Examination Requirements

There are some basic requirements to be followed when setting up a vision acuity examination system. The distances mentioned above are examples but there are also detailed requirements for the vision chart.

The chart should consist of a white matte finish with black characters or letters. The background should extend at least the width of one character beyond any line of characters. Sloan letters as shown in Fig. 12 were designed to be used where letters must be easily recognizable. Each character occupies a five stroke by five stroke space.

FIGURE 12. Letters used for acuity examination charts (measurements in stroke units)



The background luminance of the chart should be 85 ± 5 cd•m^{-2}. The luminance is a reading of the light reflected from the white matte finish toward the reader.

When projected images are used, the parameters for the size of the characters, the background luminance and the contrast ratio are the same as those specified for charts. In no case should the contrast or illumination of the projected image be changed. A projection lamp of appropriate wattage should be used. When projecting the image, room lighting is subdued. This should not cause any change in the luminance of the projected background contrast ratio to that of the characters.

The room lighting for examinations using charts should be 800 lx (75 ftc). Incandescent lighting of the chart is recommended to bring the background luminance up to 85 ± 5 cd•m^{-2}. Fluorescent lighting should not be used for vision acuity examinations. Incandescent lamps emit more light in the yellow portion of the visible spectrum. This makes reading more comfortable for the examinee. Fluorescent lamps, especially those listed as full spectrum, *are* good for color vision examinations.

Many of the lighting conditions for vision acuity examinations can be met by using professional examination units. With one such piece of equipment, the examinee views slides under controlled, ideal light conditions.

Another common design is used both in industrial and medical examinations. With this unit, the individual looks into an ocular system and attempts to identify numbers, letters or geometric differences noted in illuminated slides. The examinee is isolated from ambient light.

The slides and their respective data were developed by the Occupational Research Center at Purdue University, based on many individuals tested in many different occupations. Categories were developed for different vocations and are provided as guides for examinations required by various industries. Such equipment is expensive and accordingly eye charts are still very popular. Table 1 compares the results of these three vision acuity examination systems.

TABLE 1. Eye examination system conversion chart

Eye Chart	Slide Display	Slide Display with Ocular System 360 mm (14 in.)
1	10	20/20
2	8	20/28
3	6	20/33
4	5	20/38
5	4.6	20/42
6	4.3	20/50
7	4	20/55
8	3	20/60
9	2.5	20/63
10	2	20/65

There are slight differences between the reading charts and the slides. The reading chart distance for one popular letter card is 400 mm (16 in.). The simple slide viewer is set for near vision testing at 330 mm (13 in.).

There also are some differences between individual examination charts. Most of the differences are the result of variances in typeface, ink and the paper's ink absorption rate. Regardless of the examination system that is used, the requirements for the lighting and contrast remain the same.

Visual Angle

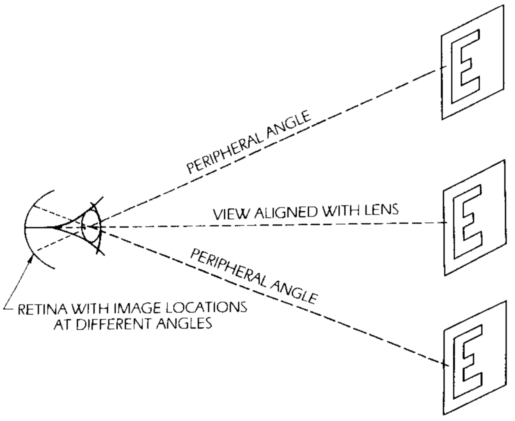
Posture

Posture affects the manner in which an object is observed—appropriate posture and viewing angle are needed to minimize fatigue, eyestrain and distraction. The viewer should maintain a posture that makes it easy to maintain the optimum view on the axis of the lens.

Peripheral Vision

Eye muscles may manipulate the eye to align the image on the lens axis. The image is not the same unless it impinges on the same set of sensors in the retina (see Fig. 13). As noted above, different banks of sensors basically require different stimuli to perform their functions with optimum results. Also, light rays entering the lens at angles not parallel to the lens axis are refracted to a greater degree. This changes the quality and quantity of the light energy reaching the retina. Even the color and contrast ratios vary and depth perception is altered.[12]

FIGURE 13. Vision acuity of peripheral vision



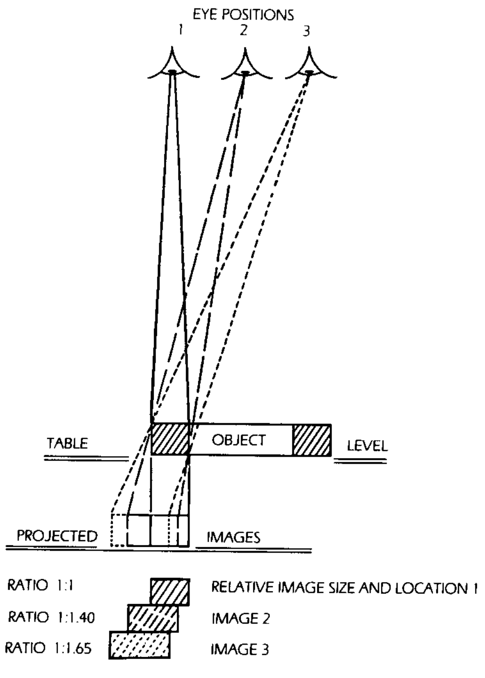
The commonly quoted optimum, included angle of five minutes of arc is the average in which an individual encloses a sharp image. There are other angles to be considered when discussing visual testing.

The angle of peripheral vision is not a primary consideration when performing detailed visual tests. It *is* of value under certain inspection conditions: (1) when surveying large areas for a discontinuity indication that (2) has a high contrast ratio with the background and (3) is observed to one side of the normal lens axis. The inspector's attention is drawn to this area and it can then be scrutinized by focusing the eyes on the normal plane of the lens axis.

Visual Testing Viewing Angle

The angle of view is very important during visual testing. The viewer should in all cases attempt to observe the target on the center axis of the eye. The angle of view should not vary more than 45 degrees from normal. Figure 14 shows how the eye perceives an object from several angles and how the object appears to change or move with a change in viewing angle.

FIGURE 14. Shifting eye positions change apparent object size and location



The same principle applies to objects being viewed through accessories such as mirrors or borescopes. The field of view should be maintained much in the same way that it is when viewed directly.

On reflective backgrounds, the viewing angle should be off normal but not beyond 45 degrees. This is done so that the light reflected off the surface is not directed toward the eyes, reducing the contrast image of the surface itself. It also allows the evaluation of discontinuities without distorting their size, color or location. This is very important when using optical devices to view areas not available to direct line of sight.

Color Vision

There are specific industries where accuracy of color vision is important: paint, fabrics and photographic film are examples. Surface inspections such as those made during metal finishing and in rolling mills are to determine manufacturing discontinuities. Color changes are not indicative of such discontinuities and therefore, for practical purposes, color is not as significant in these applications.[13] However, heat tints are sometimes important and colors may be crucial in metallography and failure analysis.

When white light testing is performed, it must be remembered that white light is composed of all the colors (wavelengths) in the spectrum. If the inspector has color vision deficiencies, then the test object is being viewed differently than when viewed by an inspector with normal color vision.

Color deficiency may be as critical as the test itself. During visual testing of a white or near white object, slight deficiencies in color vision may be unimportant. During visual testing of black or near black objects, color vision deficiencies make the test object appear darker.[14]

Color Vision Examinations

Ten percent of the male population have some form of color vision deficiency. The so-called *color blind* condition affects even fewer people—truly color blind individuals are unable to distinguish red and green. But, there are many variations and levels of sensitivity between individuals with normal vision and those with color deficiencies.

There are two causes of color deficiency: inherited and acquired. And each of these may be subdivided into specific medical problems. Most such subdivisions are typically discovered during the first vision examination.

The most common color deficiencies are hereditary and occur in the red-green range. About 0.5 percent of the affected individuals are female, in the red-green range. Women constitute about 50 percent of those affected in the blue-yellow range. Most such deficiencies occur in both eyes and in rare instances in only one eye. About 0.001 percent of the affected groups in the hereditary portion have their

TABLE 2. Causes of acquired color vision deficiencies

Color Vision Deficiency	Cause of Deficiency
Blue-yellow deficiency	Glaucoma
	Myopic retinal degeneration
	Retinal detachment
	Pigmentary degeneration of the retina (including retinitis pigmentosa)
	Senile macular degeneration
	Chorioretinitis
	Retinal vascular occlusion
	Diabetic retinopathy
	Hypertensive retinopathy
	Papilledema
	Methyl alcohol poisoning
	Central serous retinopathy (accompanied by luminosity loss in red)
Red-green deficiency	Optic neuritis (including retrobulbar neuritis)
	Tobacco or toxic amblyopia
	Leber's optic atrophy
	Lesions of the optic nerve and pathway
	Papillitis
	Hereditary juvenile macular degeneration (Stargardt's and Best's disease)
Blue-yellow deficiency	Dominant hereditary optic atrophy
Red-green or blue-yellow deficiency	Juvenile macular degeneration

TABLE 3. Classification of color vision deficiencies and percent of affected males

Color Vision	Percent Males Affected
Hereditary deficiencies	
trichromatism (three colors: red, green, blue)	
normal vision	92
anomalous (defective)	6 or 7
dichromatism (two colors)*	
protanopia (red lacking)	1
deuteranopia (green lacking)	1
trianopia (blue lacking)	rare
tetratanopia (yellow lacking)	very rare
Acquired deficiencies	
tritan (blue-yellow)	data not available
protan-deutan (red-yellow)	data not available

*DEFICIENCY MOST OFTEN REFERENCED WHEN DISCUSSING COLOR BLINDNESS

TABLE 4. Naval Submarine Medical Research Laboratory color vision classification system

Class	Description
0	Normal
I	Mild anomalous trichromat
II	Unclassified anomalous trichromat (includes mild and moderate classes)
III	Moderate anomalous trichromat
IV	Severely color deficient (includes severe anomalous trichromats, dichromats and monochromats)

deficiency in the blue-green range. Individuals in the red-green group may make misinterpretations of discontinuities in shades of red, brown, olive and gold.

Acquired color deficiency is a greater problem to good color vision testing. The acquired deficiencies may affect only one eye and a change from acceptable color vision to a recognizable problem may be very gradual. Various medical conditions can cause such a change to occur (Table 2 lists conditions that produce color vision deficiencies in particular color ranges). Most acquired color vision problems vary in severity and may be associated with ocular pathology. If the disease continues for an extended period of time without treatment, the deficiencies may become erratic in intensity and may vary from the red-green or blue-yellow ranges. Aging can also affect color vision.[15]

Color Vision Classifications

Two functions that determine an individual's sensation range are their color perception and color discrimination. When a primary color is mistaken for another primary color, this is an error in perception. An error in discrimination is an error of lesser magnitude involving a mistake in hue selection.[16] During a vision examination, these two functions are tested independently.

A color vision examination performed with an anomaloscope allows the mixing of red and green lights to match a yellow light standard. Yellow and blue lights may be mixed to match a white light. An individual with normal vision requires red, blue and green light to mix and match colors of the entire color spectrum. A color deficient person may require fewer than the three lights to satisfy the color sensation.[17] Table 3 indicates the type of deficiencies and the percent of the male population known to be affected.[18]

For the practical purpose of classifying personnel affected by hereditary color deficiencies, the Naval Submarine Medical Research Laboratory has developed the classifications shown in Table 4. about 50 percent of color deficient people can be categorized in accordance with this table. Class I covers 30 percent of the color deficient population and Class III accounts for 20 percent. Individuals in Class I can judge colors used as standards for signaling, communication and identification as fast and as accurately as zero class persons can. The limitation of Class I people is when good color discrimination is necessary. Persons in Class III may be used in other areas such as radio repair, chemistry, medicine and surgery, electrical manufacturing or general painting. Class II encompasses staff members, managers or clerical help, whose need for color resolution is not critical. Individuals in Class IV must be restricted from occupations where color differentiation of any magnitude is required.

As with vision acuity examinations, there are many different examinations for color vision.[19] Color vision is often tested with pseudoisochromatic plates or cards on which the detection of certain figures depends on red-green discrimination. Unfortunately, most common vision acuity examinations were designed to identify hereditary red-green deficiencies and ignore blue-yellow deficiencies.[20]

A good, discriminating examination technique is illustrated in color Plates 1 to 7. The diagrams show the sequence in which the colors are arranged in each photograph for each deficiency, differing from the sequence according to normal vision illustrated in Plate 1.[21] (Caution: These plates are provided for educational purposes only. Photography, print reproduction and chemical changes all cause colors to vary from the original and fade with time. Under no circumstances should illustrations in this book be used for vision examinations.)

The exam consists of the examinee's arranging fifteen colored caps into a circle according to changes in hue progressing from a reference cap. To help evaluate the outcome, each cap is numbered on the back. A perfect score has the caps in numerical sequence. This test is used for those known to have a color vision deficiency. The test allows for the evaluation of the individual's ability and determines the specific area of the deficiency. The arrangement of colors allows confusion to exist across the quadrants of the circle. For instance, reds can be confused with blue-greens. One authority has stated that anyone who can pass this test should have no problem in any work requiring color vision acuity.

Two types of red-green deficient patterns can be noted. Individuals in these categories confuse green (4) with red-purple (13) and blue-green (3) with red (12). The sequence then appears as 4, 13, 3 and 12. Persons with the blue-yellow deficiency confuse yellow-green (7) with purple (15), creating a sequence of 7, 15, 8, 14 and 9.

As in the normal vision acuity examinations, lighting requirements and time must be controlled for color vision examinations. The illumination intensity of full spectrum fluorescent lighting should be no less than 200 lx (20 ftc). The rating of the light source is known as the *color temperature*. A low color temperature lamp such as an incandescent lamp makes it easier for persons with borderline color deficiencies to guess the colors correctly. A color temperature of 6,700 K is preferred. Too high a color temperature increases the number of reading errors. To eliminate glare, the light source should be 45 degrees to the surface while the patient is perpendicular to it. The reading distance should be about 400 to 600 mm (15 to 24 in.) or arm's length. To perform such an examination, two minutes should be allotted to arrange all fifteen caps in their appropriate positions.

In summary, color deficiency can be acquired or inherited. Some color deficiencies may be treated, alleviated or minimized. Pseudoisochromatic plates in conjunction with the progressive hue color caps provide an adequate test for most industrial visual inspectors. Full spectrum lighting (6,700 K) is necessary for accurate test results.

It should be added that, because the visible spectrum is made up of colors of varying wavelengths and the black and white colors consist of various combinations of colors, deficiencies in any part of the color spectrum has an impact on certain black and white inspection methods, including X-ray film review.

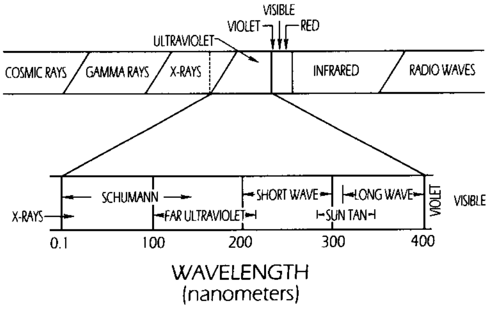
It is recommended that all nondestructive testing personnel have their color vision tested annually, while taking their vision acuity examination.

Fluorescent Materials

Fluorescence is a complex phenomenon that occurs in gases, liquids and solids. It has also proved to be the greatest and most efficient source of the so-called *cold light*. For the purpose of visual nondestructive testing, fluorescence is used in conjunction with long wave ultraviolet radiation as an excitation source (see Fig. 15).

Text continued on page 21.

FIGURE 15. Electromagnetic spectrum and an enlargement of the ultraviolet region



Caps for Color Vision Examinations

The exam consists of the examinee's arranging fifteen colored caps into a circle by a change in hue progressing from a reference cap. To help evaluate the outcome, each cap is numbered on the back. A perfect score has the caps in numerical sequence. The diagrams show the sequence in which the colors are arranged in each photograph for each deficiency, differing from the sequence according to normal vision illustrated in Plate 1.

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PLATE 1. Colored caps for normal color vision examination

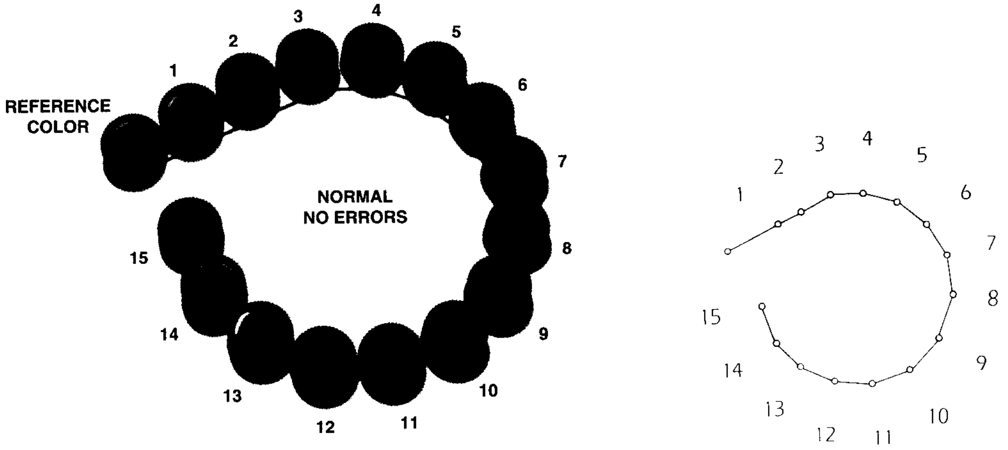


PLATE 2. Colored caps for normal color vision with minor errors

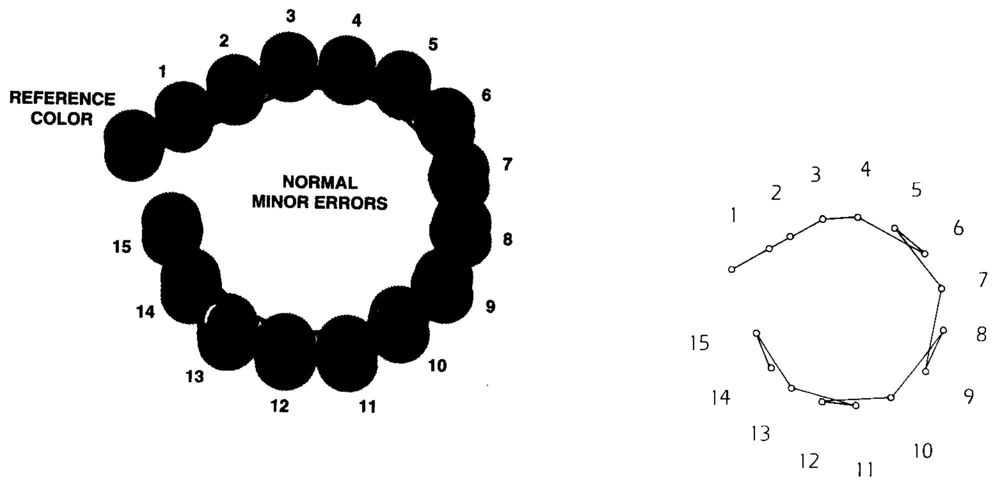


PLATE 3. Colored caps for normal color vision with one error

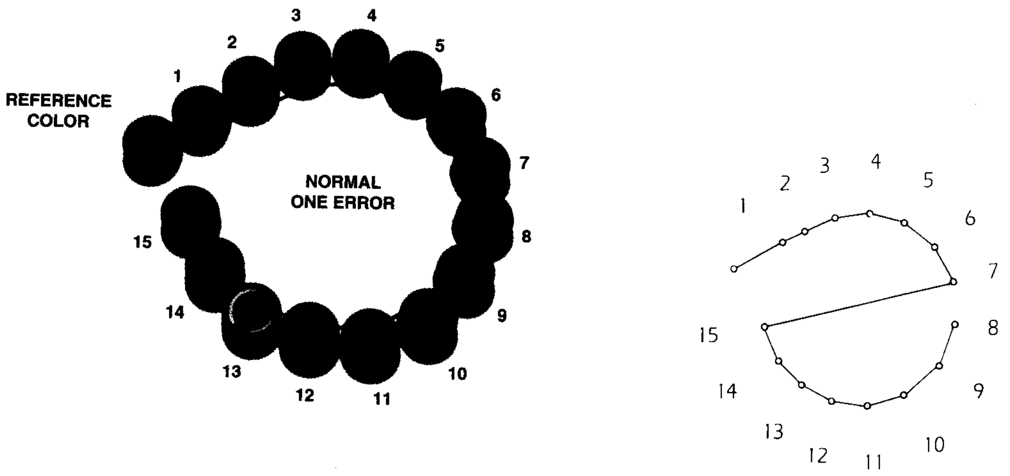


PLATE 4. Colored caps for red blindness

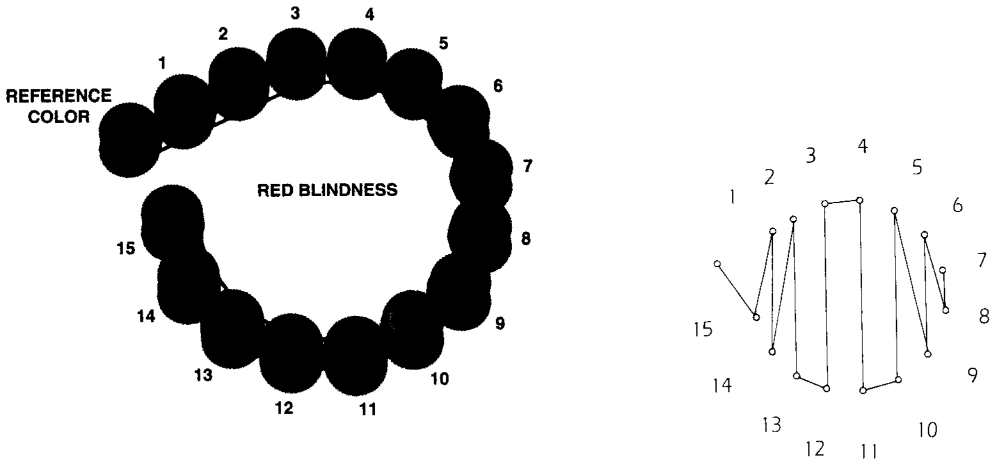


PLATE 5. Colored caps for green blindness

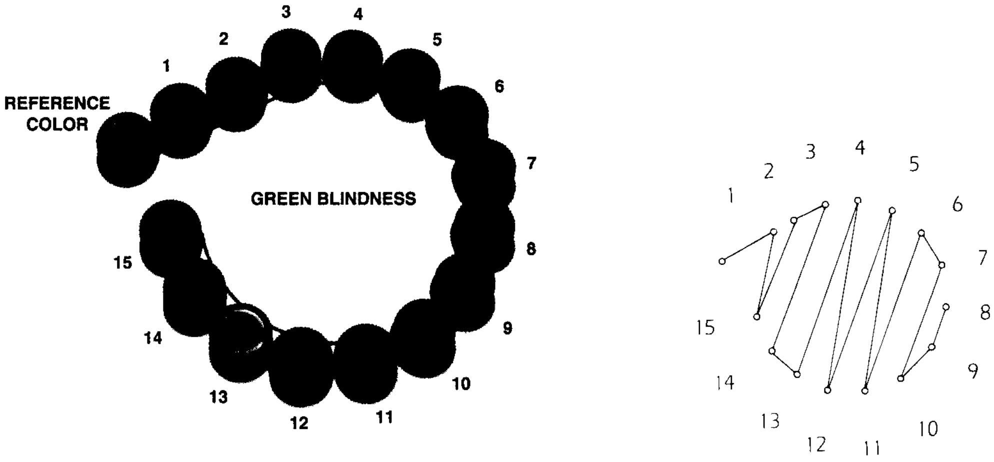


PLATE 6. Colored caps for blue blindness

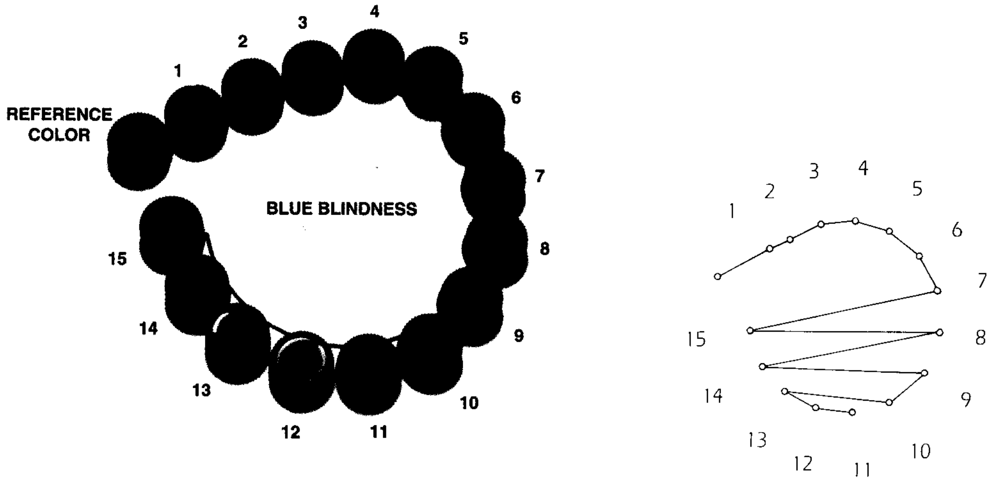
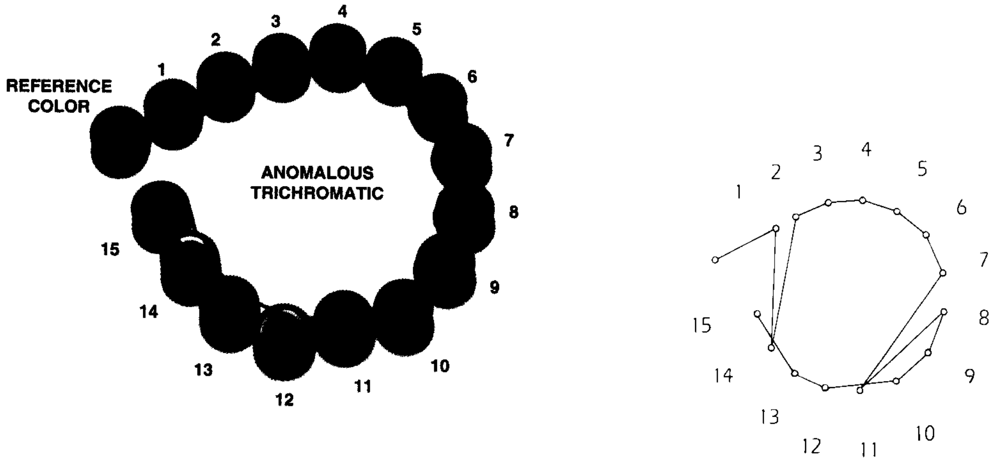


PLATE 7. Colored caps for anomalous trichromatic vision



Continued from page 16.

Visible light rays are made up of billions of *photons*, packets of particle-like energy. Photons are so small they have no mass. They do however carry energy and this is what we see when a light bulb is energized—the photons have carried energy from the bulb to the eye.

Photons have different energies or wavelengths which we distinguish as different colors. Red light photons are less energetic than blue light photons. Invisible ultraviolet photons are more energetic than the most energetic violet light that our eyes can see.

Studies show that the intensity of fluorescence in most situations is directly proportional to the intensity of the ultraviolet radiation that excites it. Fluorescence is the absorption of light at one wavelength and reemission of this light at another wavelength. The whole absorption and emission process occurs in about a nanosecond and because it keeps happening as long as there are ultraviolet radiation photons to absorb, a glow is observed to begin and end with the turning on and off of the ultraviolet radiation. Care *must* be taken when using short wave or wide bandwidth ultraviolet sources. A safe, general operating principle is to always hold the lamp so the light is directed away from you.

Long wave ultraviolet is generally considered safe. However, individuals should use adequate protection if they are photosensitive or subjected to long exposure times.

Commercially available fluorescent dyes span the visible spectrum. Because the human eye is still the most commonly used sensing device, most nondestructive testing applications are designed to fluoresce as close as possible to the eye's peak response. Figure 16 shows the spectral response of the human eye, with the colors at the ends of the spectrum (red, blue and violet) appearing much dimmer than those in the center (orange, yellow and green).

While the fundamental aspects of fluorescence are still incompletely understood, there is enough known to ensure that nondestructive testing methods using fluorescence will continue to improve with the development of new dyes or new solvents to increase brightness or eye response matching.

FIGURE 16. Human eye response at 1070 lx (100 ftc)