Transitions®

LIGHT, SIGHT, AND PHOTOCHROMICS

This is an exciting time in the optical industry because of the many opportunities to advance patient care. By learning about the various aspects of vision-related quality of life, eyecare professionals can offer patients more comprehensive eyewear solutions to meet their overall visual needs.

Clinical research plays a vital role in evaluating the benefits of various lens options to patients and enabling eyecare professionals to make informed product recommendations based on objective evidence.

That's why Transitions Optical is so committed to education and research. Along with sponsoring major symposia at national and international meetings, concentrating on promoting eye health and maximizing quality of vision, we have supported several independent clinical studies that explore vision-related quality of life. We're proud to bring the results of this research to you as part of an overall discussion on "Light, Sight and Photochromics." We'd like to thank New York University School of Medicine's Department of Ophthalmology for spearheading this research and pulling together the results for the monograph.

This research is significant because it provides clinical substantiation of the importance of visual comfort and long-term vision protection to vision-related quality of life. This implies that eyecare professionals can offer a more comprehensive solution with recommendations of products like Transitions photochromic lenses, which address these aspects of the overall visual experience. Transitions are higher-performing everyday lenses because they are indistinguishable from regular, clear lenses indoors for uncompromised visual acuity, and darken when exposed to UV radiation outdoors providing visual comfort in varying light conditions and convenient 100 percent UV protection. By approaching vision-related quality of life as more than visual acuity, eyecare professionals can add value to their recommendations and, as the research shows, increase patient satisfaction.

We're pleased to serve our eyecare professional partners by bringing them this valuable new information and through our continued commitment to innovative product developments. Education is an important focus of our efforts because it enables us to provide practitioners with the knowledge required to bring state-of-the-art vision correction to their patients. We hope this monograph is helpful in understanding vision-related quality of life and the latest information on "Light, Sight and Photochromics."

For more information on the research or Transitions Optical, Inc., e-mail researchinfo@transitions.com.

Sincerely,

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INTRODUCTION

"Nearly blind.... The light is intolerable....
This is the first time ... that I have had too much sunshine....
Thin clouds cast a grateful shadow over all the glowing
landscape. I gladly took advantage of these kindly clouds."

Excerpt from the journal of John Muir, describing the sunblindness
he suffered while exploring the Muir Glacier in Glacier Bay, 1890.

We thought how carelessly he'd asked
That every day be sharp and drenched with light,
Nor wanted a moment of vision masked,
But begged for depth and clarity of light.

Gray Burr, "Eyestrain"
A Choice of Attitudes

The relationship between light and sight is a complex one. Light is essential to vision. But while light mediates vision, it may also moderate vision, and the relationship between light and sight is not always a positive one.

To many patients, light is perceived to be the solution to a variety of visual problems. For the forty-something individual, struggling to read the label on a bottle of medicine, or trying to decipher a listing in the telephone book, turning up the light can make all the difference between seeing and not seeing. How many older patients with vision-compromising conditions like cataract or macular degeneration complain that they know they would see better if only they could get more light?

But there are others who view light as an obstacle and not a help. Consider the person with a posterior subcapsular cataract, where the constriction of the pupil induced by a bright light accentuates lenticular changes and may prove virtually blinding. Or the mother walking her children to school who is thrown off balance by glare as she crosses the street and risks being hit by an oncoming car. So while light is indeed essential to vision, it is the appropriate quality and quantity of light that are essential to good vision.

And it is not only the light that can be seen that is important. Invisible light, especially light in the ultraviolet range, may be a significant factor in the development of a number of ocular diseases that ultimately compromise sight.

Fortunately, light can be manipulated. Ophthalmic lenses may be used to moderate light and, in so doing, to improve the quality of vision and protect the eye from potentially dangerous light exposure. They serve to balance the positive and the negative effects of light on the eye, in addition to correcting refractive errors.

This monograph explores the relationship between light and sight, and suggests how best to use spectacle lens treatments – such as fixed tint sunglasses, photochromic lenses, and anti-reflective coatings – to make that relationship a positive one.

CHAPTER 1.

LIGHT AND SIGHT

Light and sight are intimately connected. Taking advantage of the relationship between the two is what vision care is all about. But how often is that relationship considered?

What is light? What is sight? How are they connected?

Light arises in the sun, where thermonuclear reactions generate electromagnetic radiation. Light is carried in an energy-bearing vehicle (the photon). When a photon contacts matter, a series of physicochemical phenomena occur that can produce biological reactions. In the eye, the retina is the mediator for these reactions. Detectors in the sensory retina transform the physical energy of light into nerve signals that result in sight. Vision, then, may be considered to be a transducing process, where a physical element (light) is converted into electrical energy (sight).

When considering the relationship between light and sight, it is usually visible light that is the concern. Visible light is that light which produces vision. But the electromagnetic spectrum consists of both visible and invisible light, and, while it is visible light that is responsible for sight, the invisible portion of the spectrum is also important. Visible light falls in the range of 380-700 nm. Ultraviolet radiation is in the shorter wavelengths (100-380 nm), and infrared in the longer wavelengths (700-1400 nm). **Figure 1.**

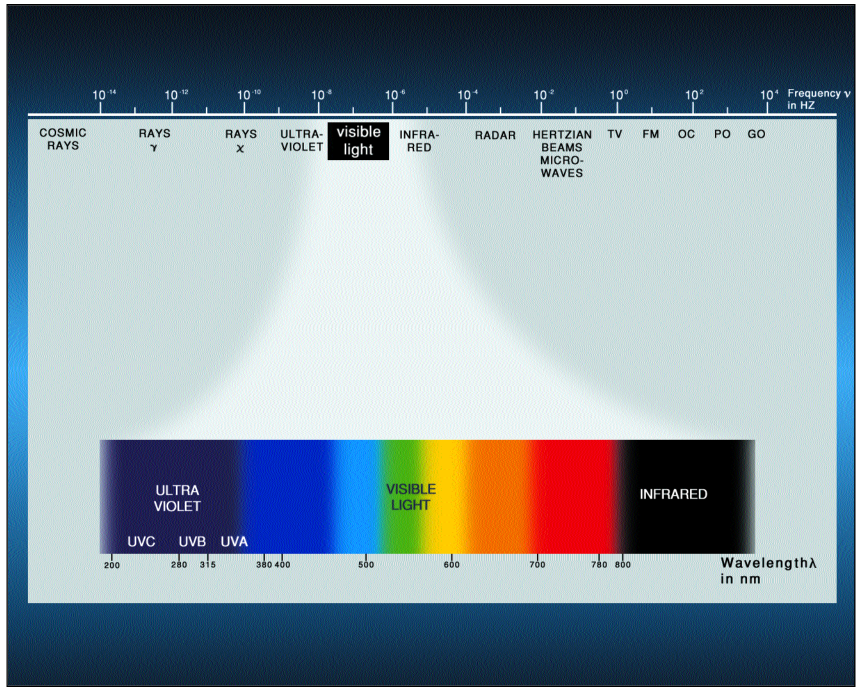


Figure 1. The electromagnetic spectrum.
(Courtesy of Essilor International)

The Eye and Sight

The eye may be considered a vehicle or a facilitator for the transformation of light stimuli into sight. While it is the retina that is directly responsible for the actual transduction process that converts physical into electrical energy to produce vision, the other structures of the eye transmit and moderate light entering the eye to affect the quality and quantity of light that reaches the retina and determines vision. This transmission and moderation of light are both essential elements for good vision, and the anatomy of the eye is such that the appropriate balance between transmission and moderation might be achieved.

The eyelids and iris serve to titrate the amount of light entering the outer and inner eye respectively. The eyelids close or squint to limit excessive light, and open wide to accommodate the maximum amount of light when conditions are dim. The iris sphincter controls the entry of light into the inner eye, constricting to decrease the light stimulus with bright illumination, and dilating to maximize the light stimulus with decreased illumination. Of the protective outer coats of the eyeball itself, the surface area of the semi-opaque sclera is several times that of the clear cornea, serving to limit the access of light to the inner eye. And both the cornea and the lens absorb and bend light, acting as refractive filters to moderate and direct the light stimuli that reach the retina.

In short, the eye is designed to act as much as a protection against light as a conduit for its transmission. There is a good reason for this. As far as sight is concerned, with light it may sometimes become a case of too much of what is generally a good – and a necessary – thing. For while light is crucial to vision, light can actually impair vision or even damage the visual apparatus and compromise sight.

With visible light, the primary problems are excessive light and glare. Excessive light can be modulated through the use of a filter, a device that alters the intensity and the spectral distribution of light passing through it. Glare is essentially misdirected light. It compromises visual function by producing glare disability, where visual acuity is reduced because of light elsewhere in the field of vision. Filters can decrease glare. Special anti-glare coatings for lenses are also available. These treatments will be discussed in more detail in Chapter 4.

UVR and the Eye

It is the invisible component of light – specifically ultraviolet radiation (UVR) – that may pose an actual risk to the health and function of the eye. Potential damage to ocular structures from UVR occurs through two mechanisms: ionization and non-ionization. In the former, tissue exposure to UVR leads to the production of positively-charged molecules called free radicals, which may alter the structure of proteins or DNA. Non-ionizing effects of UVR may be thermal or photochemical. Photochemical damage is generally produced by lower wavelengths (350-530 nm). It is a relatively low-energy, long-exposure phenomenon, which may be at least partially reversible. Thermal damage, on the other hand, is associated with higher wavelengths (530 nm or greater) and shorter exposures. Here effects are profound, immediate, and largely irreversible.

Ultraviolet radiation is short wavelength radiation (100-380 nm). Falling outside of the visible spectrum, it is invisible to the human eye. UVR is subdivided into four regions, based on wavelength: UVA (315-380 nm), UVB (280-315 nm), UVC (190-280 nm), and UVV (100-190 nm). Since both UVV and UVC are filtered by the protective ozone layer in the stratosphere, UVB and UVA have been of primary concern from the viewpoint of eye (and skin) exposure. The cornea absorbs the bulk of UVB, with a small amount reaching the crystalline lens. The lens absorbs most of the UVA, with only a minute proportion reaching the retina. **Figure 2.**

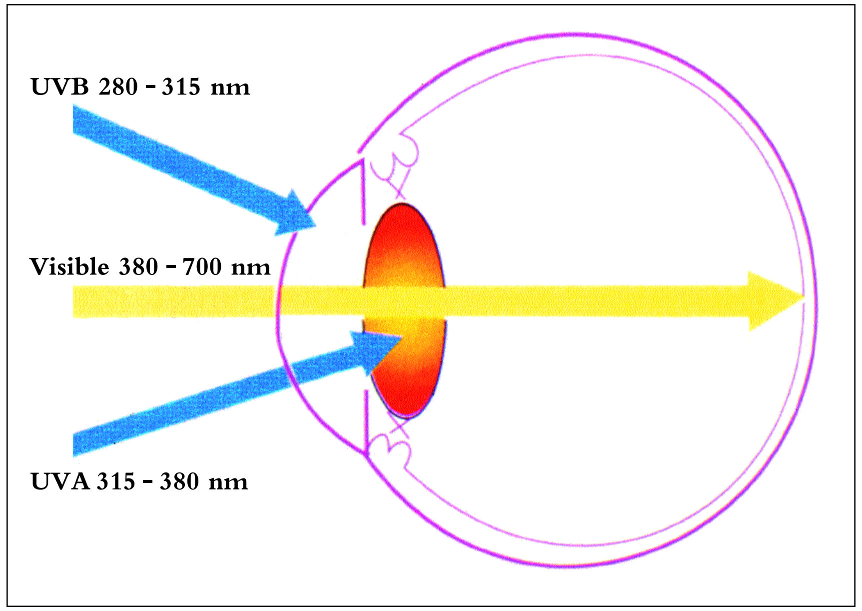


Figure 2. UVR and ocular tissue sensitivity.

Although only a fraction of UVA and UVB reach the inner eye, the high sensitivity of ocular tissues to the effects of UVR and the importance of cumulative exposure make these fractions clinically significant.

The ocular structures primarily at risk from UVR exposure are the eyelid skin, the conjunctiva, cornea, crystalline lens, and the retina. Acute and chronic exposure can produce acute and chronic disease.

Acute Ocular Manifestations of UVR Exposure

Probably the most common acute ocular manifestation of UVR overexposure is sunburn affecting the eyelid skin, manifested by cutaneous swelling and erythema, in severe cases followed by blistering and exfoliation. UVB has been tied to sunburn, and UVA to tanning effects in the skin.

Photokeratitis is characterized by pain, foreign body sensation, photophobia, and blurred vision. On examination there is typically a mild-to-moderate conjunctival hyperemia with ciliary flush and an epithelial keratitis affecting the superficial layers, with or without staining, and usually accentuated in the exposed interpalpebral zone. **Figure 3.** As a rule, this is self-limited with no long-term residua.

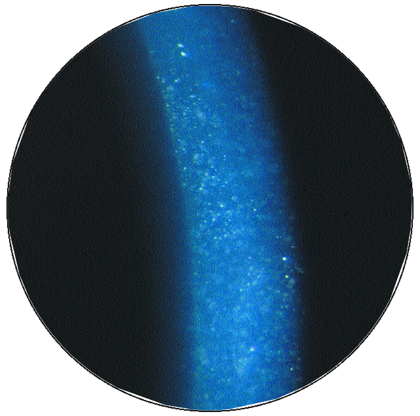


Figure 3. Photokeratitis.

Solar retinopathy develops after intense, unprotected UVR exposure, most commonly occurring after looking at the sun directly during an eclipse. **Figure 4.** It may also be observed in arc welders, in individuals monitoring sky or sea conditions, in laboratory workers exposed to UVR, and in sunbathers.

Figure 4. Solar retinopathy.

Chronic Ocular Manifestations of UVR Exposure

Among the ocular diseases attributed to chronic UVR exposure are cutaneous neoplasms of the eyelids (basal and squamous cell carcinomas and melanomas – **Figures 5. – 6.**), pingueculae, pterygia (**Figure 7.**), cataracts (**Figure 8.**), and age-related macular degeneration (ARMD) (**Figure 9.**). Evidence is based on a combination of laboratory and epidemiological studies, and, while highly suggestive, remains inconclusive. Some individuals may be more susceptible to effects of UVR than others. Skin and eye pigment may play a role, along with hereditary factors. The existence of a light resistance gene has been postulated. Since many of the disorders linked to UVR exposure occur in older individuals, it is interesting to consider a possible relationship between UVR exposure and the overall aging process. The combination of dry skin, deep wrinkles, sagging and loss of elasticity in the skin, mottled pigmentation, and telangiectasia – all of which characterize photoaging – has been tied to UVA exposure.

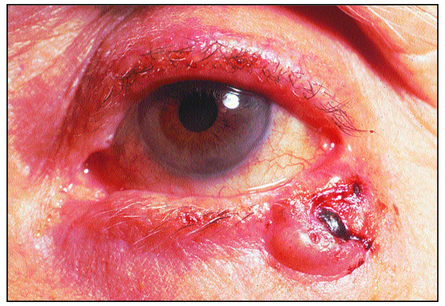


Figure 5. Basal cell epithelioma of the eyelid.
(Courtesy of Dr. Richard Palu)

Figure 6. Malignant melanoma of the eyelid.
(Courtesy of Dr. Richard Palu)

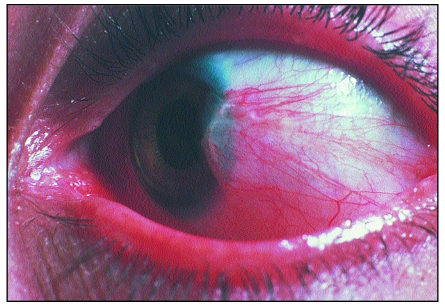


Figure 7. Pterygium.

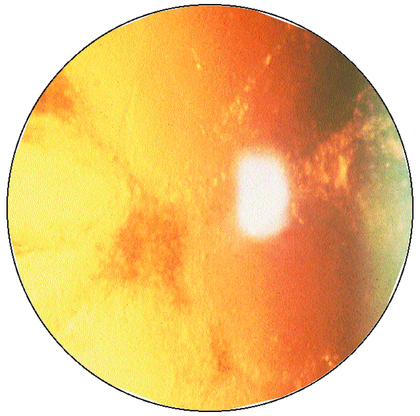


Figure 8. Cataract.

Figure 9. Age-related macular degeneration (ARMD).

There have been any number of studies in laboratory animals demonstrating adverse effects of UVR exposure on the cornea, crystalline lens, and retina. Damage to all levels of the cornea occurs with UVR, with the earliest damage in the epithelium, progressing to stromal and endothelial changes with increasing levels and duration of exposure. Acute intense exposure to UVR produces anterior cortical and subcapsular cataractous changes. Chronic exposure to UVA and UVB leads to cortical and posterior subcapsular cataracts.

The two most widely cited epidemiological studies in humans are the Chesapeake Bay Waterman Study and the Beaver Dam Study. These suggested a relationship between prolonged time spent outdoors in the sun and the development of cortical cataracts and averred exudative or atrophic macular degeneration. In a recent follow-up to the latter study, a strong relationship was found between time spent outdoors in the summertime during the teenage (13-19) and early adult (30-39) years and the risk of early-onset ARMD.

In addition to ocular disease related to UVR exposure, from the viewpoint of pure visual function, UVR can adversely affect acuity through light-scattering effects in the cornea and lens, producing a decrease in low-contrast sensitivity acuity.

Protecting the Eye From UVR

The greater longevity people are enjoying in the 21st century increases the total potential lifetime exposure to UVR. This, along with profound alterations in the protective ozone layer seen after years of environmental abuse, has served to increase the risk of UVR-related ocular disease. Depletion of the ozone layer continues to represent an international health threat. Despite worldwide efforts to halt this trend, it is still progressing at an estimated rate of 12% per decade globally (3% in the Northern Hemisphere). It has been postulated that for every 1% decrease in the ozone layer, there will be an associated 4% increase in skin cancer and a 0.6-0.8% increase in cataract. Although traditionally UVA and UVB have been considered the wavelengths posing the greatest potential threat for UVR damage to ocular structures (with the atmosphere filtering out the lower wavelength UVC and UVV), the ongoing loss of the protective ozone layer increases the potential risk from the more toxic UVC, particularly at higher altitudes, in more southern latitudes, and during winter months when the ozone layer is thinner and holes appear more frequently.

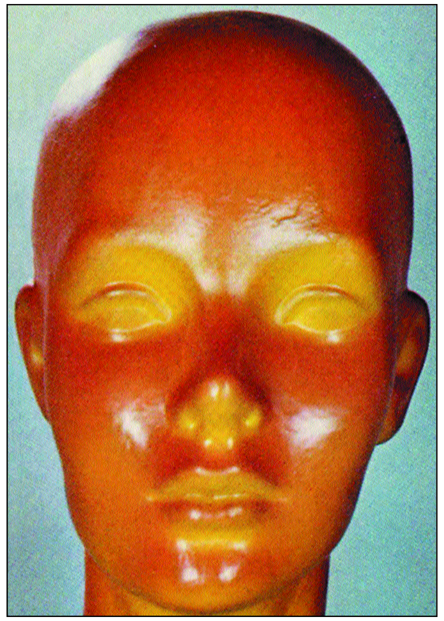
It has been mentioned that the eye tends to protect itself from UVR. Aside from the obvious light entry level protection provided by the mechanical actions of the lids and iris, the cornea and lens serve to moderate light by absorbing it, in addition to their recognized functions of refracting and focusing it. This is particularly important with UVA and the retina. It is the lens that is primarily responsible for filtering UVA and protecting the retina from the potentially harmful effects of exposure. This filtering action of the crystalline lens becomes more significant in adulthood. As an individual ages, the lens opacifies through the accumulation of fluorescent pigments which result from photo-induced chemical reactions. For example, before age ten more than 75% of incident UVR passes through the lens, compared to only about 10% at age 30.

It is interesting to postulate a form of ocular natural selection here, where possible UVR-related (and potentially reversible) cataractogenic effects developing from infancy onwards serve to protect the older eye from more serious and largely irreversible UVR effects on the retina.

UVR and the Eyelids

Since vision-threatening UVR-related ocular disease is believed to occur after years of UVR exposure, in much the same fashion as cutaneous neoplasia, the importance of UVR protection starting in early childhood cannot be overemphasized. Children generally spend significantly more time outdoors than adults. It has been estimated that 80% of the total lifetime sun exposure occurs before 18 years of age.

The dermatology community has done an excellent job of educating the public about the importance of avoiding overexposure to UVR and the need for protective sunblocks. The situation with the eye is not nearly as good. In a recent survey (April, 2002), sponsored by Transitions Optical, Inc., and conducted by ICR in Media, Pennsylvania, while 79% of people were aware of the potential hazards to the skin from UVR exposure, only 6% knew that UVR exposure could be associated with eye disease.



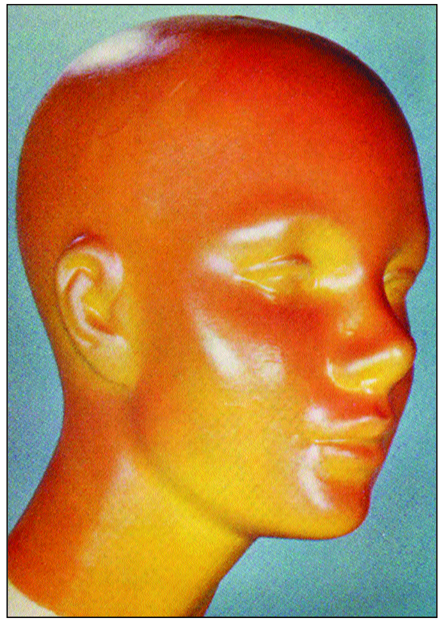


Figure 10. Manikin demonstrating sunlight exposure, using a chemical UVR dosimeter.
(Courtesy of Dr. Frederick Urbach)

More than 90% of all UVR-related skin cancers (basal cell, squamous cell, and melanomas) occur above the neckline in the so-called exposed zones. **Figure 10.** The lids are a common site for the development of these neoplasms, with an estimated 10% of all non-melanoma skin cancers found in the eyelids. Although the lids are an especially vulnerable site for UVR exposure, because of their proximity to the external eye they are not an area where the use of topical sunblock preparations is recommended (due to the potential for contact with or leakage into the eye, producing a chemical keratoconjunctivitis). For this reason, protection of the eyelid skin from UVR should be combined with protection of the eye itself, and must be achieved in other ways.

When Is UVR Protection Necessary

Simply put, UVR protection is necessary whenever there is risk of UVR exposure, which is all the time. There is a common myth that sunlight is synonymous with ultraviolet light, with most people thinking about UVR protection as sun protection. This is not the case. Since UVR is invisible, there is no easy way for the average person to accurately assess the risk of exposure to UVR. The media is attempting to address this problem by announcing UV indices and issuing ozone alerts, but the best way to deal with UVR exposure is to understand that it is a constant. It's always there: on bright sunny days, for sure, but also on those cloudy overcast days when there doesn't seem to be any sun. In fact, 50% of the UVR dose the average person receives is indirect – not direct – and due to reflected or scattered UVR.

Certain times of the day tend to place an individual at higher risk for UVR exposure, i.e., in the late morning/early afternoon, between 10 a.m. and 2 p.m. UVR intensity may also be higher in certain geographic areas, i.e., at higher altitudes and in southern latitudes. And, contrary to popular belief, direct sunlight does not pose the greatest risk for UVR; actually, snow has the highest UVR reflectance factor, followed by water and sand.

Furthermore, ongoing ozone depletion increases the danger of exposure, not only to UVB and UVA, but also to the potentially more harmful UVC.

The Logistics of Protecting Against UVR

If UVR is always there and cumulative exposure is the crux of the problem, then the conclusion must be that an individual should be constantly protected from UVR. Since UVR is ubiquitous in the environment, complete avoidance is not possible. Protection is the next best tactic. Certainly protection under circumstances when the potential for exposure is high – e.g., sunbathing on the beach on a cloudless day or snow skiing at high altitudes – is recommended. And, whatever the circumstances, protection must be simple and convenient to be consistently used.

Broad-brimmed hats or visors have been advocated as effective sun protection, but they will only eliminate approximately 50% of incident light. Glasses are the simplest and most effective UVR protection for the eye, and not necessarily sunglasses, since sun and UVR are not the same thing. For UVR protection, a clear spectacle lens that absorbs UVR, or has been specially treated to absorb UVR, is sufficient to protect the eye – and the eyelids, if a large enough frame or a warp-around design is used – from exposure. The larger the frame the better: A 13 square cm surface area offers 60-65% UVR protection for the eye and the lids, while a 20 square cm area increases this protection to 96%. The shorter the vertex distance – i.e., the closer the lens is to the eye – the better the protection, as well.

But there are also practical – and functional – aspects to UVR protection. Since potential exposure to UVR is generally higher under conditions where glare and sun comfort are also issues, in addition to UVR protection, people expect glasses to filter out excessive sun and minimize bothersome reflections. This is best achieved through the use of a sunglass or a photochromic lens that achieves sunglass darkness.

The government has mandated that all sunglasses – prescription and over-the-counter – block UVR effectively: 99% of UVB and 95% of UVA. But the ideal sunglass must meet other criteria as well. It must be comfortable to wear, and this means that it cannot compromise vision or unduly distort color perception. Unfortunately, by definition, all tints affect vision – especially when measured as contrast sensitivity acuity – and color vision, and the effect is greater with darker tints that offer increased ocular comfort under conditions of high levels of illumination or glare. But while some compromise in contrast acuity or fine color discrimination in exchange for the modulation of troublesome glare or intense sunlight is acceptable, the basic problem with using sunglasses for constant UVR protection is that constant sunlight protection is not necessary ... and not beneficial. Standard sunglasses act as filters. They utilize a fixed-tint design that cannot adapt to different levels of illumination. They are not capable of providing both full-time UVR and on-demand sunlight protection, allowing as much transmittance of light as feasible to minimize negative effects on color and contrast acuity.

If it is accepted that UVR is ubiquitous, that it may pose a threat to good vision and the health of the eye so that constant protection is optimal, that the appropriate filtering of sunlight and glare is important to visual comfort and performance, and that people live – and function – in an indoors-outdoors world where the amount of exposure to sunlight varies, the ideal protective spectacle lens should offer effective, complete, and consistent UVR protection, as well as on-demand (or as needed) sun and glare protection. It should minimally alter color values. And it should not impair or diminish visual acuity.

This optimal spectacle lens then should allow the wearer to see well, to see accurately, to see comfortably, and to see conveniently, all the while protecting the eye to preserve good vision, as much as possible, for a lifetime. Photochromic lenses meet these criteria.

CHAPTER 2.

COLOR VISION IN THE REAL WORLD

Filters change the intensity (or quantity) of light. They also affect the quality of light. Color is an important characteristic of light that may be modified by filters. Since tinted lenses are basically colored lenses, they change the colors of objects viewed through them. In this way, they may alter color perception. Looking at the world through rose (or blue or green or yellow or violet) colored lenses makes the world look different. To appreciate how various spectacle lens tints may alter color perception in the real world, some understanding of color vision is necessary.

Aspects of Color Vision

Color vision has evolved to a high level in man, and the ability to see a wide array of colors enriches the experience of the visual world. The perception of the color of an object is dependent not only on spectral content and luminance, but also on the surrounding environment and the state of the visual system. There can be individual differences in color perception. The best examples include congenital and acquired color vision defects. In addition, color perception normally changes with age. A brief review of the theories and mechanisms of color vision is helpful in understanding natural and artificially-induced alterations in color perception.

Theories and Mechanisms of Color Vision

There are two main theories of color vision: the trichromatic and the opponent process theories.

Trichromatic Theory

The trichromatic theory was proposed by Thomas Young in 1802 and refined by Hermann von Helmholtz half a century later. This theory states that color vision results from the action of three cone receptor mechanisms with different spectral sensitivities. When light of a particular wavelength is presented to the eye, these mechanisms are stimulated to different degrees and the ratio of activity in the three mechanisms results in the perception of color. Each color is coded in the nervous system by its own ratio of activity in the three cone receptor mechanisms.

Color vision is mediated by three classes of cone photopigments: the short-wavelength sensitive (SWS) photopigment, which is maximally sensitive around 440 nm; the middle-wavelength sensitive (MWS) photopigment (maximally sensitive around 540 nm); and the long-wavelength sensitive (LWS) photopigment (maximally sensitive around 565 nm). The cones containing the photopigments are referred to as SWS or S-cones, MWS or M-cones, and LWS or L-cones.

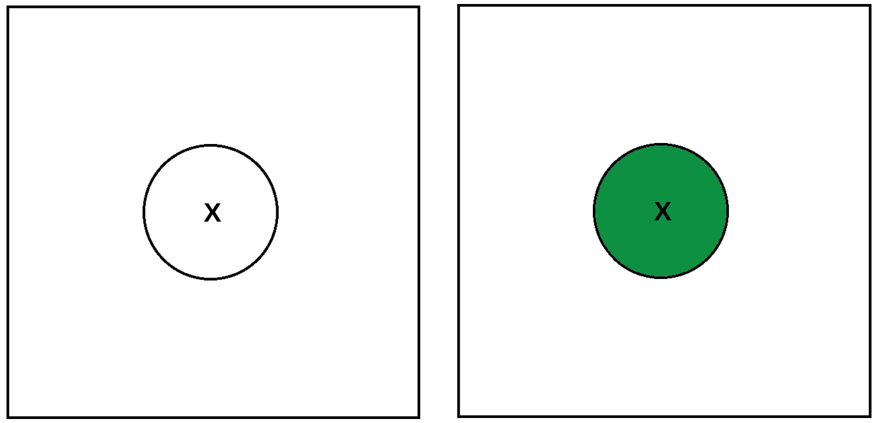
The absorption spectra of the cone photopigments have been determined using psychophysical color matching techniques and physiological techniques such as microspectrophotometry, retinal densitometry, and electrophysiologic recordings. The cone spectra obtained in the late 1980s using electrophysiologic techniques are very similar to the spectra obtained many years ago using psychophysical color matching techniques.

Opponent-Process Theory

The opponent process theory (Ewald Hering, 1878) proposes three mechanisms: a black-white mechanism, a red-green mechanism, and a blue-yellow mechanism. Each responds in opposite ways to different wavelengths of lights. The black (-) white (+) mechanism responds positively to white light and negatively to the absence of light. The red (+) green (-) mechanism responds positively to red and negatively to green light, and the blue (-) yellow (+) mechanism responds negatively to blue and positively to yellow light.

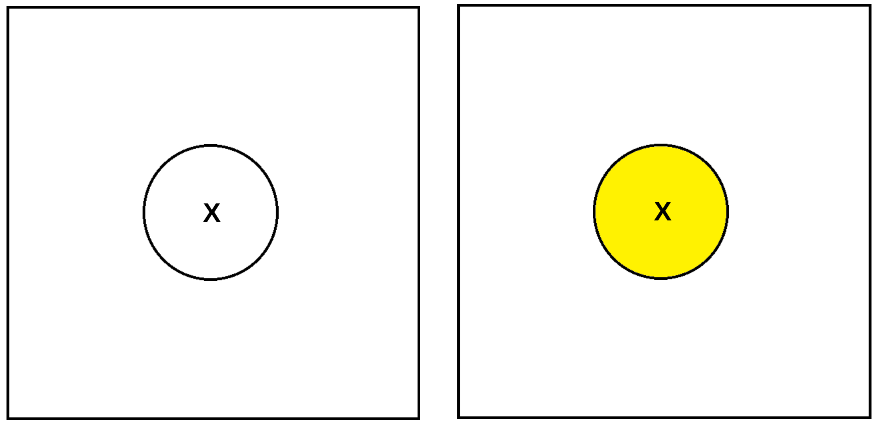
Hering's theory was based on psychophysical observations (e.g., a red after-image follows exposure to green light). **Figure 1.**

Figure 1. Illustration of opponent process of red-green, blue-yellow "after-image" effects.



Look at the X in the center of the white circle, then look at the X in the center of the green circle for 15 seconds. Look back at the X in the center of the white circle. The circle will appear to be red.

Repeat the above process for the yellow circle. When looking at the X in the center of the white circle, the circle will appear to be blue.



It was only in the late 1950s and 1960s that electrophysiological data were obtained in support of the theory. For example, in the macaque monkey many retinal ganglion cells and cells in the lateral geniculate nucleus receive antagonist inputs from different types of cones; these cells which receive opposed inputs are called color opponent cells.

Trichromatic or Opponent-Process Theory: Which is Correct?

Both theories appear to be correct. There is evidence that in the normal eye there are three types of cone photoreceptors and there are also post-receptoral neurons and pathways that compare the outputs of the different receptor types. The trichromatic theory explains how the cone photoreceptors function, and the opponent-process theory explains how information is encoded post-receptorally.

Color Perception

Specifying Color

Color is specified along three dimensions: hue, saturation, and brightness. Hue is the perception most closely associated with wavelength. A spot of 540 nm light has a hue that is green. Saturation refers to the white content of a color. A desaturated color looks as though it has been mixed with white; it appears washed out. Examples of desaturated colors are pastels. Brightness of a color depends on the amount of radiant energy. A color appears brighter as radiant energy is increased.

Factors Affecting Color Perception

The colors of objects are based on the wavelengths of light that they reflect or transmit, but color perception is also affected by the surrounding environment, by the observer's knowledge of an object's characteristic color, and by the state of the individual visual system.

Color Perception and Different Light Sources

Light sources with different spectral distributions can affect color perception. A visit to the supermarket can demonstrate how color perception is manipulated in everyday life. The type of lighting used is based on the results of studies investigating the effects of different light sources on the appearance of fresh beef and chicken. Consumers preferred incandescent light for beef, as the color of beef under this light source appeared to be red, as opposed to a less desirable dark brown when seen under the fluorescent and metal halide lights. In contrast, consumers preferred chicken under fluorescent light rather than incandescent or metal halide light.

Color Perception and the Surrounding Environment

The apparent color of an object can also be affected by the surroundings. For example, the two circles in **Figure 2.** are the same color, but they look different when they are seen against the two surrounds. This effect is called color contrast.

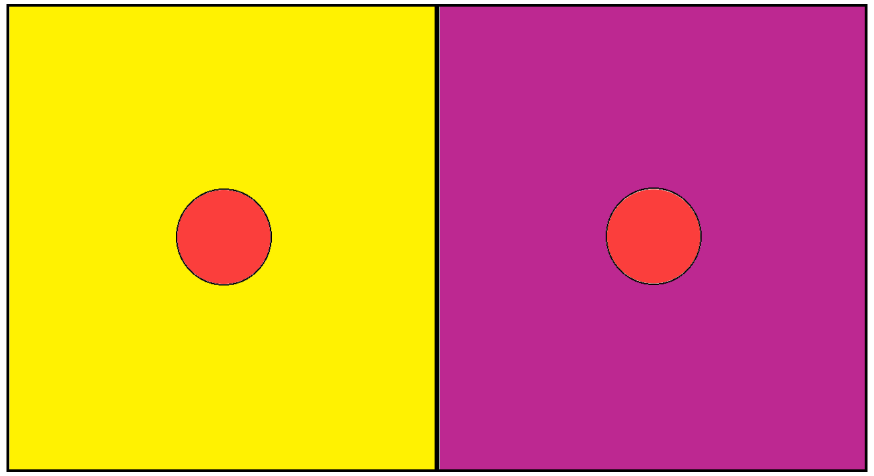


Figure 2. Examples of the effects of surroundings on the color of an object.

Color Perception and Aging

Color vision changes with age. The ability to discriminate between different colors diminishes in older individuals. The mechanisms underlying these age-related changes are not fully understood. However, it is known that changes in the refractive media of the eye (the pre-receptoral mechanisms) contribute to a reduction in short wavelength light (or “blue” light) on the retina.

For example, there are age-related changes in the lens and in the diameter of the pupil. The lens becomes more yellow with age, acting like a yellow filter and decreasing the amount of short wavelength light that reaches the retina. The yellow or brownish lens absorbs short-wavelength light and produces a blue-yellow color vision deficit. The effect of the progressive yellowing of the lens on color vision is exaggerated by the decrease in pupil diameter (senile miosis) that also occurs with age. Color vision can be improved in the elderly by using a higher illuminance level.

Color Perception and Color Vision Defects

When color vision is defective, the three attributes of color vision (hue, brightness and saturation) will be defective in varying degrees. There are two main groups of color vision defects: congenital and acquired.

Congenital Color Vision Defects

Congenital color vision defects occur in approximately 8% of all males and about 0.5% of females. They are relatively easy to classify, are constant, and present with no observable pathology. Both eyes are equally affected. The color-blind individual is often unaware of the color defect and is usually able to name object colors correctly. Typically, congenital color-vision defects are red-green, with an X-linked recessive mode of inheritance.

Acquired Color Vision Defects

Acquired color vision defects develop secondary to diseases of the visual system or toxicity. They are less clear-cut, may progress with time, are often associated with observable pathology, and the two eyes are usually involved to different degrees. Males and females are equally affected. The individual with an acquired color vision defect tends to have reduced visual acuity and/or visual field loss, and names object colors incorrectly.

How Are Color Vision Defects Classified?

The traditional classification of color vision defects is based on the observer’s color-matching performance. An observer who needs three primary colors to match an arbitrary spectral color is defined as a trichomat. An observer who needs only two primaries for a match is defined as a dichromat. An observer who needs only one primary for a match is a monochromat.

There are three types of dichromats. An observer with a color vision defect related primarily to a loss of the LWS pigment has a protanopic defect. The missing photopigment is replaced with MWS pigment. An observer with a color vision defect related to a loss of MWS pigment has a deuteranopic defect. The missing photopigment is replaced with LWS pigment. An observer with a defect related primarily to a loss of the SWS pigment has a tritanopic defect. Dichromatic defects are relatively rare. It is far more common to find individuals who need three primary colors in anomalous proportions to make a color match. They are called anomalous trichromats.

There are three types of “color weak”observers: protanomalous, deuteranomalous and tritanomalous trichromats. Congenital tritanomalous defects are very rare. Anomalous trichromats have all three photopigments, but the peak absorption spectrum of one of the photopigments is displaced. The MWS pigment is shifted towards longer wavelengths for the deuteranomalous trichromat, whereas the LWS pigment is shifted towards shorter wavelengths for the protanomalous trichromat.

How Hue Discrimination is Affected for Protan and Deutan Observers

Both protan- and deutan-observers show a discrimination loss along the red-green axis. Protanopes and deuteranopes are essentially monochromatic for wavelengths greater than 530 nm. Greens, yellows, oranges and reds are indistinguishable. Protanomalous and deuteranomalous observers may have wavelength discrimination close to that of dichromats (severe anomaly) or discrimination may be close to normal. Although both protan and deutan subjects confuse reds and greens with yellow, the reds appear darker for protanopes and protanomals.

Types of Acquired Color Vision Defects

There is an old clinical rule, often disobeyed, which states that outer retinal diseases result in blue-yellow (tritan) defects, while diseases affecting the inner retina and optic nerve result in red-green defects (protan or deutan). It is now known that diseases affecting the outer retinal layers can result in red-green defects and diseases affecting the inner retina and optic nerve often result in blue-yellow defects, particularly during the early stages of the disease process.

Clinical Tests for Color Vision Defects

The majority of color vision tests are designed to identify abnormalities in chromatic discrimination and in color matching. As acquired defects are not symmetrical, color vision must be assessed in each eye. Two types of screening tests are routinely used: the pseudoisochromatic plate tests and arrangement tests.

Pseudoisochromatic Plate Tests (designed to be used with a standard illuminant C lamp)

Plate tests are designed to screen for congenital red-green (protan or deutan) color vision defects. The choice of colors takes advantage of the particular discrimination losses seen in congenital color vision defects. An example of a pseudoisochromatic plate from the Ishihara test is shown in **Figure 3.** Subjects with normal color vision can easily see the number on the background. The Ishihara test is an efficient screening test for protan or deutan defects, but it cannot be used to determine if an observer is a dichromat or an anomalous trichromat.

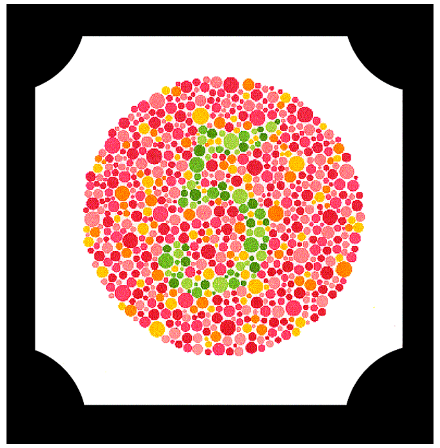


Figure 3.
Example of an Ishihara pseudoisochromatic plate. In this plate, the individual with normal color vision sees the number 5. The majority of individuals with color vision defects cannot see the number.

Arrangement Tests (also designed to be used with a standard illuminant C lamp)

Arrangement tests assess hue discrimination ability. The observer is required to arrange a set of colored samples according to their similarity. Observers with congenital color vision defects make characteristic errors; discrimination loss in acquired defects is more variable. One screening test designed for subjects with moderate or severe color discrimination loss is the Farnsworth D-15 test. The test and an example of a score sheet used to record the results are shown in **Figure 4.**

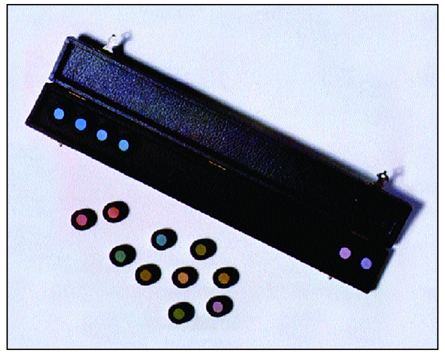
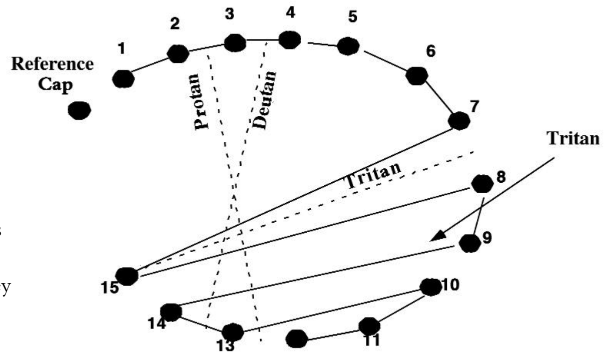


Figure 4.
Farnsworth D-15 Color Vision Test.



The D-15 test is scored by connecting the cap numbers in the order chosen by the subject. Cross-overs indicate a color vision deficiency, they occur along and/or parallel to the protan, deutan or tritan axes.

The Farnsworth D-15 test can be used to screen for both red-green and blue-yellow defects. It consists of 15 color samples. The color differences between the color samples are large so that errors across the color circle are possible. The test evaluates color confusions.

Another arrangement test that is useful for classifying the type and extent of a color vision defect is the Farnsworth-Munsell 100-hue test. It consists of 85 color samples and is a hue discrimination test.

Is There Any Treatment for Color-Vision Defects?

Congenital color-vision defects are constant throughout life. These defects cannot be cured, but it is possible to improve discrimination of some colors for protan and deutan subjects with the use of a red filter (the X-Chrom lens, a red-tinted contact lens). Red and green objects appear equally bright to the naked eye, but when viewed through a red filter red objects appear brighter and green objects appear darker. The lens is prescribed monocularly, but the decrease in light can produce stereo anomalies.

Some acquired color-vision defects can be effectively treated. Perhaps the simplest example occurs in patients with nuclear sclerotic cataracts, where the yellow filter effect of the cataractous lens is eliminated after successful lensectomy. Another interesting example of a reversible acquired color vision abnormality is the “yellowing” of vision reported in some cases of digitalis toxicity. This typically regresses when the drug is stopped.

The Use of Specific Tints to Improve Visual Function

A variety of specific lens tints have been suggested to improve vision or enhance visual function in normal and diseased eyes. Reports of their uses are largely anecdotal, based on personal observations by patients or practitioners, and not necessarily supported by scientific evidence.

Specific Tints in Diseased Eyes

Certain tints have been recommended for specific ocular diseases. These include yellow tints to increase the apparent brightness of objects or their surroundings in optic nerve disease secondary to glaucoma or optic neuropathy; orange, yellow-orange, or plum tinted lenses for outdoor viewing in macular degeneration; and red tints to improve contrast in retinitis pigmentosa.

A sizable body of research has been conducted to evaluate the use of colored filters and contact lenses by dichromats to assist in their perception of colored objects. Green, or its cousin G-15, shifts the color vision of the normal observer towards protanomaly. The deuteranomalous individual is shifted towards normal by this tint; however, the protanomalous color defective is shifted away from normal. Care must be taken in recommending green lenses to deuteranomalous color defectives to assist in color discrimination, as the loss of brightness in a red traffic light may prove more detrimental than the gain in intensity in a green traffic light.

Red is generally a very uncomfortable color to look through.

Brown lenses shift the color vision of the normal observer toward deuteranomaly. Since they shift the protanomalous individual toward normal, they provide a definite benefit when traffic lights are observed by these color defectives.

Specific Tints in Normal Eyes

Yellow tints act as blue blockers. Yellow is often the color of choice for target shooters, because it reportedly decreases haze and makes objects appear sharper, increasing contrast.

Whether blue light is harmful to the eye is still the subject of some controversy. Research sponsored by the U.S. Army Environmental Hygiene Agency indicated that blue-light hazard does play a role in the occurrence of lesions developing as a result of observing a solar eclipse without ocular protection, but, under normal situations, sunlight does not create a blue hazard. Lenses that block blue light are usually amber and make the surroundings appear yellow or orange. This tint supposedly makes distant objects appear more distinct, particularly in snow or haze. For this reason, amber sunglasses are popular among skiers, boaters and pilots.

In the ANSI X80.3-1986 and ISO 1889-3 1999 standards for ophthalmic non-prescription lenses, color requirements are based on the recognition of traffic signals. The finding that all colored lenses alter the color vision of military pilots to such an extent as to hamper the recognition of color signals was a major consideration in the selection of neutral gray as the tint of choice by the U.S. Military.

Selecting Spectacle Tints

The choice to wear tinted vs. clear spectacle lenses may be based on a number of perceived benefits, including enhancement of visual performance, heightened color perception, light or glare reduction, and/or cosmesis. There are also a variety of misconceptions and even frank myths that may guide tint selection. Looking at a tint is not necessarily the same as seeing through it.

Blue	478
Grey	550
Green	572
Yellow	575
Brown	578
Orange	584
Red	602
Purple	Non-spectral
Pink	Non-spectral

Table 1.
Peak Wavelengths.

In a study of aesthetic preferences, groups of individuals with normal vision and others with mild-to-moderate cataracts were first asked to select a fixed tint based on how much they liked how that tint looked when placed over white and flesh-colored backgrounds. Gray, brown, yellow, green, purple, red, orange, and blue tints at 50% transmittance levels were tested. **Table 1.** For the normal group, blue was the most preferred tint, followed by green, purple, and gray. Least preferred were yellow, brown, and pink. For the cataract group, blue was again the first choice and brown the last, in order of decreasing preference.

These same test subjects were then asked to wear the various tints (gray, brown, yellow, green, purple, and blue at 50% transmittance levels) and compare them with a clear lens as they viewed a series of art works and nature photographs. **Figures 5. and 6.** show the dominant wavelengths for each test picture (measured using a

Figure 5. Paintings with dominant wavelengths.

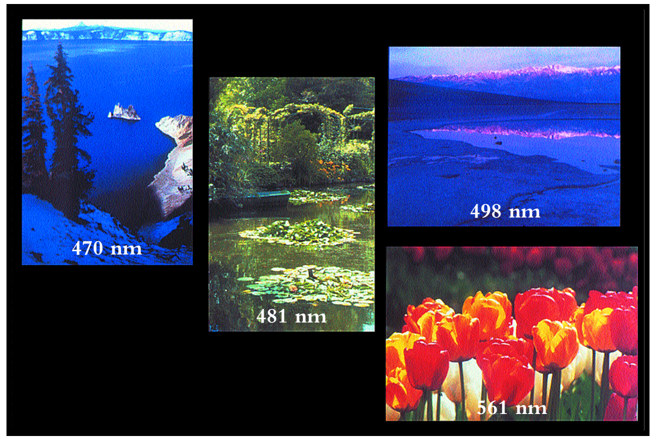


Figure 6. Photographs with dominant wavelengths.

Figure 7. The chromaticity of paintings with dominant wavelengths.

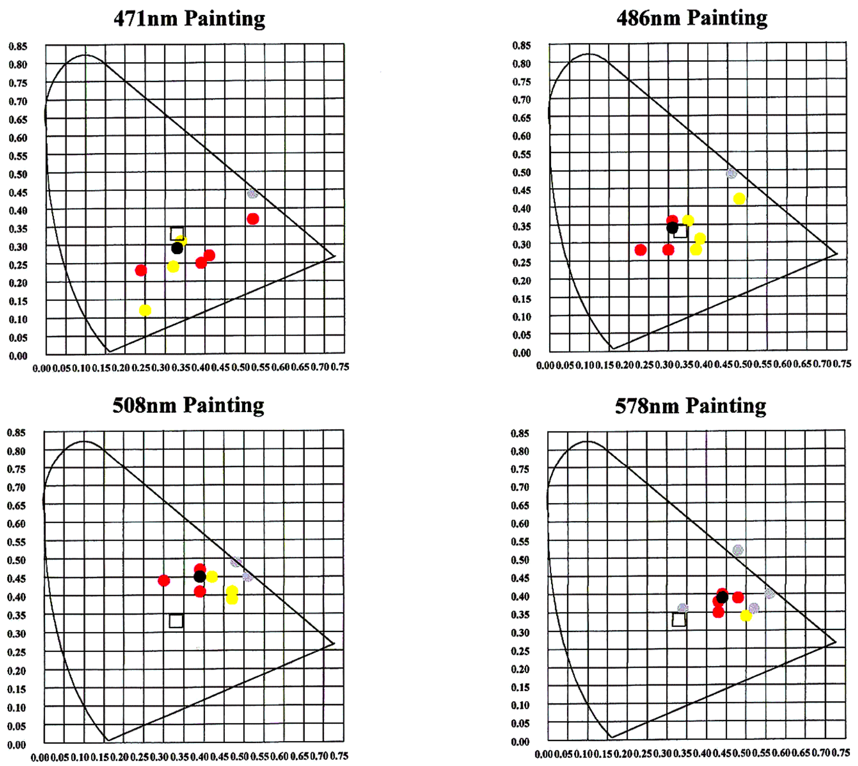
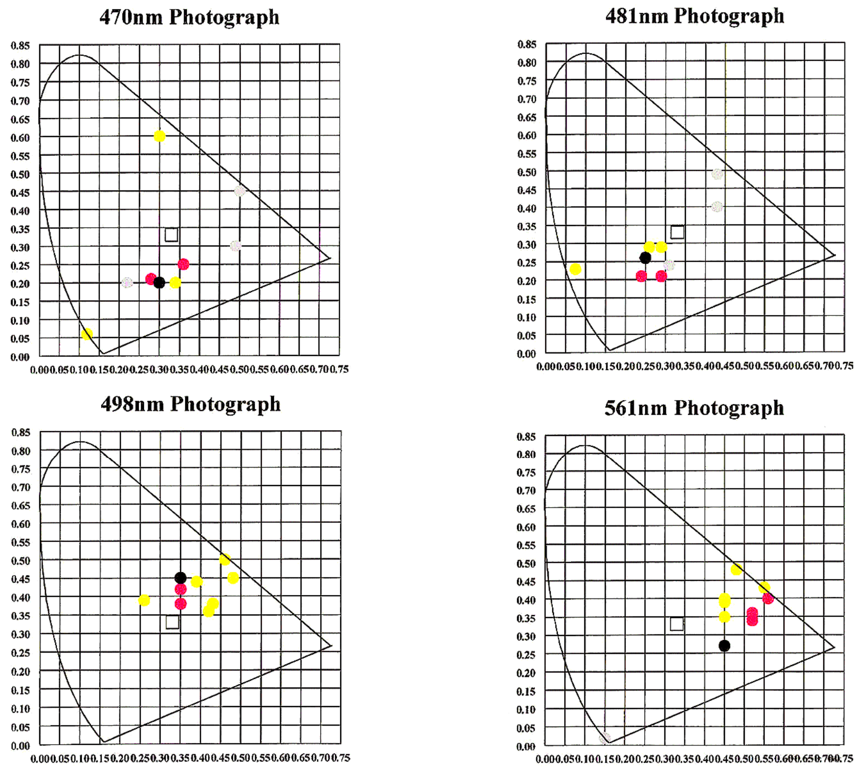


Figure 8. The chromaticity of photographs with dominant wavelengths.



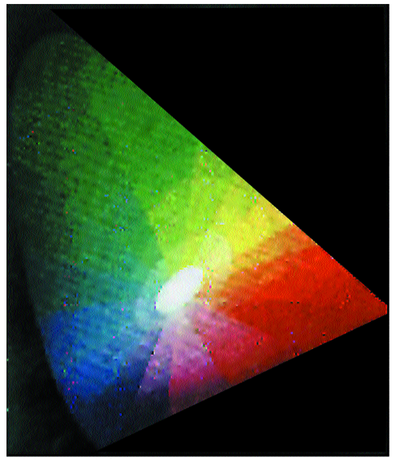


Figure 9. C.I.E.1931 chromaticity diagram.

Pritchard 1908B scanning spectral radiometer). The chromaticity of each of the pictures through the clear and through each of the tinted lenses was obtained. In **Figures 7. and 8.**, the x-y coordinates for each picture through each lens were then plotted on the C.I.E. 1931 chromaticity diagram. **Figure 9.** The rank of each tinted lens was then plotted against the absolute distance between the chromaticity coordinates of the picture through the clear lens and through the specific tinted test lens. In general, the further the lens shifted the chromaticity coordinates, the less it was preferred for viewing. In other words, the less the specific fixed tint changed the color of the test picture, the higher it was ranked by the observer. Overall the clear or the purple lenses were preferred. Of interest was the finding that in neither test group were the same lens tints preferred for looking at versus seeing through.

Glare-related increases in contrast thresholds for the two test groups using the various tints (gray, brown, yellow, green, purple, and blue at 50% transmittance levels) were also evaluated. In the normal eyes, the least glare-induced increase in contrast thresholds was found when viewing through the purple or blue lenses. For cataractous eyes, contrast thresholds under glare conditions were least impaired when viewing through the brown lens.

Conclusions

Tints are a category of filter that may prove useful in moderating the effects of excessive light and decreasing glare, but they also serve to alter color perception. This alteration may be for the better or for the worse, as regards visual function and color vision.

Specialized tints may be beneficial for certain individuals under specific circumstances to improve vision and promote visual comfort, but wearers must be warned that these tints do not necessarily function as effective and safe sunglasses or general purpose eyewear. Since photochromic lenses are available in a variety of tints, with changes in both the depth of color and the level of transmittance depending upon illumination, they would appear to offer a superior alternative to fixed tint lenses in providing a specific, on-demand, color filtering effect when this is indicated, while minimally affecting color values under circumstances where true-to-life color perception is desirable.

CHAPTER 3.

WHEN 20/20 IS NOT ENOUGH: CONTRAST SENSITIVITY AND GLARE ACUITY

People wear spectacles to see better. “Better,” however, can mean different things to different people under different circumstances. The standard way to determine better is through Snellen visual acuity. Here 20/20 is the benchmark. In fact, the term 20/20 is so pervasive that it has become a colloquial phrase.

Although 20/20 acuity suggests “normal” vision, it is purely a quantitative measure of visual acuity determined under controlled conditions. It says nothing about the quality of vision and does not address the issue of visual function in the real world. It does not convey any information about compromises in visual field, loss of retinal elements, color vision deficiencies or decreased contrast sensitivity. Each of these alone, or in combination, may affect visual function to a greater or lesser extent, while not altering Snellen chart acuity.

Since spectacle lens filters (and tints) may modify the quantity and quality of vision in a variety of ways, a more truth-to-real-life measurement of visual acuity is important in determining the effects of these filters. Contrast sensitivity acuity is a good way to assess real vision in the real world, because the real world is not black and white. Contrast sensitivity measures the various shades of gray.

Spatial Resolution

What is visual acuity?

An acuity of 20/20 denotes the ability to recognize letters that are approximately 0.35 inches tall and wide from a distance of 20 feet. For acuities less than 20/20, the denominator refers to the equivalent distance at which a normally sighted observer can identify the letters. For example, the observer with a visual acuity of 20/200 has to be at 20 feet to identify the same letter size that a “normal” can identify at 200 feet. The establishment of 20/20 as normal is somewhat arbitrary, since many individuals have acuity that is actually better than 20/20 and others might have acuity slightly less than 20/20 and still have normal eyes.

Measuring letter acuity is an indirect way of assessing the spatial resolution capacity of the central retina. In psychophysical work, spatial frequency is measured in units of visual field space. For example, how much information (in terms of the spatial distribution of luminance) is imaged in one degree of visual space? In visual psychophysical measures of spatial resolution, grating stimuli are usually presented in order to standardize the amount of information. A grating consists of spatially repeating light and dark bars. One cycle of a grating consists of one light and one dark bar, and when each bar has a width of 30 minutes of arc (minarc), the grating has a spatial frequency of one cycle per degree (cpd). In an experimental procedure typically performed in the laboratory to measure the limits of spatial resolution, gratings of increasing spatial frequency are shown to a subject until he or she can no longer resolve the light and dark bars. In healthy young observers, the foveal resolution limit for a high contrast grating is about 60 cpd, which is equivalent to bar widths of one-half of a minarc each.

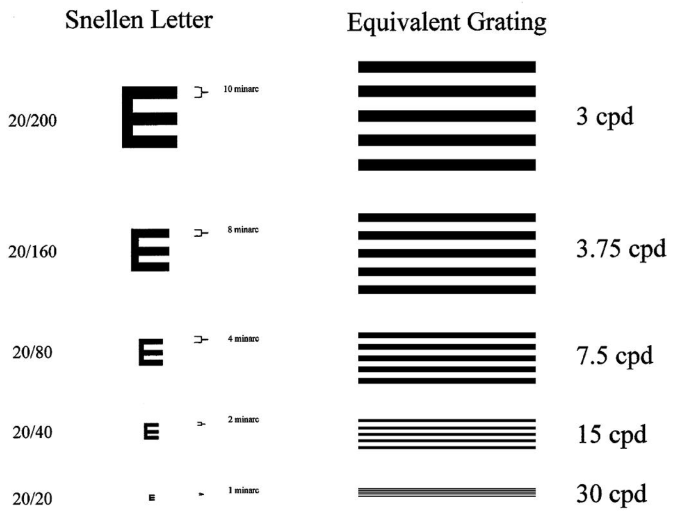


Figure 1. The relationship between spatial frequency in cpd and letter size.

In the clinic the resolution capacity of the fovea is measured indirectly by presenting letter optotypes of decreasing size. The theory behind letter acuity is directly related to the resolution capacity as measured with gratings. The relationship between spatial frequency in cpd and letter size is demonstrated in **Figure 1.** For example, an acuity chart “E” of 20/200 size subtends an overall size of 50 minarc on the retina. In this example the width of each dark and light stroke is 10 minarc. This letter size is equivalent to a grating whose bar widths are 10 minarc each, and therefore has a spatial frequency of 3 cycles per degree. For a letter size of 20/20, the equivalent letter stroke width is 1 minarc. Acuity of 20/20 denotes that dark letter strokes of 1 minarc in width separated by light gaps of 1 minarc (equivalent to 30 cpd grating) can be resolved.

Anatomical considerations

The spatial resolution of the eye depends on the density of photoreceptors, neural elements, and their interconnections in the area of the retina underlying the stimulus. The density of cone photoreceptors is highest in the foveola (i.e., the central one degree of the retina). These central cones also have unique connections to higher order neurons, connecting to one or perhaps two ganglion cells per cone, so that spatial representations are preserved. Helmholtz postulated that the maximum spatial resolution capacity of the retina would require at least one row of cones underlying the dark bar of a grating and one row underlying the light bar. This is depicted in

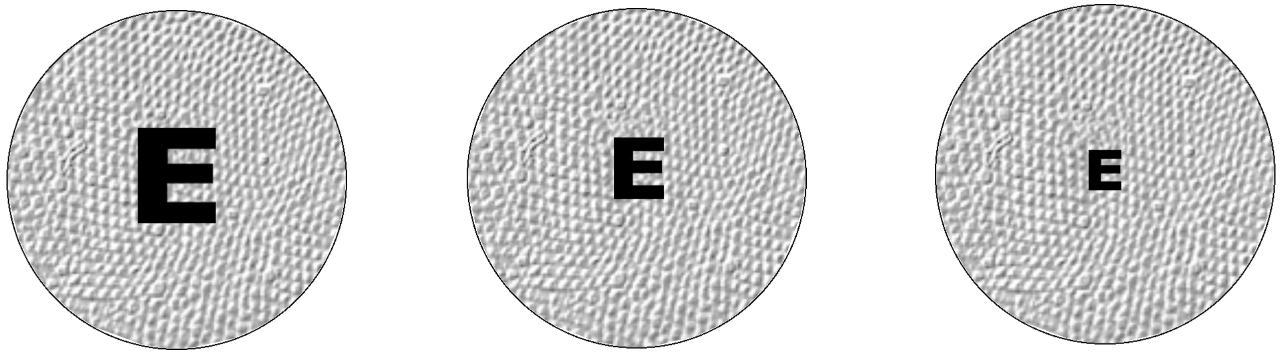


Figure 2A. Figure 2B. Figure 2C.

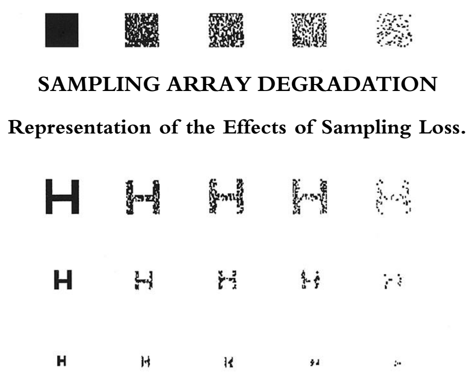
Figure 2 (A,B,C). The background of these figures is a photomicrograph of the foveal cones in a human retina. Overlaid on the cone sampling array is a letter. In **Figure 2A.**, the letter is large (within the resolution capacity of the retina). In this case, the coding of the top horizontal stroke of the "E" is coded by at least two rows of cone photoreceptors. Likewise, the space between the horizontal strokes of the "E" is coded by at least two rows of cones. Because separate rows code dark and light areas, the brain can interpret this as the letter "E." In **Figure 2B.**, the horizontal strokes of the "E" are coded by only one row each and this represents the smallest resolvable letter size. In **Figure 2C.**, the dark and light strokes of the letter fall within the aperture width of single photoreceptors. Therefore, no information concerning the spatial pattern of light and dark areas can be transmitted and the letters of this size fall beyond the resolution limit of this cone sampling array.

Pre-retinal Effects on Acuity

Measurement of letter acuity is very sensitive to pre-retinal effects. Any perturbation in the optical pathway will cause a degradation of the stimulus on the retina. An obvious example of this is an abnormal refractive pathway. If a visual target is not focused at the level of the retina, then the spatial distribution of the target's elements will be spread across a larger retinal area than normal. In the examples given in the previous sections, this would mean that larger than normal letters would be required to ensure that light and dark areas of each letter are coded by separate rows of cones.

Outer Retinal Disease and Acuity

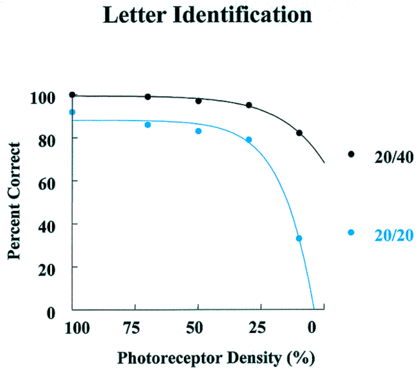
Acuity is commonly employed to track progression of heredoretinal diseases. The assumption underlying the use of letter acuity in these patients is that as photoreceptors are lost, the spatial resolution capacity of the fovea decreases. The relationship between photoreceptor disease and acuity holds in diseases whose effects are photoreceptor death in a large number of contiguous cells. However, if the disease causes death of randomly located isolated photoreceptors, there may be little relationship between the number of remaining photoreceptors and letter acuity. This is due to the redundant information contained in letters and the constructive nature of visual perception. In **Figure 3.**, there is a demonstration of the effects of random loss of sampling elements on the ability to recognize letters. The top row represents the sampling array (in the case of the retina this would represent the density and distribution of cones). From left to right, the effects of random cone loss (from 0% loss to 90% loss) are modeled on the distribution of sampling elements in the hypothetical sampling array. The bottom of the figure shows the effects of these sampling losses on the appearance of letters of various sizes. It can be clearly seen that large letters can be recognized with as few as 10% of the sampling elements intact. More importantly, even the smaller letters can still be recognized with substantial loss of sampling elements. In experiments, 20/20 size letters could be correctly identified 80% of the


SAMPLING ARRAY DEGRADATION

Representation of the Effects of Sampling Loss.

Figure 3.

time with only 25% of the sampling array intact. (**Figure 4.**) This suggests that in a disease with a spatially random loss of photoreceptors, the relationship between letter acuity and disease progression is not linear and perhaps other measures might be better assays of disease effects.

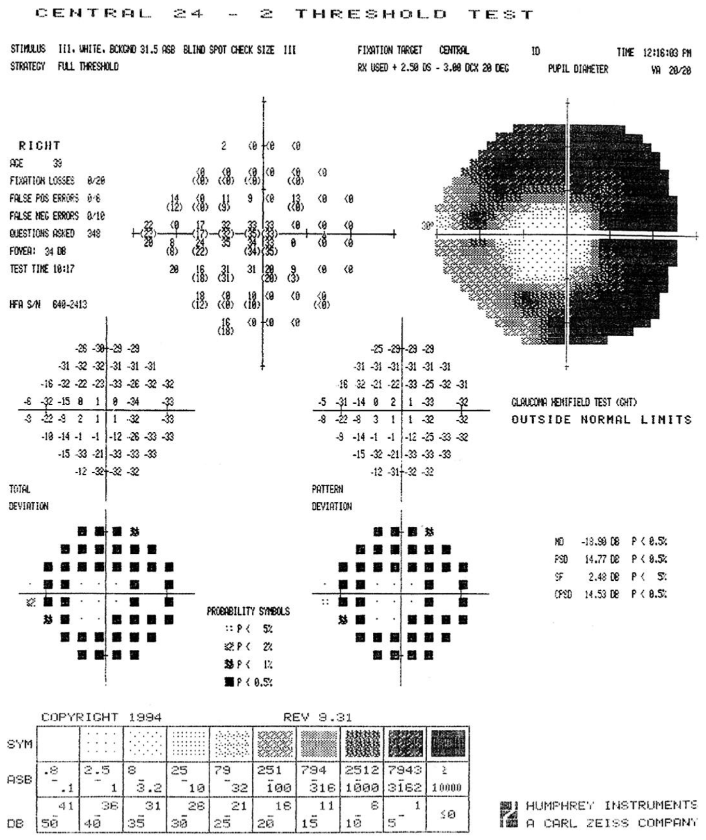


Seiple, Holopigian, Szlyk & Greenstein
Vision Research, 35:2057-2066.

Figure 4.

Visual Field Losses and Acuity

Many diseases have profound effects on vision while sparing acuity. For example, **Figure 5.** shows the Humphrey visual field of a patient with retinitis pigmentosa. This patient's visual acuity was 20/20 in both eyes and his visual field profile is shown on the top right of this figure. Areas with normal sensitivity are shown in white, and areas with reduced sensitivity are plotted as a gray scale, the darker the point the more abnormal the sensitivity. As can be seen, this patient's visual field was severely constricted and only approximately the central 10 degrees had normal sensitivity. A pictorial representation of the visual world as seen by this patient is presented in **Figure 6.** On the left is a view of a sports scene by a person with good acuity and full visual fields. On the right is a pictorial representation of this same scene, as this patient might see it. Notice that although the central details are perceived normally, most of the information in the peripheral visual field is not seen. That is, although acuity is "normal," this patient's view of the world is far from normal.



CENTRAL 24 - 2 THRESHOLD TEST

STIMULUS III, WHITE, BCKGND 31.5 ASB BLIND SPOT CHECK SIZE III
STRATEGY FULL THRESHOLD

FIXATION TARGET CENTRAL
RX USED + 2.50 DS - 3.00 DCX 20 DEG
ID
PUPIL DIAMETER
TIME 12:16:03 PM
VA 20/20

RIGHT
AGE 39
FIXATION LOSSES 0/20
FALSE POS ERRORS 0/6
FALSE NEG ERRORS 0/10
QUESTIONS ASKED 348
FOVEA: 34 DB
TEST TIME 10:17

HFA S/N 640-2413

GLAUCOMA HEMIFIELD TEST (GHT)
OUTSIDE NORMAL LIMITS

TOTAL DEVIATION

PATTERN DEVIATION

MD -18.90 DB P < 0.5%
PSD 14.77 DB P < 0.5%
SF 2.48 DB P < 5%
CPSD 14.53 DB P < 0.5%

PROBABILITY SYMBOLS
:: P < 5%
▨ P < 2%
▩ P < 1%
■ P < 0.5%

COPYRIGHT 1994 REV 9.31

SYM										
ASB	.8 .1	2.5 1	8 3.2	25 10	79 32	251 100	794 316	2512 1000	7943 3162	≥ 10000
DB	41 50	36 40	31 35	26 30	21 25	16 20	11 15	6 10	1 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

Figure 5.

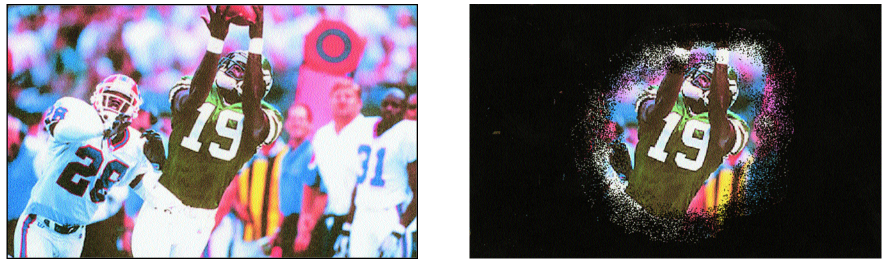


Figure 6.

Contrast Sensitivity and Acuity

As already mentioned, measurement of acuity alone may miss disease-associated losses of retinal structure and/or function. In these cases other measures might be more appropriate. One such measure is contrast sensitivity. Contrast is a measure of the relative distribution of lighter and darker parts of a visual stimulus. It is commonly defined by a formula that relates the magnitude of the difference in light intensity between the dark and light areas to the overall luminance of the stimulus. For grating stimuli, contrast is commonly calculated using the Michaelson formula: (Lmax – Lmin)/Lmax + Lmin), where Lmax is the luminance of the light bars and Lmin is the luminance of the dark bars. **Figure 7.** shows the relationship between calculated contrast and the appearance of the grating. In each set of diagrams, the grating is shown

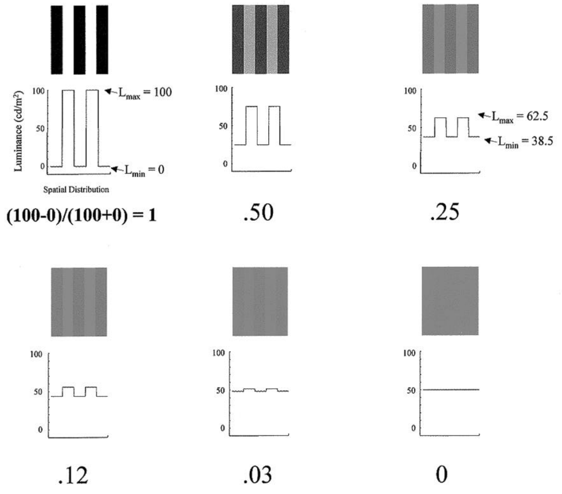


Figure 7.

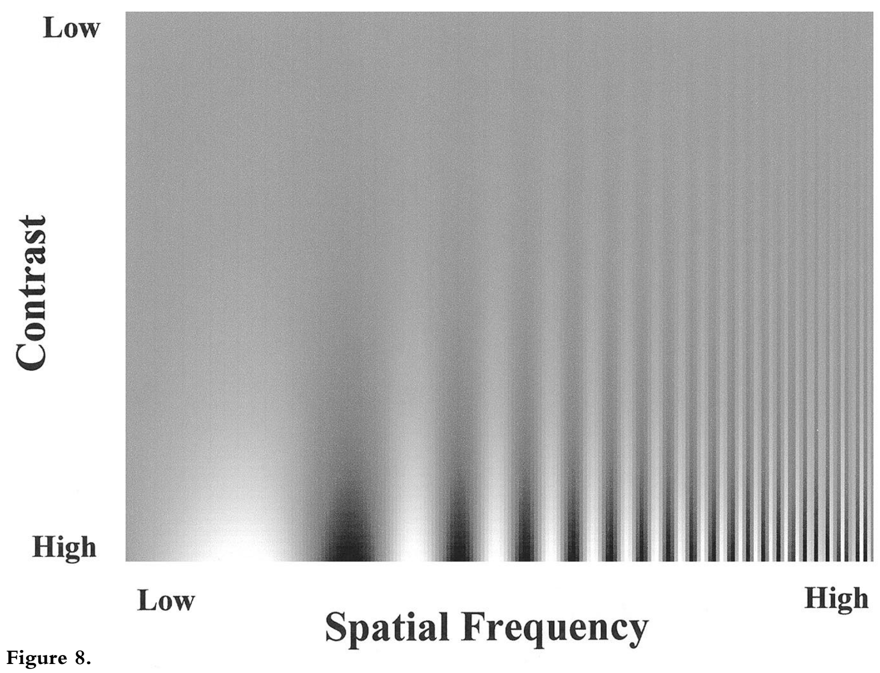


Figure 8.

above and the spatial distribution of luminance for the grating is shown below. For a grating with light bars of 100 cd/m2 and dark bars of 0 cd/m2, the calculated contrast is 1 or 100%. As contrast is reduced the luminance difference in the grating is reduced, and, at some level, the luminance difference is too small to be perceived. This point is the contrast threshold. Contrast thresholds are normally related to spatial frequency by the contrast sensitivity function (CSF). A typical CSF is plotted in **Figure 8.** In this figure spatial frequency increases along the x-axis and contrast decreases along the y-axis. In general, detection of lower spatial frequencies requires less contrast than detection of higher spatial frequencies.

Contrast thresholds are plotted as a function of spatial frequency in **Figure 9.** For a human observer, there is an optimal spatial frequency near 4 cpd where contrast thresholds are lowest. As spatial frequency decreases or increases from this point, contrast thresholds are higher. The highest spatial frequency that can be resolved at 100% contrast is the acuity limit. This function is hypothesized to be mediated by a number of independent frequency channels in the visual system, each with a range of spatial frequencies to which it is sensitive and an associated contrast sensitivity. **Figure 10.** In this model, disease may have an effect on one or more channels independently, and the associated loss in CSF may be spatial frequency-dependent. That is, contrast sensitivity might be lost at low spatial frequencies but not at high spatial frequencies. In this case acuity would be normal and deficits measured only at the appropriate spatial frequency.

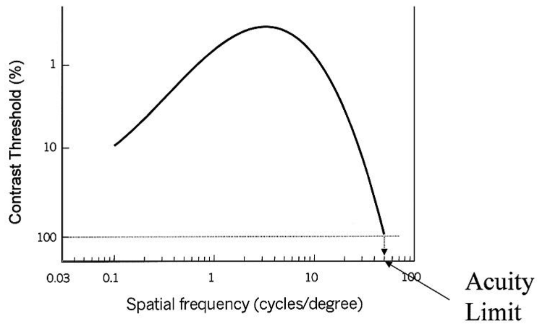


Figure 9.

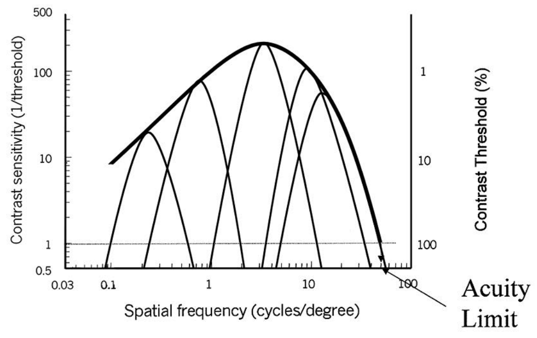


Figure 10.

Clinical Measures of Contrast Sensitivity

Because measurement of the complete CSFs requires elaborate instrumentation and experimental controls, a number of clinically applicable screening tests have been developed to identify patients with subtle contrast deficits that might indicate a subclinical visual disorder. For example, the Peli-Robson charts present letter optotypes at a fundamental spatial frequency of 0.5 cpd. The chart consists of two groups of three letters per row. The contrast of each letter group decreases from 90% at the top of the chart to 0.5% at the bottom. Patients are required to read the letters from top to bottom until two of three letters in a single group are named incorrectly. The authors of this test propose that the measurement of a single (low) spatial frequency letter coupled with a measure of high contrast acuity is sufficient to detect all patterns of CSF loss observed in patients.

A second clinical contrast measure is the Regan low contrast acuity test. This test consists of two charts of letter optotypes. The contrasts of the letters on the charts are 96% and 11%. All of the letters on a single chart have the same contrast and decrease in size from top to bottom. Patients are required to read the letters from top to bottom and the smallest identifiable letter is recorded for each chart. Using a nomogram supplied with the charts, a line is drawn between these two acuity measures. Contrast deficits are indicated if the slope of the line is steeper than normal. One advantage of this test is its relative insensitivity to refractive error, since blur reduces visual acuity equivalently for both high and low contrast.

The Usefulness of Contrast Sensitivity Testing

Contrast sensitivity testing, then, is one method of expanding the amount of visual information that can be obtained from a patient. But why should contrast sensitivity be studied? What additional information does it provide that visual acuity will not?

Why Measure Contrast Sensitivity?

The world is a visually complex place. Objects vary in many dimensions, including size, brightness and contrast. Visual acuity only provides information about high contrast resolution: the smallest, high contrast object that can be seen. Contrast sensitivity helps provide additional information about the visual world. This includes information about the visibility of objects that vary in size, contrast and orientation. Contrast sensitivity can be measured for vertical, horizontal and oblique patterns.

Another reason for measuring contrast sensitivity is that patients may describe changes in vision that are independent of visual acuity. For example, patients may complain of visual problems such as poor contrast resolution. Often these patients will have visual acuity that is within normal limits, so that without further testing it is impossible to determine the nature of the visual complaint. In this case, contrast sensitivity testing is likely to show abnormalities that may aid in diagnosis and treatment.

Contrast sensitivity can be affected by a number of factors. These factors include various parameters related to the viewing conditions, the general characteristics of the viewer, and the ocular health of the viewer. Each of these factors and their effects on contrast sensitivity need to be considered.

Effect of Viewing Conditions

One important factor that determines an individual's contrast sensitivity is the prevailing light level. Under daylight conditions (photopic conditions), contrast sensitivity is optimal and small, medium and large objects can be seen at relatively low contrasts. Under these conditions, the high spatial frequency cut-off approaches the limits of human visual acuity (i.e., Snellen equivalents of 20/20 or better). This is shown by the yellow curve in **Figure 11.**

As the amount of light is decreased to twilight conditions (mesopic conditions), contrast sensitivity is adversely affected. This is shown by the gray curve in **Figure 11.** Sensitivity is reduced (i.e., the curve is shifted downward, indicating that more contrast is needed to view objects) primarily for medium and high spatial frequencies. This means that large objects are not affected by this amount of change in light level, but as objects get smaller, the ability to detect them becomes more compromised. Finally, as the light level gets even dimmer (scotopic conditions), the ability to see even large objects becomes poorer. This is shown by the black curve in **Figure 11.** Note that the peak sensitivity (the highest point of the function) shifts to lower spatial frequencies with decreasing luminance and that many objects which would be visible under photopic conditions would no longer be visible under scotopic conditions.

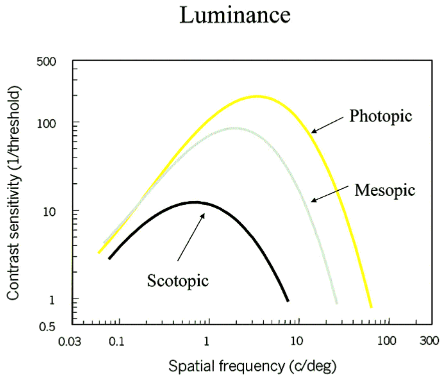


Figure 11.

Contrast sensitivity is best when the patterns are viewed with the fovea;sensitivity decreases linearly with peripheral viewing. Sensitivity for all size patterns is poorer in the periphery. The decrease in sensitivity with eccentricity has a steep fall-off. For patterns that are viewed at 5° eccentricity, there is almost a one log-unit loss in sensitivity (i.e. sensitivity is reduced by nearly a factor of 10). As expected, blur has an effect on contrast sensitivity, primarily for higher spatial frequency patterns.

Characteristics of the Viewer

Another important factor for contrast sensitivity is the age of the viewer. The ability to detect objects decreases as a function of age, as shown in **Figure 12.** The black curve shows the contrast sensitivity function for younger subjects (20 to 30 years). With age, the ability to see higher spatial frequencies (smaller objects) gets poorer. Contrast sensitivity is reduced for subjects in the 50 to 60 age range (shown by the red curve). Sensitivity is reduced even further with age as shown by the results for the patients in the 80 to 90 age range (see purple curve). What causes this decrease in sensitivity with age? There are two main factors that generally are to blame for reduced performance with age: changes in the optical properties of the eye and reduced neural factors. As shown by the blue curve, a large portion of the loss in contrast sensitivity is due to changes in the optical properties (i.e., media opacities and pupil size) of the eye. When the optical factors are bypassed during testing, contrast sensitivity is greatly improved and becomes better than that of the fifty year old group.

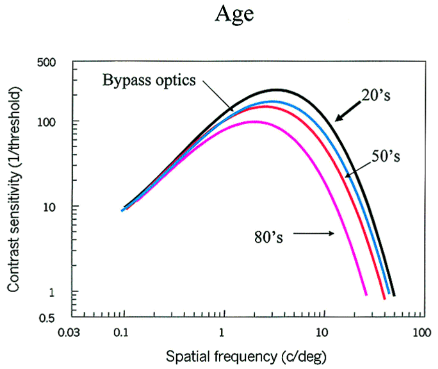


Figure 12.

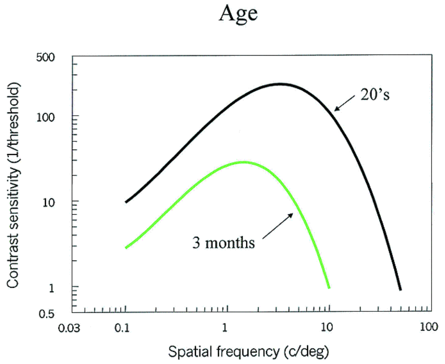


Figure 13.

Just as contrast sensitivity decreases with age, it also develops with age. A newborn has very poor contrast sensitivity. As the visual system matures, contrast sensitivity improves. As shown in **Figure 13.**, the contrast sensitivity function of a three-month-old is poor relative to adults. What is interesting about this curve is that infants are poorer at detecting low contrast objects of all sizes – not just small objects. In fact, any low contrast object is difficult for an infant to see.

Effects of Disease

Perhaps the most important determinant of contrast sensitivity is the health of the eye. Numerous ocular and systemic diseases affect the contrast sensitivity function. Different diseases affect the contrast sensitivity function in different ways: Some diseases affect high spatial frequencies, whereas other diseases affect intermediate spatial frequencies, and still others selectively affect lower spatial frequencies.

The most common change in the contrast sensitivity function is a loss in high spatial frequencies. This can be caused by a number of ocular problems, including changes in the optical quality of the eye with such conditions as corneal edema, refractive error and mild cataracts. Non-optical factors that reduce contrast sensitivity primarily for higher spatial frequency patterns include mild amblyopia and macular diseases. Patients with open-angle glaucoma and moderate field losses may also exhibit high spatial frequency losses. Likewise, patients with relatively mild retinitis pigmentosa may also have high spatial frequency losses. This type of vision loss in depicted in **Figure 14.**

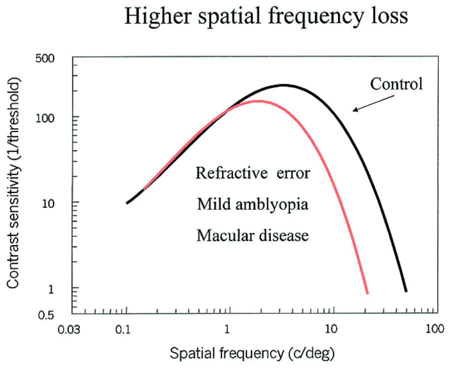


Figure 14.

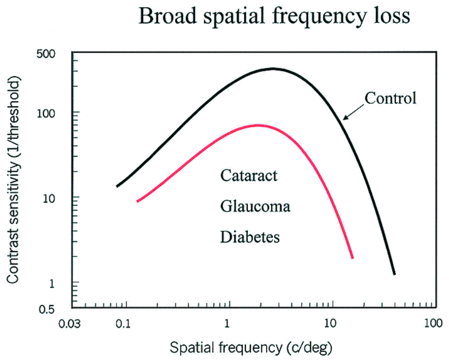


Figure 15.

Some diseases produce losses at a range of spatial frequencies, or a broad spatial frequency loss. This pattern of loss in shown in **Figure 15.** and can be caused by diabetes and certain types of cataracts. Patients with open-angle glaucoma with widespread field losses also fall into this category. Patients with moderate and severe amounts of amblyopia may also exhibit this pattern of loss. In many patients with a variety of diseases, high spatial frequency contrast sensitivity losses may progress to become broad spatial frequency losses.

The final pattern of contrast sensitivity loss is selective for lower spatial frequencies. This is shown in **Figure 16.** This type of contrast sensitivity loss is most often seen in patients with diseases of the optic nerve, such as optic neuritis. These contrast sensitivity losses can remain after the optic neuritis has resolved and may appear in the fellow eye. This type of contrast sensitivity loss is especially important because visual acuity can be normal (20/20 or better), despite complaints of vision problems. This group of patients is the most likely to be missed if Snellen visual acuity is used as the sole measure of visual performance.

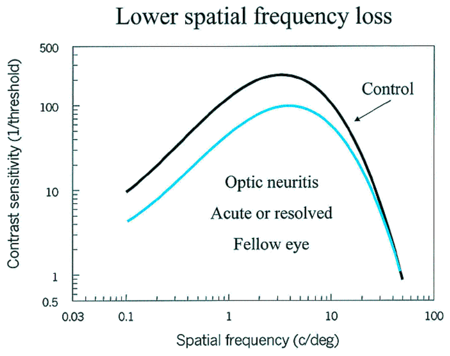


Figure 16.

Conclusions

Contrast sensitivity testing is an important adjunct to visual acuity testing. It may detect losses in visual function that are not detectable with visual acuity testing alone. In addition, contrast sensitivity testing may be able to distinguish between different patterns of disease loss. As such, contrast sensitivity testing may provide vital diagnostic information. In addition, following contrast sensitivity measures over time may provide a useful indicator of prognosis.

Filters and Contrast Sensitivity

Filters, by definition, affect contrast sensitivity. This is important in both normal and abnormal eyes. Measuring changes in contrast sensitivity with filters at various levels of transmittance and with different tints can help determine the optimal balance between environmental conditions (e.g., dim light, glare and bright sunlight), the individual eye, and the filter (tint) in maximizing visual function under circumstances where a simple 20/20 Snellen acuity is simply not enough.

Since photochromic lenses act as filters under circumstances when this filtering action is most beneficial to vision and as clear lenses when filtering is not necessary (or even desirable), they have the least potential for compromising contrast acuity.

CHAPTER 4.

CLEAR, FIXED TINT, AND PHOTOCHROMIC LENSES

Nearly 160 million Americans wear prescription eyeglasses, and about 80 million pairs are purchased annually. The primary indication for prescribing spectacles is to correct refractive errors. But achieving 20/20 vision is not always enough. Visual function and visual comfort go beyond the responses on a Snellen acuity chart and may be the most important criteria for satisfactory vision in the real world.

Light is essential to vision, but too much light can make seeing more difficult. Among the various functions prescription eyewear may serve, in addition to correcting ametropias, glare protection and light modulation rank high.

Throughout history, people have tried various ways to minimize the effects of bright light and glare. The Eskimos, while hunting and fishing, used whalebones with slits to reduce the glare off the ice. The Chinese invented the Tcha Chi, a tea lens with a brown tint.

The modern fixed tint sunglass and the more recently developed photochromic lens serve these functions more effectively. Some discussion of light exposure and the adaptation of the eye to differing light conditions is necessary to understand how and why they work.

Optimal Illuminance

A “lumen” is the unit of measurement of the amount of light incident on a surface. The higher the lumen number, the brighter is the surface. Typical values are shown in **Table 1.**

Indoor, with artificial light	400 lumens
Sunny day, in the shade	1,000 - 1400 lumens (optimum lighting)
Sunny day, on the grass	3,500 lumens (comfort limit)
Concrete highway	6,000 to 8,000 lumens
Beach or ski slopes	10,000 to 12,000 lumens
High altitude snowfield	Over 12,000 lumens

Table 1.
Illuminance of Typical Environments.

Going from indoors under artificial light (400 lumens) to the beach (12,000 lumens) can increase illuminance 30 times. Even walking from the shady side of the street (1000 lumens) to the sunny side (3500) more than triples illuminance. Optimal lighting is in the range of 1000-1400 lumens. Levels above 3500 produce ocular discomfort.

Fixed tint and photochromic lenses reduce higher luminance to more comfortable levels. Neutral gray fixed tint and photochromic lenses absorb the reflected luminance from objects and their backgrounds in the same proportions, ensuring that contrast remains constant. The transmittance of the lens determines the amount of reduction in the illuminance.

Glare

To understand the benefit in reducing glare, it is important to define glare. Glare is the loss in visual performance or visibility, or the annoyance or discomfort, produced by a luminance in the visual field greater than the illuminance to which the eyes are adapted. Glare can come directly from a light source – i.e., facing toward the sun – or be reflected. In the example of the beach, the eyes are being subjected to ten to twelve times as much light as is desirable. When glare reaches these levels, it becomes uncomfortable.

Fixed tint and photochromic lenses help eliminate glare by absorbing or reflecting light. How much light the lens can absorb or reflect depends on the darkness or reflectance of the lens and its coating. The amount of light a lens should absorb depends on how and where it is used. Here photochromic lenses offer a definite benefit over fixed tint lenses: When sunlight illumination is high, photochromic lenses provide lower transmittance, and reduce the excess illumination. Under reduced sunlight illumination, the lenses darken to a lesser extent and do not reduce illumination unnecessarily. Glare tends to affect individuals with lighter eye colors more than those with darker colored eyes for the same reason that lighter skin is more susceptible to burning: There is less pigmentation.

Discomfort Glare

There are two types of glare: (1) discomfort, and (2) disabling (or veiling) glare. Both may result from direct and reflected luminance. Discomfort glare usually starts at about 3,000 lumens and includes luminance levels that result in disabling glare. The response of the unprotected eye to low levels of discomfort glare is a slight squint. Discomfort glare can occur in any weather, including overcast days. Even mild glare causes eye fatigue. Discomfort glare to higher luminance is usually manifested by pupillary constriction, closure of the palpebral aperture, and turning of the head. The cause is not fully understood, but has been related to pupillary activity.

Disabling Glare

To quantify the discomfort caused by glare, a measure called borderline between comfort and discomfort (BCD) is used. The median BCD for ages 20 years to 68 years performing outdoor occupations is 6500 cd/m2 (1900 ft L), compared to 3400 cd/m2 (1000 ft L) for indoor workers. BCD is a function of age: At age 10 years BCD is about 8500 cd/m2. This decreases to about 1700 cd/m2 at age 50. The cause of this loss upon aging is probably due to changes in the ocular media and the neural retina.

When light reaches the intensity of about 10,000 lumens, it actually blocks vision and is referred to as disabling or veiling glare. Disabling glare causes objects to appear to have lower contrast than they would were there no glare. The light that normally contributes to the brightness of the retinal image is instead scattered to adjacent parts of the retina; this lowers the contrast of the retinal image. An important aspect of disabling glare is that a bright source close to the line of sight will cause the most visible glare, and bright sources outside of a 30° angle to the line of sight do not provide a significant glare source. An example of direct disabling glare is looking towards the sun at sunrise or sunset or towards automobile headlights at night.

Reflective disabling glare occurs when light is reflected off a car bumper or windshield on a sunny day. It is so intense that it overwhelms the eye with blinding light, masking what is behind the glare. It can seriously impair vision and create dangerous situations when driving, boating, or skiing. Long-term, it may lead to eye fatigue (asthenopia). It has been demonstrated that two or more glare sources in the field of vision are additive. Furthermore, the retina must re-adapt to resume vision after the bright source is removed from the field of vision.

Disabling glare occurs because the eye is not a perfect optical system. Instead, the inhomogeneities of the optical media obey Rayleigh's law (1/l4) and scatter light across the retina onto the retinal image of the object and reduce retinal luminance contrast. Disabling glare affects the visual system because light scattered in the ocular media reduces visual acuity and the differential light threshold is raised. Research has shown that the total scattered light at the fovea is proportional to the number of scattering particles per unit volume of the ocular media. This is why disabling glare is more problematic after age 40, especially for individuals with cloudy ocular media associated with cataracts.

Anti-Aging and Preservation of Night Vision

A lot is expected from the eyes. During a normal day, the eyes will use about the same amount of energy as the legs would use in walking fifty miles. This and the additional burden of glare may force the eyes to strain to see well. Wearing fixed tint or photochromic lenses can reduce this strain, decrease the impact of harsh glare, and eliminate the need to squint. The appeal of "anti-aging" is an important benefit of fixed tint and photochromic eyewear. Wearing fixed tint sunglasses or photochromic lenses not only keeps the sun from damaging the eyes and the skin around the eyes, it also cuts down on squinting, which helps stave off the development of fine lines and wrinkles around the eyes.

Night vision can be significantly affected by an individual's previous exposure to sunlight during the day. Visual acuity, contrast, and overall sensitivity can be reduced by up to 50%, due to the sun's sustained bleaching of the photochemical rhodopsin in the rods of the retina. The correct fixed tint sunglasses or photochromic lenses during the day can block the appropriate light and protect retinal sensitivity at night.

Exposure of the eye to bright light produces both a temporary and a cumulative effect on the subsequent ability to see at night. Studies have shown that a 2- or 3-hour exposure to sunlight delays the initial phase of dark adaptation as much as 10 minutes and elevates the final level of adaptation 0.5 log unit. After 10 daily exposures, visual acuity and contrast discrimination show a 50% elevated threshold. The visual decrement experienced from excessive sun light exposure usually returns to normal after a 24-hour period of protection against sunlight. Lenses with a luminous transmittance of 12% to 15% have been found to be effective in preventing the loss of night vision, contrast discrimination, and visual acuity.

It is particularly important for persons who engage in tasks where night vision is important – i.e., driving or flying – or in such occupations as a police officer, the military, an astronomer, and harbor/river pilots, to wear fixed tint or photochromic lenses to maintain maximum visual performance on the job. These lenses should have 20% luminous transmittance or less when undertaking activities of two hours or greater duration in bright sunlight. When complaints of poor night vision are reported, the eye care practitioner should remember to assess daytime outdoor exposure and make eye wear recommendations accordingly.

Fixed Tint Lenses

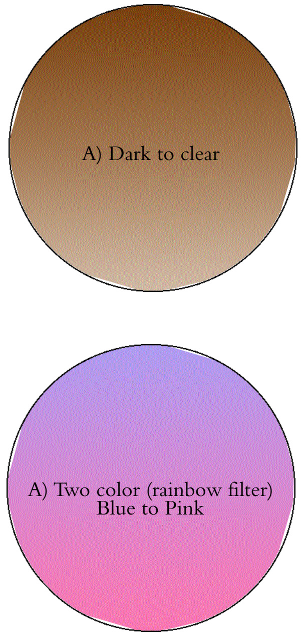


Figure 1.
Gradient lenses.

Fixed tinted lenses are available in plastic as well as glass and can be manufactured in almost any color of the rainbow. Lighter, fashion tints are used primarily for cosmetic purposes to enhance a wearer's looks. Typical colors for fashion tints include pink, purple or brown. Darker tints allow the wearer to use the lenses as sunglasses. The vast majority of lenses used as sunglasses are gray or brown, and sometimes green in color. The tint can be solid (where the entire lens is the same color), or gradient (where the lens is darker near the top of the lens and lighter toward the bottom, or where one color gradually changes to another color across the lens). **Figure 1.** Fixed tint glass lenses are produced by incorporating a colored material into the glass melt when casting the lens, or vapor depositing metal oxides onto the surface of the lens to produce the color. Fixed tint plastic lenses are produced either by vapor depositing metal oxides similar to glass lenses, or by the more ubiquitous technique of dipping the plastic lens into a dye bath and allowing the appropriate amount of time in this bath to produce the amount of color incorporation desired. Withdrawing the lens from the dye bath at the appropriately controlled rate, such that more dye is incorporated into a portion of the lens, produces lenses having a color gradient.

Fixed tint lenses are absorptive lenses that selectively transmit portions of the optical spectrum. A red lens absorbs in the blue region of the spectrum, while continuing to transmit maximally in the red region of the spectrum, resulting in the red color of the lens. Neutral lenses absorb almost equally across the visible spectrum, and, as a result, appear gray in color.

Whether specific colored tints in both fixed tint and photochromic lenses may offer benefits to normally sighted and/or visually impaired individuals in improving visual comfort and function remains a topic of great interest. Experimental support for anecdotal reports is necessary before tint-specific recommendations can be made.

Not all fixed tint lenses provide 100% UV protection. The attenuation of visible light that occurs when a fixed tint lens is worn may dilate the pupil relative to wearing no lens. This may result in more UV actually entering the eye with a fixed tint lens than without it.

Reflecting Lenses

Reflecting lenses (mirror lenses) are manufactured by vacuum or chemical deposition of metallic coating on the lens substrate. Inconel (a mixture of iron, nickel, and cobalt) is commonly used for sunglasses, because of its neutral gray color. Such coatings often are easily scratched, and should have a protective coating overlay.

Polarized Lenses

Polarized lenses are another type of lens that may be used for sunglasses. Ambient sunlight is unpolarized. In unpolarized light, the direction of vibration is random (in all directions). When light is reflected from a surface, it is partially or completely plane polarized, with the plane of polarization of the reflected light perpendicular to the plane of incidence of the light. **Figure 2.** Polarized lenses contain a stretched thin polyvinyl film with iodine and quinine compounds that result in the iodine becoming aligned and preferentially absorbing in one axis. Light incident on smooth surfaces such

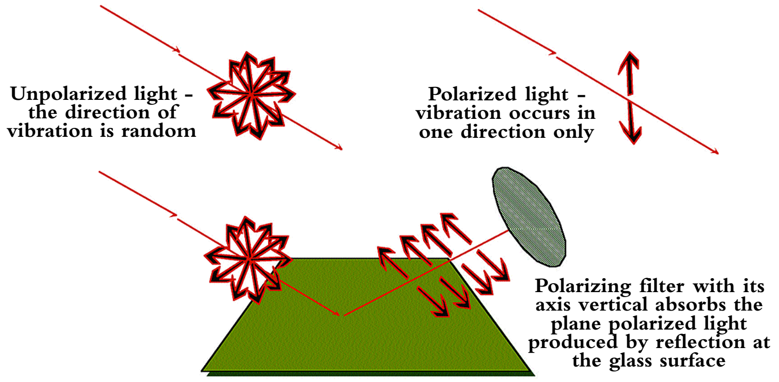


Figure 2.
Effectiveness of a polarizing lens.

as glass, concrete, or water produces polarized reflected light that may be removed by viewing the surface through a polarizing lens oriented with its vibration plane perpendicular to the reflected light. Polarized lenses eliminate reflected glare, enabling the eye to view objects illuminated by polarized light. This minimizes eye fatigue and promotes vision comfort.

Anti-Reflective (AR) Coatings

AR coatings may be applied to clear, fixed tint, or photochromic lenses to minimize the effects of low-intensity glare in the form of “ghost images”. These ghost images result from the reflection of light off the surface of the lens. In clear lenses or in photochromic lenses in their clear state, this can lead to a “mirror” effect, observed by a person looking at the lens wearer. For fixed tint sunglasses or darkened photochromic lenses, because the background illumination is reduced, a reflected image on the backside of the lens from a source behind the wearer may be particularly bothersome to the lens wearer.

AR coatings function by reflecting light. The reflected light from the AR coating destructively interferes with the light being reflected from the lens substrate or underlying layer. The effect minimizes reflections and maximizes transmitted light so that the lens performs as intended. To function properly, the film thickness of the AR coating should be one-fourth of the light’s wavelength – i.e., in the range of 100-190 nm for visible light – and the refractive index of the AR film should be equal to the square root of the underlying lens substrate or the underlying AR film.

Photochromic Lenses

Photochromism is defined as a reversible, light-induced change in color. Through a chemical reaction, a colorless species is changed to a colored species by exposure to ultraviolet radiation. Removing the radiation source will return the colored species back to a colorless species. Sunlight is the typical radiation source. Today, the most advanced technology offers a lens that is both clear indoors and achieves sunglass darkness outside.

Photochromism is a dynamic system where equilibrium between the colorless A and the colored B is established. How dark the material will become is determined by the ratio of B to A at any instant. This ratio is controlled by several factors, including the amount of ultraviolet irradiance, temperature, and rate that B fades to A (specific to the photochromic system chosen and the lens matrix). **Figure 3.** illustrates how UV irradiance shifts the reaction to the right, favoring the colored state; and heat shifts the reaction to the left, favoring the colorless state. This explains why all photochromic systems are less colored as the temperature increases and the equilibrium condition of this reaction is shifted towards the colorless state. However, researchers have made significant strides in reducing the effects of temperature on performance.

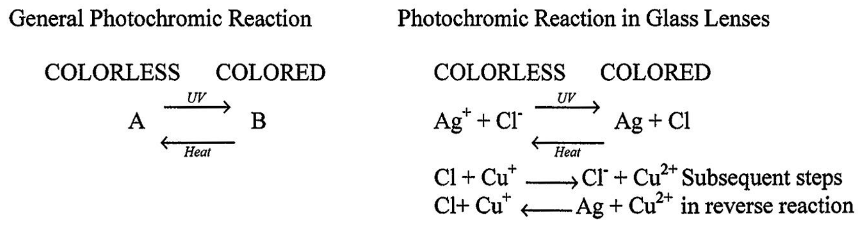


Figure 3.
Photochromic reaction in glass lenses.

Even though photochromic lenses function using UV irradiance, not all photochromic lenses provide 100% UV protection. Glass photochromic lenses normally provide only 90% UV protection, and some plastic photochromic lenses provide less than 100% UV protection. Similar to the situation with fixed tint sunglasses, 100% UV protection is important because the attenuation of visible light may dilate the pupil relative to wearing no lens, resulting in more UV entering the eye with the photochromic lens than without it.

Photochromic Glass Lenses

In photochromic glass lenses, the photochromic reaction is achieved through the UV-induced oxidation of chloride ions to chlorine atoms and the reduction of silver ions to silver atoms. These silver atoms cluster together and block the transmittance of light, causing the lenses to darken. The presence of copper(I) chloride permits the reversibility of the reaction by permitting the copper(+1) atom to react with the chloride atoms, prohibiting their escape from the matrix as gaseous atoms. In the process the copper(+1) ion is oxidized to produce copper(+2) ions, which then react with the silver atoms to complete the reverse reaction, resulting in the lens becoming transparent again upon removal from UV irradiance.

Photochromic Plastic Lenses

Plastic photochromic lenses are a relatively new development. Transitions Optical introduced the first commercially viable plastic lens in the early 1990s. The photochromic reaction in plastic lenses differs from that in glass. Organic compounds such as oxazines, pyrans and fulgides are added to the lens material. These materials absorb strongly in the UV region. When these molecules are exposed to UVR, the molecule undergoes a rearrangement resulting in two or more small chromophores converting to one large chromophore. **Figure 4.** On a molecular level, this large chromophore is capable of absorbing at lower energies or at wavelengths that are in the visible region of the electromagnetic spectrum. Millions of these photochromic molecules undergo this chemical reaction upon exposure to UVR. The photochromic molecules in this large chromophore or "open" state absorb visible light, causing the lens to darken. The open state also absorbs UV as well, or to a greater extent, than in the colorless closed state. When the exciting wavelength is removed, the molecules return to their original orientation and the tint fades, returning to a clear or slightly tinted lens, depending on the technology used. Photochromic compounds are incorporated into a lens by one of two technologies.

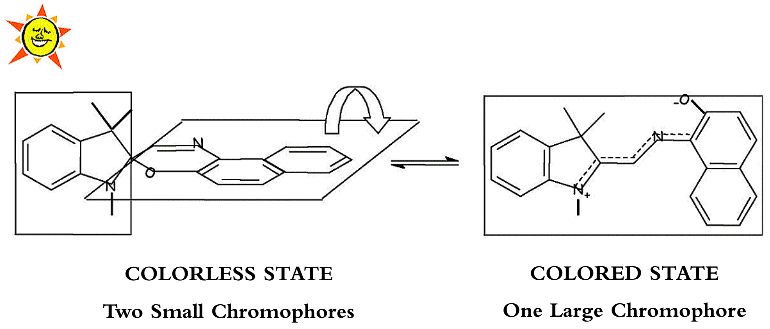


Figure 4.
Photochromic reaction in plastic lenses.

The earlier method consisted of the incorporation of photochromics throughout the lens material or "in-mass." This was first done in the mid-1960s using molten glass containing silver halides. Thirty years later, this technology was adapted for plastic lenses. Here photochromic compounds are mixed into the monomer, then poured into a mold and cured. Limitations of this technology include the possibility of "bull's eye" or "raccoon" effects for high plus or high minus lenses respectively, and the inability to deliver truly clear performance indoors because of the excessive photochromic dye.

Front surface incorporation through Imbibition or Trans-Bonding are proprietary processes developed and commercially introduced by Transitions Optical, Inc. With Imbibition, the photochromic compounds are driven into the surface of the lens. The photochromics are permanently imbedded into the surface to a uniform depth of 150 to 200 microns, about 20 times deeper than an ordinary lab tint. The compounds become part of the lens and cannot be scratched or peeled off. Imbibed lenses have no bull's eye or raccoon effect.

Certain lens materials offer excellent physical characteristics, but function poorly as photochromic host materials because the kinetics of the photochromic reaction are slow in these materials. The Trans-Bonding process made it possible to offer state-of-the-art photochromic technology in desirable lightweight, strong, durable (high-impact) materials like polycarbonate and Trivex™. In Trans-Bonding, a high-impact lens receives proprietary surface treatments and a series of ophthalmic grade layers, which provide excellent adhesion, scratch resistance, and optical purity, along with 100 percent UVR protection and outstanding photochromic performance. Trans-Bonding has made it possible to produce photochromic polycarbonate, an ideal lens material for children.

When comparing the performance of photochromic lenses, the following list of properties should be considered:

- Indoor clarity
- Activation and fade speed
- Outdoor darkness
- Consistent coloration, plus uniform color darkened and faded
- Lens lifetime – continues to darken
- Ability to darken at high temperatures
- UV protection
- Availability in lens designs and materials

Photochromic lenses provide many patient benefits, not the least of which is the convenience of allowing a single pair of lenses to perform well under a wide variety of circumstances. These lenses are clear indoors, semi-dark under cloudy or shaded conditions, and sunglass dark under high illumination conditions. They provide visual comfort by mitigating the illuminance extremes to which the eye is exposed. At the same time, they do not unnecessarily decrease illuminance under conditions where illumination is low, thereby maximizing visual function.

Fixed Tint Sunglass Lenses vs. Photochromic Lenses

Fixed tint lenses offer definite advantages for visual function and visual comfort over clear lenses under conditions of excessive optical illumination. Fixed tints may prove disadvantageous, however, under conditions of reduced optimal illuminance. The benefit of photochromic lenses over fixed tint lenses is that indoors, at night, or on dark days, there is much less or no activating radiation, so that these lenses function as clear lenses. When high illumination conditions are encountered outdoors, these lenses darken to sunglass darkness. This is particularly true with the latest technology lenses offered by Transitions Optical, Inc., with 89% transmittance indoors and 15% transmittance outdoors.

Ideally spectacles lenses should: 1) Modify the solar ambient illuminance for optimum visual comfort and performance (appropriate darkness for the given illumination situation); 2) Eliminate the harmful portion of the optical spectrum that is not required for vision (100% UV protection); 3) Preserve night vision (appropriate darkness for high illumination); 4) Permit normal color vision (in particular, traffic light signal recognition.); 5) Require minimal care (resistance to scratching and impact); and 6) Be optimized for the situational lighting environment (clear under low illumination and dark under high illumination). Photochromic lenses – as opposed to clear or fixed tint lenses – change, on demand, with various levels of optical illuminance to better meet these requirements,and offer the most convenient – and most physiologic – solution to changing light conditions.

Clear Lenses vs. Photochromic Lenses

The performance of clear lenses was compared to that of photochromic lenses in a recent clinical study. Test subjects were given a pair of clear lenses to wear for 30 days, and a pair of the latest photochromic technology lenses offered by Transitions Optical, Inc. to wear for 30 days. At the end of each trial period, subjects were asked to complete a VRQOL instrument. This instrument was developed by a team of eyecare professionals, statisticians and photochromic scientists in 1999. Structured as a questionnaire, it explores various aspects of visual acuity and comfort according to five subscales: Vision Comfort, Daily Activities, Conditions Experienced, Features and Satisfaction.

Photochromic lenses were found to produce a significant improvement in visual comfort and satisfaction over clear lenses during outdoor wear. Experiences with regular, clear lenses and photochromic lenses were equivalent indoors.

Results clearly demonstrated that glare-induced conditions may prevent a patient with 20/20 vision from “seeing” satisfactorily – i.e., being totally satisfied with a given visual situation. Specific findings, based on the comparison of photochromic lenses to clear lenses, included: 1) Decreased eye strain (tearing and burning); 2) Reduction in pain and loss of visual performance due to glare; 3) Improved adjustment from indoor to outdoor lighting; 4) Better adaptation to different lighting conditions; and 5) Enhanced performance of outdoor activities, with the photochromic lenses.

In this study, photochromic lenses scored significantly higher than regular, clear lenses in overall satisfaction. In fact, four out of five patients preferred the visual comfort experienced with the photochromic lenses over that found with regular, clear lenses.

Conclusions

Fixed tint sunglasses can provide significant attenuation of high illumination conditions outdoors. However, they also act to further decrease illumination under low light conditions, indoors and out, and can impair vision.

Clear lenses, on the other hand, provide minimal reduction in light intensity indoors or at night, but they do not protect the eyes from excessive light or glare under conditions of high light intensity.

Photochromic lenses offer similar clarity to clear lenses with the added benefit of situational attenuation of light intensity. The finding that four out of five patients in the clear versus photochromic lens comparison study preferred photochromic lenses over clear lenses indicates how important glare reduction is to the overall visual experience. The potential long-term vision protection afforded by the 100% UVR filtering function of photochromic lenses, their ability to shield the lids from photoaging changes induced by light exposure and squinting, and the preservation of night-vision they may provide are important considerations. With the introduction of the latest photochromic technology, it is now possible to offer patients a higher-performing everyday lens that provides excellent visual acuity, visual comfort, visual convenience, and long-term vision protection.

CHAPTER 5.

SEEING WELL FOR A LIFETIME: FIXED TINT AND PHOTOCHROMIC LENSES AND CHILDREN

There is a growing belief that environmental factors may play a key role in the etiology of a rapidly increasing list of ocular and systemic diseases. Both acute and chronic exposure to these environmental factors can be important, and with chronic exposure, susceptibility may be greatest in early life, i.e., during infancy and childhood. Although the die may be already cast, disease-wise, in some conditions even before birth, by the complement of genes inherited from the parents, there is accumulating evidence that it is a combination of genetic predisposition and environmental exposure that contributes to certain disease states.

The argument for this joint genetic/environmental theory for disease is especially strong in the case of cutaneous neoplasms. Skin cancers are the most common form of cancer, with more than one million Americans diagnosed with cutaneous malignancies annually. While most can be cured, an estimated 7000 people in the U.S. die from skin cancer each year. UVR exposure plays a major role in its etiology. Cumulative exposure is the issue here and most relevant is the history of blistering sunburns during childhood. Dermatologists have done an admirable job of alerting the public to the risks of UVR exposure, and the public by and large has taken their advice seriously, using protective clothing and topical sunblocks almost routinely – especially young children, who are considered to be most at risk.

UVR Exposure and Ocular Disease

Table 1.
Total % of Adults and Children Who Use Clear, Fixed Tint, and Photochromic Prescription Spectacles.

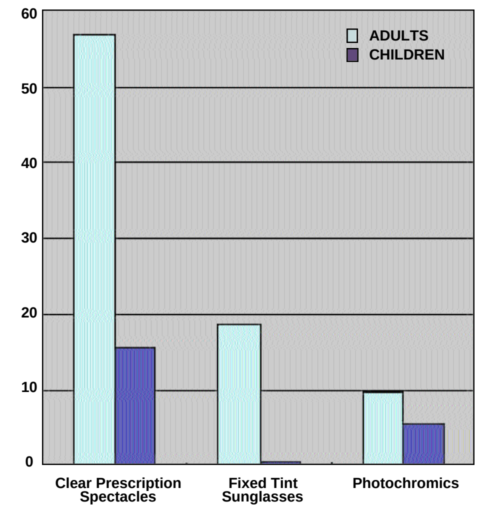
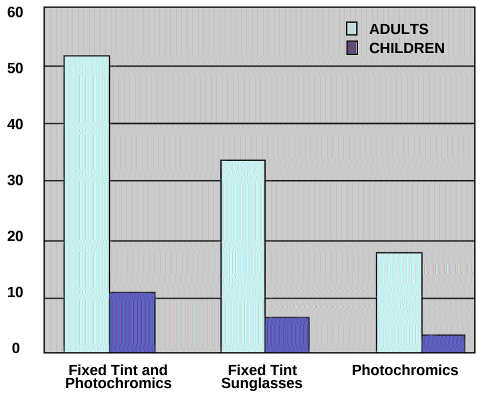


Table 2.
% Adult/Children Spectacle Wearers Who Use Fixed Tint Sunglasses and Photochromics.



The eye and the skin share much in common, and it appears that the eye and the ocular adnexa may suffer from the same potential for damage from UVR exposure as the integument. The eye may be at an even greater risk than the skin, since, unlike the skin, the eye does not develop a tolerance to UVR, but becomes more sensitive with repeated exposure. Chronic UVR exposure has been implicated in a number of eye diseases, including neoplasms of the eyelid skin, pingueculae, pterygia, cataract, and macular degeneration. Laboratory studies in animals have demonstrated that UVR exposure damages ocular tissues. The epidemiological studies done in humans have provided suggestive, but not definitive, evidence of UVR-induced ocular pathology. The two most frequently quoted studies – the Beaver Dam Study and the Chesapeake Bay Waterman Study – were conducted in an adult population and focused primarily on patterns of sunlight exposure in adult life. If indeed it is early exposure that is most significant, perhaps the absence of a clear-cut definitive cause-and-effect relationship between UVR and cataracts/macular degeneration in these studies can be explained because early childhood exposure was not specifically evaluated.

And while Dermatology has implemented a highly successful public health movement to protect the skin from adverse effects of UVR exposure, the eye has been sadly neglected. There are no available topical sunblock preparations that can be used safely and effectively in and around the eyes. And while UVR-filtering spectacles offer excellent protection against UVR for the eye (and the eyelids), the very population that is considered the most susceptible to UVR-related diseases in later life – children – represent the smallest segment of the population wearing spectacles.

120,300,000 individuals or 57% of the adult population (defined as 18 years old or more) wear prescription spectacles, as compared to 8,960,000 or 16% of children (defined as under age 18). And while the majority of adults (52%) who wear prescription spectacles also wear prescription sunwear (34% fixed-tint sunglasses and 18% photochromics), only 11% of children wearing prescription spectacles also wear prescription sunwear (7% fixed tint sunglasses and 4% photochromics). **Tables 1. and 2.** These statistics, combined with the fact that children spend much more time outdoors than adults, with an estimated 80% of lifetime sun exposure occurring before age 18, should make ocular sun protection for children an absolute priority.

As serious as the situation with the potential for UVR-related eye and skin disease may be in the U.S., it is worse in other areas of the world, particularly in regions of high altitude, in southern latitudes, and where ozone depletion is more marked. A good example is Australia, whose inhabitants suffer one of the highest rates of skin cancer anywhere, with one out of two Australians being treated for skin cancer at some point during their lifetimes and melanomas being the third most common cancer nationwide. More than two decades ago (in 1980), the Anti-Cancer Council of Victoria launched an aggressive campaign to alert the public to the necessity of UVR protection. Their "Slip! Slop! Slap!" admonition ("Slip on a shirt, slop on sunblock, slap on a hat!") has become more than a slogan; it is now a way of life for most Australians, many of whom are all too aware of the dangers of UVR as manifested by eye disease and skin cancer in themselves, relatives, or friends. **Figure 1.** In 1988, this highly successful public health initiative evolved into The SUNSMART program. **Figure 2.**

Figure 1.
Sid Seagull:"Slip! Slop! Slap!"
(Reproduced with the kind permission
of The Cancer Council Victoria)

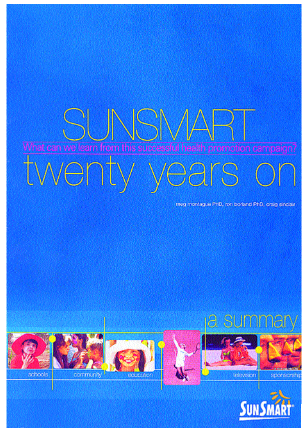


Figure 2.
SUNSMART
(Reproduced with the kind permission
of The Cancer Council Victoria)

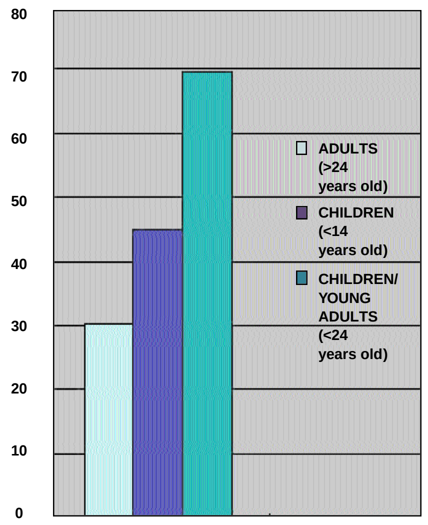
Children are a very important focus of this program. In many Australian schools, students are not permitted to play outdoors in summer months without a hat, sunblock, and, in some cases, sunglasses. ("The Slip! Slop! Slap!" campaign has been expanded to become "Slip! Slop! Slap! And Wrap!", with wrapping on a pair of sunglasses added.) In years to come, preventive campaigns like this one will likely produce the best indirect evidence in human subjects of the risk of UVR exposure to the skin and the eye, if the children of this protected generation, being raised with strict guidelines for UVR protection, demonstrate a decrease in the incidence of skin cancer, pterygia, cataract and macular degeneration, as compared to earlier unprotected generations.

Spectacles and Sports Protection

The primary role of spectacles is to improve and enhance vision. In addition to correcting subnormal vision and, when specially treated, protecting the eye from excessive UVR exposure, spectacles can perform other important functions that are especially significant for children. Polycarbonate lenses offer excellent UVR protection.They are also shatterproof and can shield the eye from impact injuries in play and in sports, particularly when sturdy or wrap-around frame designs are used. Because the rough-and-tumble lifestyles of most children increase their susceptibility to ocular injuries, polycarbonate is the material of choice when prescribing for children and adolescents.

There were an estimated 42,915 sports-related eye injuries in 2000. (Figures courtesy of Prevent Blindness America, based on statistics provided by the U.S. Consumer Product Safety Commission National Electronic Injury Surveillance System Product). Of these, nearly half (20,114) were related to ball sports (basketball, baseball, softball, football, golf and racquet sports). 44.7% occurred in children 14 years old and younger, and 69.6% in children and young adults up to age 24. **Table 3.** To protect this vulnerable population, it is strongly recommended that all child, adolescent, and young adult athletes – even emmetropes – wear protective eye wear.

Table 3.
Ocular Sports Injuries (2000)



Spectacles and Eye Comfort

While appropriate spectacles can provide the wearer with good vision, they can also promote comfortable vision, particularly under conditions of excessive light or glare. UVR protection in and of itself does not provide sunlight and glare protection; this is the role of specialized filters and lens treatments. For this purpose filters typically take the form of tinted lenses, e.g., in the ordinary sunglass.While all sunglasses function as filters of light to some degree, not all necessarily function as effective UVR filters. Although the government has set standards for adequate UVR filtration in both prescription and non-prescription sunwear, these standards are not necessarily adhered to, particularly in low-end over-the-counter (OTC) sunglasses. And since there is a higher percentage of emmetropes in the child versus the adult population, and since emmetropes do not require corrective spectacles and therefore typically do not use prescription glasses, the majority of children who wear sunglasses do not wear prescription sunglasses. Unfortunately, many of the OTC sunglasses manufactured for children are of very low quality. They may not meet ANSI standards and provide adequate UVR protection. The extremes are the "play" sunglasses, sold in toy and convenience stores, the lenses made of cut-out disks of cheap tinted plastic, of such inferior quality that they may actually distort and impair vision and give little if any UVR protection.

Spectacles and Ocular Convenience

The indoors-outdoors life style of most children translates into sunglasses-off-sunglasses-on, and, as any parent knows, the more kids handle anything, the more potential for damage or loss. But the same pair of sunglasses that might cut down excessive sunlight and glare on the baseball field and enhance performance as the first game of a double header commences with the sun high at 12 noon, may become an obstacle in the eighth inning of game two as dusk approaches and the unnecessary – and unwelcome – filtering action impairs contrast vision and can adversely affect performance. But proper UVR protection is important noon-to-dusk, as is the impact protection for the eye that polycarbonate lenses provide. This is precisely why polycarbonate photochromic lenses would appear to be the first choice in eyewear for children. The full-time UVR and impact protection, plus the on-demand sunlight and glare protection they provide, accommodates the indoors-outdoors life of the child. For the ametropic child who requires corrective spectacles, prescribing a photochromic lens makes the most sense: one pair for many purposes. And for the emmetropic child, where it is not visual correction, but UVR, impact, sunlight and glare protection that is called for, a versatile lens that will adequately protect the eye in all ways and offer the convenience of fitting in with the rapidly changing indoors-outdoors life style of the average child, while providing visual comfort, is what is required. Here again, a quality polycarbonate photochromic lens fills the need precisely.

The Many Roles of Spectacles

In both children and adults, spectacles have been traditionally prescribed to enable the wearer to see well. This is no longer enough. Spectacle wearers expect to see well, to see comfortably, and to see conveniently with their glasses. In the child, the right spectacles should achieve all of these goals and, in addition, help the child to continue seeing well for a lifetime, by providing protection against potential UVR-related vision-threatening diseases in adult life.

Children growing up in this enlightened age of preventive medicine are a work-in-progress who will one day demonstrate that preventing disease is a far more effective approach than treating it. Parents are the guardians of their offspring in this regard. Long overdue measures to take better care of the environment are finally being implemented. Global warming and ozone depletion are the inheritances being left behind by this generation to future ones. Perhaps to compensate for this unfortunate legacy, there is currently a strong emphasis being placed on the importance of a healthy lifestyle, balanced diet, the use of nutritional supplements, and the avoidance of additives and toxins.

UVR protection has already been incorporated into this formula for a healthy life as far as the skin is concerned. But the same conscientious parents, who would not think of allowing their children to spend an afternoon at the beach without the generous application of sunblock, may allow their eyes to go unprotected. This despite the fact that survey after survey has shown that people value their sight above all the other senses. Perhaps better education of their patients by eye care practitioners on the hazards of UVR exposure to the eye will remedy this dangerous oversight.

CHAPTER 6.

LOOKING AT THE WORLD THROUGH ROSE-COLORED GLASSES: IS IT REALLY BETTER?

There are those who would argue that the world shouldn't need a tint to look good. The real world is best seen as a real world to the eyes of the beholder. But there are circumstances where real may not be best – world-wise or vision-wise. It's all a question of balance and of degree. Just as too little light can impede vision, too much light can impair vision. There are times and places where the use of filters to decrease excessive or stray light will increase the efficiency of light in mediating vision. And the quality of light is important, as well.

The simplest example occurs with bright sunlight. Here the simple filtering action of a tinted sunglass lens can lessen visual discomfort, enhance visual efficiency, and improve contrast acuity. Unfortunately these same parameters might well be adversely affected when illumination decreases and the filtering effect of the sunglass is no longer necessary – or advantageous.

Specific selective filters have been suggested to improve vision in normal individuals under certain circumstances. Yellow and amber tints, for example, have been purported to improve contrast sensitivity and cut down reaction times in pilots, marksmen, and skiers. Blue tints have been recommended for tennis players to facilitate tracking the ball.

Filters are used by industry to color the real world what is felt to be a better or more attractive shade, with selective lighting and tints enhancing things ranging from meats and produce in supermarkets to people looking at themselves in dressing room mirrors.

Certain tints have been advocated to improve qualitative and/or quantitative acuity in the visually impaired. The prescription of colored lenses to facilitate discrimination of red/green traffic signals in colorblind drivers is a common device to promote road safety. It has been suggested that specific tints might prove helpful in enhancing visual function in such sight-threatening disorders as cataract, macular degeneration, glaucoma, and retinitis pigmentosa.

There have been largely unsubstantiated reports of blue tints proving useful in visual training in children with dyslexia.

And then there are those proverbial rose-colored glasses, promising not so much that the wearer will see better with them as that the world will look better through them.

Recent research has challenged some of these vision myths and demonstrated that not all tints are created equal. Some may show promise for improving the quality and quantity of vision in different individuals under different circumstances. Experimentation continues to investigate which ones, in which people, and under what conditions may indeed prove to be enhancing tints.

Aside from the functional aspects of visible light and sight, there is the even more important issue of that invisible component of light – ultraviolet radiation or UV – and its possible role in the etiology of such vision-threatening diseases as cataract and macular degeneration. Protecting the eye from UVR is a definite priority in this era of preventive medicine... and ophthalmology. Spectacle lenses with UVR filters are the most convenient, effective, and efficient way to provide this protection for the eye. Furthermore, it is becoming increasingly clear that this protection must begin early in life to be effective.

But sunlight is not synonymous with ultraviolet light. Ideally spectacles should provide the consistent protection required against UVR-mediated ocular disease as a constant and the as-needed or on-demand functional protection against excessive sunlight and glare to maximize visual comfort and performance.

One fact has already been made clear, however. All tints work in some way as filters, so that, by definition, they cut down on the amount of light entering the eye. This will clearly only prove beneficial when it is a matter of too much light, not too little, being presented to the eye. The conclusion must be that the ideal filter filters light when filtering is necessary for visual comfort and efficiency and otherwise does not impede transmission of light that is essential to sight. Photochromic lenses provide this variable, as-needed, on-demand type of filtering and provide the ideal spectacle lens to both mediate and modulate light in its function of producing sight. In addition they provide complete and constant protection against UVR to help preserve good vision.

CONCLUSION

This monograph started out with the words of John Muir and Gray Burr to dramatize the sometimes ambivalent relationship between light and sight. These same men will help end it.

Muir recovered completely from his sunblindness and went on, among other things, to see the establishment of his beloved Yosemite as the jewel of the national park system, describing his great joy in returning "... into Heaven's light... making haste with all my heart to store my mind with the Lord's beauty."

And Burr continued his romance with light and sight, extolling the eye as the marvelous instrument that turns one into the other:

Only the eye can drink
From a lake a mile away
Or climb ten mountains in
Less time than it takes to say,

Land on the moon, the stars;
Fall, rise, hurdle, sprint;
Put a lid on the world
Or narrow it to a squint.

Lover of light, whose lies
Deceive us, doctors say,
Let physics chew surmise.
Dine out on the crusty day

And drink the sun's gold wine,
Devouring all that seems.
From color, form, and depth
Concoct your optic dreams

And give them to the mind
As its best evidence.
Then only, thought may grind
A harder sharper lens.

Gray Burr, "Eye"
A Choice of Attitudes
Wesleyan UniversityPress, 1969

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First edition.
Printed in the United States of America.

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