

Review Article

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Colour Vision Alterations and Eye Conditions

Mrityunjay Shukla¹ and Raj Kumar^{2*}¹M. Optom. Scholar, Department of Optometry, School of Allied & Health Sciences, Galgotias University, Greater Noida, Plot No 17A, GB. Nagar, India²Professor, Department of Optometry, School of Allied & Health Sciences, Galgotias University, Greater Noida, Plot No 17A, GB. Nagar, India

ABSTRACT

Our ability to see color is essential to our perception of the world, and different eye disorders can have a big impact on it. This review examines the effects of various eye conditions on color vision. For instance, cataracts can cause color perception to be distorted, particularly for reddish-green and blue-yellow hues, yet most patients see improvements in color vision following cataract surgery. The ability to discern blue-yellow hues is mostly affected, and persistent color vision issues are frequently caused by retinal detachment, especially when it affects the macula. Additionally, glaucoma can cause color vision impairments; the most prevalent type are blue-yellow abnormalities, which are most likely caused by damage to the blue-sensitive cones in the eye and their connections. Color sensitivity, particularly to blue light, decreases more quickly in Age-Related Macular Degeneration (AMD) patients than is often assumed with aging. Color vision problems are exacerbated by diabetic retinopathy, and they get worse when blood glucose levels rise. All things considered, these disorders emphasize how crucial it is to keep an eye on and treat changes in color vision in order to preserve quality of life.

*Corresponding author

Raj Kumar, Professor, Department of Optometry, School of Allied & Health Sciences, Galgotias University, Greater Noida, Plot No 17A, GB. Nagar, India.

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Introduction

For proper visual function, color vision is essential. When signals are produced by photoreceptors, transduced by post-receptor channels, and relayed by the optical system which consists of the cornea, pupil, and crystalline lens the visual cortex analyzes the data to experience color [1-3]. The occipital cortex of the brain receives impulses from light entering the eye and interacting with the different photoreceptor cells in the retina. The complex interplay between the optical components of the eye and the brain's interpretive processes underpins the sensitive and subjective process of color perception. Deeb and Motulsky distinguish between rods and cones as the two types of photoreceptors found in the human retina [4]. Cones are in charge of seeing in strong light and are essential for recognizing form and color, whereas rods are specialized for seeing in low light. The peak spectral sensitivity of cones is used to further categorize them into three categories.

The wavelength of light at which long-wavelength cones (L-cones) are most sensitive is around 560 nm, or red light. Cones with a wavelength of about 530 nm, or medium-wavelength cones (M-cones), are especially sensitive to green light. The maximal sensitivity of short-wavelength cones, or S-cones, is around 430 nm, or blue light [5]. Three types of cones, the brain is able to comprehend colors thanks to the overlapping absorption spectra of these cones. Color vision abnormalities can be caused by a variety

of causes that interfere with this intricate mechanism of color perception, such as toxins, ocular diseases, or systemic illnesses. Because this color recognition mechanism is so complex, any interference can have a major negative effect on color vision. For example, certain disorders or poisons might interfere with the cones' normal activity; causing impairments in color vision [6]. accurate color perception can be further complicated by systemic disorders that impact the eyes. This vulnerability to different stimuli emphasizes how crucial it is to keep your eyes healthy in order to maintain your ability to see color [7]. Since the 17th century, eye illnesses have been linked to deficiencies in color vision. Köllner classified color vision loss resulting from eye illnesses into two categories in 1912: "blue-yellow" blindness and "progressive red-green blindness." Köllner's rule states that red-green discrimination loss is exhibited by people with optic nerve illnesses, whereas blue-yellow discrimination loss is seen in people with retinal diseases. Köllner's rule is not always followed, though. Examples of such diseases are glaucoma, which can result in blue-yellow faults, and central cone degeneration, which can create red-green defects. A rare possibility of non-specific loss of color vision also exists [8].

Colour Vision Mechanism

Photoreceptors: Cones and Rods

• **Cones:** These cells are in charge of color perception. Cones, primarily located in the fovea, the retina's center, respond differently to various light wavelengths, enabling us to perceive color. Cones of the three different types are responsive to red, green, and blue light. The combination of these three cone types

is referred to as trichromatic color vision.

- **Rods:** In contrast to cones, rods aid in low-light perception but have no role in color vision. The reason we have trouble seeing colors in the dark is because they are outside the fovea and function best in low light.

Processing by Retinal Cells

The cones detect light, but other retinal cells process this information before it's sent to the brain:

- **Bipolar Cells:** These cells link ganglion cells to photoreceptors, such as cones and rods. They assist in processing the signals received from various photoreceptors and transmitting this data.
- **Ganglion Cells:** These cells travel through the optic nerve to the brain after processing signals from bipolar cells. Certain ganglion cells respond more strongly to particular light wavelengths, which aids in our ability to discern between colors.
- **Horizontal and Amacrine Cells:** By lateral connections between photoreceptors and bipolar cells, these cells improve contrast and color clarity in visual signals.

Neural Connections and Pathways

The retina contains a complex network of synaptic connections between the different types of cells. These connections help integrate and refine the visual information, allowing for more accurate color perception and contrast sensitivity. Signal Transmission to the Brain Once the ganglion cells process the visual data, they send the information to the brain via the optic nerve. The brain's visual cortex then interprets this data, allowing us to see colors, details, and depth in the world around us. And mainly, color vision deficiency is divided into two types.

Congenital and Acquired

Hereditary defects in cone photopigments result in congenital impairments in color vision. The most common type of deficiencies are red-green ones, which result from either aberrant or absent long-wavelength (proton-type) or intermediate-wavelength (deuton-type) photopigments. Less frequently, aberrant or absent short-wavelength photopigments lead to triton-type defects. Recessive inheritance of red-green color vision deficits occurs through an X-linked pattern involving two genes.

An acquired color vision defect refers to impairment in color perception due to injury, disease, or other ocular problems. In acquired color vision deficiencies, Verriest's 1963 categorization is the most widely used method. It connects the location of the illness and retinal chromatic processes to the kind of color deficiency. Foveal disorders are often the cause of type I (red-green) deficiencies, but type III (blue-yellow) defects, the most widely used classification approach for acquired color vision deficiencies is Verriest's 1963 scheme. It links the type of color deficit to the location of the sickness and retinal chromatic processes. Type III (blue-yellow) deficits are usually caused by macular diseases with intact visual acuity, whereas type I (red-green) deficiencies are often caused by disorders of the fovea. If visual acuity is unaffected, type III deficits are more likely to occur, even though type II (red-green) impairments are the typical result of optic nerve diseases. It is suggested that specific color vision systems have been specifically harmed by the similarities between congenital patterns and acquired color vision disorders, with chromatic sensitivity being more vulnerable than light sensitivity [8].

Numerous studies demonstrate how changes in ocular health can affect color vision and how neurological conditions can impair

it, ultimately leading to acquired color vision insufficiency, or ICV. We've already discussed a few research papers on how various diseases affect color vision. Disturbed Perception of Colours Associated with Localized Cerebral Lesions, Different degrees of color perception impairment were encountered by patients with cerebral achromatopsia, who frequently reported that their surroundings appeared grayscale or monochromatic. Certain hues appeared muted, less vivid, or unidentifiable in certain instances. This limitation interfered with daily activities, like object identification and color-based comparison of similar items. Bilateral lesions in the occipital or occipitotemporal areas of the brain, specifically affecting the fusiform and lingual gyri, are usually the source of cerebral achromatopsia. These lesions cause problems with color perception, but they do not seriously affect other aspects of vision, such as sharpness. One visual field may have color vision problems as a result of unilateral lesions, but bilateral damage is necessary for complete achromatopsia. The disorder is frequently associated with other [9]. Selective Loss of Blue Cones and Rods in Human Retinal Detachment, in this study nearly all blue cones and many rods either had irreversible necrosis on them or were absent following retinal detachment. The findings demonstrate how retinal detachment causes a quick and irreversible loss of blue cones, which accounts for the clinically observed blue-yellow color confusion. According to the research, blue cones are more brittle compared to rod and red/green cones. This conclusion has significant implications for our comprehension of acquired color vision impairments in retinal diseases [10].

Acquired color vision defects in glaucoma their detection and clinical significance, red-green faults were less common (5%), with blue-yellow errors present in 30–50% of glaucoma patients. Short-wavelength ganglion cell injury is associated with blue-yellow abnormalities. Chromatic discrimination tests, especially for blue-yellow abnormalities, are beneficial in detecting early glaucomatous damage [8].

Chromatic Discrimination Losses in Multiple Sclerosis Patients, Significant loss of color discrimination was observed in MS patients, both with and without optic neuritis (ON), with impairment along the red-green and blue-yellow axes. Patients with MS undergo a progressive loss of color vision that affects both the parvocellular and koniocellular pathways. Patients without ON experience a higher rate of deterioration [11].

Migraine with aura (MA) is associated with impaired color vision: Results from the cross-sectional German DMKG headache study, Loss in MA compared to MwoA: Compared to participants with migraine without aura (MwoA) and healthy controls, those with migraine with aura (MA) had noticeably greater probabilities of color perception impairment. The study found a strong correlation between aura-producing migraine and poor color vision, which may be related to underlying neurological variations in migraine subtypes. On the other hand, no widespread sensory impairment was noted [12].

Impairment of Color Vision in Diabetes with No Retinopathy: Sankara Nethralaya Diabetic Retinopathy Epidemiology and Molecular Genetics Study (SNDREAMS-II, Report 3), Impaired Color Vision in Diabetes Without Retinopathy 39.5% of diabetics without retinopathy had impaired color vision (ICV), and the ICV group had greater TES. The gender (female), elevated intraocular pressure, and elevated resting heart rate were significant risk factors. Cataract surgery was a protective factor. Even in diabetics without retinopathy, ICV is common, indicating the onset of early neurodegenerative alterations. For diabetic patients

without retinopathy, routine color vision testing can be helpful in monitoring their condition [13].

Visual dysfunction in Parkinson's disease, even in the early stages and in patients who are not receiving treatment, color vision impairments are typical in Parkinson's disease. Mainly affects red-green and blue-yellow eyesight. Color vision impairments are associated with motor symptoms such as axial motor problems. Deficits in color vision are substantial and start early in Parkinson's disease. These deficiencies may act as indicators of the course of the illness [14].

Detection of Early Loss of Color Vision in Age-Related Macular Degeneration: With Emphasis on Drusen and Reticular Pseudo drusen, Significant chromatic sensitivity loss was seen in patients with early and intermediate AMD, especially in the yellow-blue axis. RPD, or reticular pseudo drusen, was linked to the greatest loss. Particularly in patients with RPD, chromatic sensitivity loss, notably in the yellow-blue axis, is an early functional indicator for the advancement of AMD. Chromatic tests may be used to identify macular atrophy early on [15].

The impact of age-related cataracts on color perception, postoperative recovery, and related spectra derived from tests of hue perception, Patients with cataracts performed poorly on preoperative color discrimination tests, especially in the green-blue and yellow-green color bands (470–580 nm range). Postoperative recovery markedly enhanced color perception, and surgery lowered total estimated score (TES) to levels comparable to controls. In individuals with age-related cataracts, phacoemulsification surgery efficiently recovers color perception, especially in the 470–580 nm wavelength range [16].

Color Perception Deficits after Posterior Stroke: Not So Rare After all, 22% of stroke patients experienced color perception abnormalities, particularly those with bilateral lesions. Problems with color vision following posterior strokes are more common than previously believed, and lesions primarily affecting the left hemisphere are responsible [17].

The Following are Some Implications of Color Vision in Ocular Problems Leading to Acquired Color Vision

Cataract

Age-related cataracts had a significant impact on color discrimination, with the red-green and blue-yellow color axes being most affected. The study found that the interference of cataracts with the contrast and saturation of retinal pictures led to a decline in older people's performance on color vision tests and hue sensitivity. Postoperative recovery after cataract surgery resulted in a considerable improvement in color vision, especially in green tones. Improvements were also seen in specific color bands that correspond to light wavelengths between 470 and 580 nm [16].

Retinal Detachment

A trait that set them apart from the other thirty-six patients that Kollner studied in 1907 was blue-yellow, resembling tritanium. Findings from multiple organizations indicate that the most common color vision impairment linked to retinal detachment is blue-yellow confusion. However, as is the case with any acquired color vision loss, the impairment is not always total. The impairments in color vision occurred regardless of when the macula detached; however, the recovery was less complete and occurred more slowly. Recovery of color vision after retinal detachments was also often inadequate [10].

Glaucoma

Numerous published studies demonstrate that glaucoma may or may not impair color vision. This study examines the prevalence of various color vision impairments in individuals diagnosed with Primary Open-Angle Glaucoma (POAG) and looks into the explanations of the predominant blue-yellow (tritan-like) deficiencies in these patients. Usually, prevalence estimates indicate that 20–40% of POAG patients have normal color vision. 30% to 50% had yellow-blue flaws. In addition to 20–30% exhibiting a general loss of chromatic discrimination, 5–10% has red green deficiencies. The effects of high Intraocular Pressure (IOP) on short wavelength (blue) cones or the neurons that connect them may be the cause of the preponderance of blue-yellow abnormalities. Furthermore, because of their larger receptive fields, unique morphology, and special connections to second-order neurons, blue-yellow-sensitive ganglion cells may be more vulnerable to damage in POAG as a result of IOP-related factors.8 According to some morphologic studies, acquired color vision loss in glaucoma is consistent with Kollner's rule, which postulates that the outer retina is damaged. More specifically, it seems that both the L- (long wavelength) and M- (medium wavelength) cones are equally damaged in glaucoma cases [18].

ARMD (Age Related Macular Degeneration)

Our perception of color and light diminishes with age, partly because of modifications to the lenses of our eyes but also because of changes in the way our brain interprets visual data. People with intermediate age-related macular degeneration (AMD) see a more marked deterioration in their visual acuity, particularly in color vision. Studies reveal that the sensitivity of the eye's color-detecting cells is decreased by approximately 200%, which is significantly more than the usual age-related decline in color perception, especially for blue light. On the other hand, the cells that aid in our perception of brightness have experienced a 155% drop, which is still a notable amount. This implies that color vision is more badly affected by AMD than is perception of brightness [19]. The yellow-blue or red-green color vision thresholds, or occasionally both, were found to be abnormal in every AMD-affected eye when compared to normal values for individuals of the same age [15].

Diabetic Retinopathy

Color vision loss in diabetic retinopathy is frequently associated with a blue-yellow (tritan-like) defect that intensifies with worsening macular edema. This impairment involves the short-wavelength sensitive cones (S-cones) that are responsible for blue vision, making them more susceptible than the cones that detect green and red. The degree of color vision loss is largely determined by the severity of macular edema, though patients without macular edema often struggle with some degree of color discrimination [20]. Numerous studies demonstrate how patients with both diabetic retinopathy and diabetic retinopathy alone experience alterations in colour vision in response to elevated blood sugar. The findings indicate that colour vision deteriorates in proportion to blood glucose levels and diabetic retinopathy [21]. Colour vision impairment was seen in children with juvenile diabetes [22]. this indicates that colour vision is affected by the degree of diabetes.

Multiple Sclerosis

The manner in which Multiple Sclerosis (MS) affects the visual pathways accounts for the color discriminating deficits that are seen in its sufferers. As a demyelinating disease, multiple sclerosis damages the nerve cells of the central nervous system. Studies reveal impairments to the parvocellular (red-green) and

koniocellular (blue-yellow) visual pathways, with the parvocellular route being more severely affected. This deficiency is noticeable even in the absence of ocular neuritis, indicating that MS may be a factor in color vision impairments. Furthermore, these losses may get more severe as we age, which is a reflection of both the natural aging process and the advancement of multiple sclerosis [16].

Discussion

There are two ways that color vision affects the eye. The first and most prevalent is congenital, when inheritors' mutations on the X chromosome cause the color vision to be affected congenitally. In the review, we concentrated on acquired color vision, which results from modifications to the refractive medium (lens) and from aging-related or other problem-related alterations in cone cells. Acquired color vision aids in determining the disease's severity. The L- (long-wavelength), M- (medium-wavelength), and S- (short-wavelength) cone types are among those impacted by retinal disorders. The kind of color vision that arises in various ocular problems depends on the type of cone. Refractive medium changes, such as cataract lenses, can also affect color vision. Specifically, lens modifications can result in decreased contrast and retinal picture saturation. Congenital color vision is completely irreversible, although acquired color vision can be partially or completely recovered with the right medical care, depending on the illness's severity.

Conclusion

The ability to see color is fundamental to our perception and comprehension of the environment. This vital sense can be severely impacted by a number of eye disorders, such as cataracts, retinal detachment, glaucoma, Age-Related Macular Degeneration (AMD), and diabetic retinopathy. While color vision can frequently be restored with cataract surgery, chronic and particular color vision problems can also result from other disorders such as glaucoma and retinal detachment. More severe color vision loss can be caused by AMD and diabetic retinopathy, especially as these conditions worsen. Effective treatment of color vision abnormalities is essential for many eye illnesses. Early detection and treatment of these impairments can help patients retain their quality of life and carry out their daily activities to the fullest.

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