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Review Article

Pathophysiology of altered color perception

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Human beings are able to perceive hundreds of shades of color which depends on the three types of cone system and various ratios of stimulation in response to different wavelengths. Perceptually and cognitively, men and women may experience appearance of color differently. The convention seems to be that women tend to prefer brighter and gratifying colors and men are more comfortable with stifled and soft colors. The reason may be linked to hormonal, developmental and environmental differences amongst both the sexes. The present review discusses various types of clinical and experimental studies done on alteration in color perception.

Key words: color vision, cone system, shades of color, gender variation

Introduction

A number of studies have compared male and female use of the color lexicon, and provided convergent evidence that women access a larger repertoire of words to describe standardized sets of color stimuli [1]. The relative fluency with color terms among females extends to finding color samples to match them, and providing glosses or definitions [2]. This trend emerges across a range of cultures and languages [3]. It is already evident in childhood: girls are earlier than boys to learn the names of primary colors [4], though this may reflect an overall lead in language skills among girls. There may be a link to the tendency for females to be better than males at matching colors from memory [5]. Cognitive and social phenomena could account for these differences: it may be that the divergent patterns of socialization for males and females instill a greater awareness of color among women.

Sex Differences in Color Perception

Early investigations done by Guilford on the harmony of color combinations found that a person is likely to see balance in colors that are closely related or the opposite [6]. Guilford also found some evidence that more pleasing results were obtained from either very small or very large differences in hue rather than medium differences, with this tendency more frequent in women than men. An even earlier study found men preferred blue to red and women red to blue. It also stated that yellow had a higher affective value for the men than women and that blue for men stands out far more than for women [7]. Eysenck's study, however, found only one

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gender difference with yellow being preferred to orange by women and orange to yellow by men [8]. This finding was reiforced later by Birren who found men preferred orange to yellow; while women placed orange at the bottom of the list [9].

Guilford and Smith found men were generally more tolerant toward achromatic colors than women [10]. Thus, it was proposed that women might be more color-concious and their color tastes more flexible and diverse. Likewise, McInnis and Shearer found that blue green was more favored among women than men, and women preferred tints more than shades [11]. They also found 56% of men and 76% of women preferred cool colors, and 51% men and 45% women chose bright colors. In a similar study, it was found men had a tendency to prefer stronger chromas than women [12].

Kuller conducted a study on the effects of color in two opposite environments [13]. Six men and six women were asked to stay in two rooms; one room was colorful and complex; while the other was gray and sterile. Electroencephalogram (EEG) and pulse rates were recorded throughout the period, as well as the individuals' subjective emotional feelings. The results showed heart rates were faster in the gray room than in the colorful room. Moreover, men were found to have stress reactions more than women. Men also became more bored than did the women in the gray room. Kuller also postulated that men could not achieve the same degree of mental relaxation as women.
Thomas, Curtis, and Bolton interviewed 72 Nepalese and asked them to list the names all the colors they could think of [14]. There was a significant difference between men and women. Although, the women consistently listed more color names than men did, the cultural context of this study must be noted since Nepalese women traditionally wear more colorful clothing than men do. A similar study examined the color identification and vocabulary skills of college students [15]. They were asked to identify the colors of 21 color chips. The results showed that women recognized significantly more elaborate colors than did the men. Findings also indicated that gender different responses in color identification may be attributed to a difference in the socialization of men and women.

About 8% of men exhibit a hereditary deficiency of color perception but recently it was recognized that there are measurable differences in the color perception even amongst the people with normal color vision [16]. The subject of 'color and gender' is an important and intricate topic. There may be some logic behind the widely accepted modern color convention of 'pink-for-girls' and 'blue-for-boys'. Here convention seems to be that women tend to prefer brighter and gratifying colors and men are more comfortable with stifled and soft colors. The reason may be linked to hormonal, developmental and environmental differences amongst both the sexes [17].

Color Vision

Color sense or vision is the ability of the eyes to discriminate between the light rays of different wavelengths. Our visual system works out the color by comparing the relative rates at which photons of light rays are absorbed in different classes of cones in retina exposed to bright light – photopic vision. Interpretation of any color needs initial processing in the three cell layers of retina and then signals from different cone systems on reaching brain are compared to be perceived [16, 18, 19].

Perception of color begins with specialized retinal cells containing pigments with different spectral sensitivities, known as cone cells. In humans, there are three types of cones sensitive to three difference spectra, resulting in trichromatic color vision [20]. These are based on different type of photopigments. Three classes of photopigments are known to exist: those most sensitive to the short-wavelength region of the spectrum (abbreviated SWS cones), those most sensitive to the middle wavelength region (MWS cones), and those most sensitive to the long-wavelength region (LWS cones). These three classes of photopigments respond to visible light and are generally believed to transmit their signals into a postreceptoral neurally trivariant processing system. This defines the three-channel color signal processing called trichromacy, which governs perceptual behaviors such as color matching [21].

Photochemistry of Color Vision by the Cones

Both rods and cones contain chemicals that decompose on exposure to light and, in the process, excite the nerve fibers leading from the eye. The light-sensitive chemical in the rods is called rhodopsin; the light sensitive chemicals in the cones, called cone pigments or color pigments, have compositions only slightly different from that of rhodopsin [22].

The photochemicals in the cones have almost exactly the same chemical composition as that of rhodopsin in the rods. The only difference is that the protein portions, or the opsins—called *photopsins* in the cones— are slightly different from the scotopsin of the rods. The *retinal* portion of all the visual pigments is exactly the same in the cones as in the rods. The color sensitive pigments of the cones, therefore, are combinations of retinal and photopsins.

Only one of three types of color pigments is present in each of the different cones, thus making the cones selectively sensitive to different colors: blue, green, or red. These color pigments are called, respectively, *blue-sensitive pigment, green sensitive pigment,* and *red-sensitive pigment.* The absorption characteristics of the pigments in the three types of cones show peak absorbencies at light wavelengths of 445, 535, and 570 nanometers, respectively [22]. The approximate absorption curves for these three pigments are shown in Figure: 1. Also shown is the absorption curve for the rhodopsin of the rods, with a peak at 505 nanometers [22].

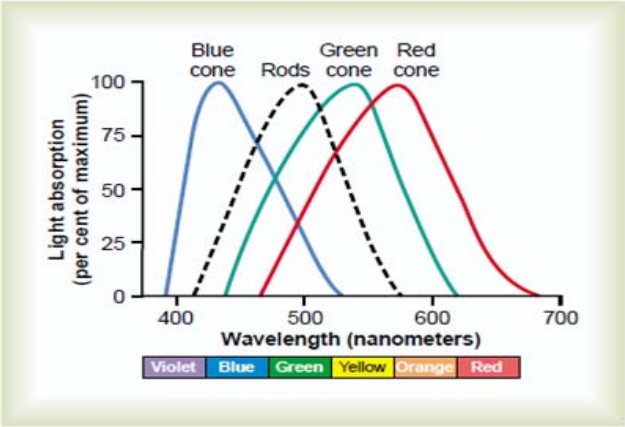

Figure: 1 Light absorption by the pigment of the rods and by the pigments of the three color-receptive cones of the human retina.

There is the linkages between individual's genetic potential for possessing retinal photopigments (or the visual pigments responsible for color perception) and individual color perception differences. Women with four-photopigment genotypes are found to perceive significantly more chromatic appearances in comparison with either male or female trichromat controls. Photopigment opsin genes, which are simply defined as the genetic sequences responsible for the response properties of the photosensitive material (i.e., opsin tuned cis-retina1) in human retinas. Retinal photopigments occupy cone cells in the retina that respond maximally to specific portions of the visible electromagnetic spectrum [21].

The biological basis of trichromacy

The 19th century Young- Helmholtz three-component theory developed the idea that color vision is trichromatic due to the presence of three retinal visual pigments, or "photopigments". Genetic research showed that color vision is a sex-linked trait, because the genes coding for Long Wavelength- Sensitive (LWS) and Medium-Wavelength Sensitive (MWS) photopigments are X chromosome inherited, and the genetic sequences associated with these photopigments were isolated [21].

Recent studies show that these commonly occurring genetic polymorphisms produce variations in spectral tuning of expressed photopigments. Such spectral shifts are attributable to amino acid substitutions at specific location in the opsin gene. The X-linked inheritance feature, when coupled with the possibility of opsin gene polymorphisms, allows for a considerable percentage of females to be heterozygous at certain critical amino acid positions for MWS or LWS opsin genes. That is, females who possess two distinct genetic variants at certain codons (with one variant on each of two X chromosomes). Long-Wavelength-Sensitive (or LWS) and Medium-Wavelength-Sensitive (or MWS) photoreceptors to denote retinal cones maximally sensitive to the long-wavelength portion of the visible spectrum and medium-wavelength portion of spectrum, respectively. By convention, the terms used in genetic research for photopigment opsin genes are red and green for LWS and MWS, respectively.

The gene corresponding to the short-wavelength-sensitive, or bluish-sensitive, photoreceptor is located on chromosome 7 and is acquired through autosomal inheritance. Another term for heterozygote females is "female carriers of color abnormality," or "carriers of color-blindness". Typically, female carriers of color abnormality are genetically heterozygous for red-green deficiency. That is, when genetically tested, they usually carry genes for both normal and abnormal photopigments (for one photopigment class) as seen in genetically identified heterozygotes [21].

Genetic Structure Underlying Visual Pigment Variation

Because the molecular structures of the LWS and MWS visual pigment gene bases are 98% identical to each other, there are relatively few locations in the amino acid sequences where the LWS and MWS genes can be differentiated by a genetic test. For the LWS and MWS pigment genes, these include only 18 variable amino acid positions. Substitutions of amino acids caused by differences in the genetic sequence can eventually produce different spectral absorption properties in retinal cones. These "dimorphic" or "polymorphic" sites are locations in the gene sequence where two different amino acids can be alternatively present. Among these 18 sites of variation, only 7 (at codons 116, 180, 230, 233, 277, 285 and 309) involve amino acid substitutions that produce shifts in spectral absorption of the X-linked photopigment opsins.

One position in particular, position 180 on exon 3 of the LWS and MWS genes, is one of three positions in the gene sequence (along with codons 277 and 285 at which LWS and MWS genes can be uniquely distinguished) where a single amino acid substitution determines a major portion of the spectral shift between LWS and MWS color vision pigments. This is exemplified by the fact that amino acid substitutions at codons 180, 277 and 285 can eventually transform a red-sensitive retinal photoreceptor into a green-sensitive photoreceptor, and vice versa.
This codon(serine-180-alanine) of the gene sequence is important because this position has the following properties: (1) It is one of the seven sites where an amino acid substitution or "polymorphism" occurs, (2) It is believed to produce some of the most substantial shifts in spectral sensitivity; (3) In general, shifts are readily apparent in codon 180 of the L-pigments but are either smaller or not detected in the M-pigments as evidenced by the measured spectral peaks; and (4) Substitutions occurring at position 180 are likely to yield the largest L-pigment peak absorption shift. Compared with relatively smaller spectral shifts produced by changes that occur at other locations in the gene array, the amino acid substitutions at position 180 play an essential role in producing individual differences in normal color vision and also play a role in modulating the severity of color vision defects. Thus, codon 180 is a crucial site to consider when investigating the impact of shifted-peak spectral sensitivity on perception [21].

Other Causes of Change in Color Perception

Color perception changes and degradation can occur naturally with age. Age related macular degeneration causes visual problems, including color vision deficits. Diseases, including Alzheimer's disease, diabetes and chronic alcoholism can cause color vision defects. Medications are also responsible for some cases of color perception changes. Drugs, such as antibiotics, high blood pressure medication and barbiturates, can cause changes in color perception. Toxic chemicals, such as carbon monoxide, fertilizers, styrene and carbon disulphide, may cause some color perception changes, and often the changes may be too subtle to notice. Less frequently mentioned eye trauma is also a cause of color vision deficits. Strokes and accidental eye injury can damage the retina or portions of the brain and lead to color blindness [23].

Alzheimer's disease

The lack of a color effect in Alzheimer patients' accords with the presence of color vision impairments associated with this disorder. The occurrence of senile plaques, neurofibrillary tangles and astrocytic gliosis in the striate cortex is consistent with the visual dysfunction in AD patients reflecting neuropathology of the visual cortex rather than the retina or optic nerve [24].

Diabetes

Diabetes, a complex metabolic disorder is frequently encountered in ophthalmic practice. The mechanism and causation of defective color perception in diabetics is a matter of conjuncture. In fact the complexities of diabetic retinopathy as well as the associated defects of color perception are little understood and theoretically a discoloration of lens, pre-mature senility, and disturbances of cone pigments, faulty perception or transmission owing to the pathological changes in neurons may individually or collectively contribute to loss of brightness or color perception. The color vision defects in diabetics have recently been well documented and reported a very high incidence of yellow-blue losses among diabetics even without retinopathy. However, they found the mean red green losses within normal limits in diabetics even with retinopathic changes [25].

Chronic alcoholism

A report suggests that color vision changes related to chronic alcoholism can occur in the absence of impairment of spatial luminance contrast sensitivity, suggesting that color vision evaluation is an important aspect to be considered in the clinical examination of this condition. Additionally, the changes in a subject's color vision may occur in the absence of pronounced anatomic changes of the eye fundus detectable by conventional retinoscopy.

Research also suggests that more advanced stages of chronic alcoholism, whether attributable to long-term exposure to ethanol or large quantities of daily ethanol intake, or because of the association between alcoholism and severe forms of malnutrition and vitamin deficiency, color vision dysfunction appears to be associated with decreased visual acuity, contrast sensitivity losses, visual field central defects, and anatomical signs of retinal damage, such as degeneration of the papillomacular nerve fiber bundle and atrophy of the temporal optic disk. Such deleterious effect are possible if retinal ganglion cell loss related to chronic alcoholism progresses from preferential damage to P and K ganglion cells involved with color vision in the first stages of the disease to include the several ganglion cell classes involved in achromatic vision in later stages [26].

Conclusion

Observers in color-perception research are typically screened for normal color acuity, using pseudo-isochromatic plates or a standardized hue test such as the Farnsworth 100-Hue, but separate analyses of males and females are not always considered or performed. This is despite indications that perceptually and cognitively, males and females may experience color appearance differently. Some of the research reviewed above supports the suggestion that these sex differences correspond to variations at the retinal level, but there remains uncertainty in the color vision literature concerning the connection between the two levels.

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