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How Understanding the Primary Function of the Human Eye in Low Light Can Benefit Digital Imaging Operators.

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Abstract

Color accuracy is essential in digital imaging for Cultural Heritage when reproducing an object into digital format. As a practitioner in the field, curiosity rose as to what the long-term effects are of working in a low-light environment after chronic fatigue and strained eyes became the daily norm. Multiple literatures were reviewed to extract the groundwork of color vision in low light and what achieves proper and consistent information processing; however, there were no known specific studies for the impetus for this topic. This research aims to explore color vision in low light to recognize potential short- and long-term physiological vision changes. Studies uncovered multiple variables impact human vision when processing an image or scene. This paper investigates the structure of the eye by comparing human vision to the structure of a camera system, the processing of color in the retina, the recommended viewing environment for cultural heritage capture, different conditions that impact perception, and solutions for regular eye maintenance. As is often said, awareness is the first step to prevention.

Introduction

Successful image capturing is predicated on understanding how the camera operates, from the general mechanics of the machine to maintenance. A camera system has five primary parts: the lens, the aperture, the shutter, the mirror, and, most importantly, the image sensor. The human eye has six primary parts: the cornea, the iris, the lens, the retina, the macula, and the optic nerves.

The eyelids serve as the shutter for the eye, while the iris serves as the aperture. The lens focuses the information going into the retina; the retina is equivalent to the camera sensor, which contains the photoreceptors that process light and color (rods and cones). On average, the retina has five to six million cones and one hundred million rods [1].

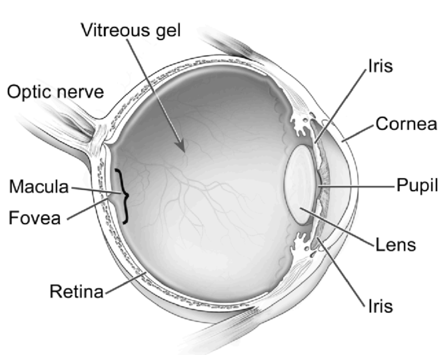

Figure 1 Demonstration of the major parts of the human eye. The retina wraps 80% of the eye's interior, where rods are lined. The cones are primarily clustered in the fovea. *National Eye Institute, 2019 [2]*

Optic researchers have found rods to be the light processors and cones to be the color processor units. This discovery has led to debates and further experimentations to uncover whether rods have the capacity to detect colors. Some literature explores the possibility of rod hue detection at the threshold of the electromagnetic spectrum where rods initiate color experience [3]. Results conclude that rods are achromatic, whereas night vision, or scotopic vision, is near black and white [4], lest the eye detects faint colored light. Figure 2 shows the spectrum of the three illumination gradients: low, medium, and high; scotopic, mesopic, and photopic. Mesopic vision is the mediary between low and bright light conditions. In this state, both rods and cones are activated relatively harmoniously. Meanwhile, in photopic, or daylight vision, light saturates the retina, and cones are the primary activated cells [5]. Digital imaging operators work in the higher end of the mesopic range as lights are often ambient or indirect.

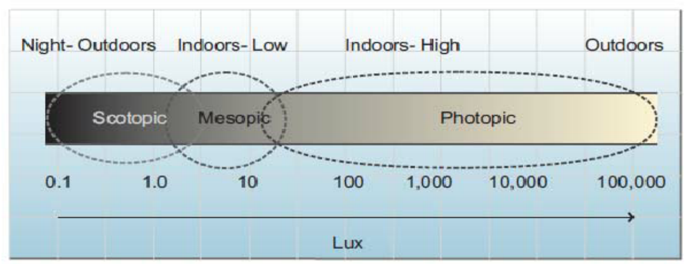

Figure 2 Spectrum of the three illuminance ranges. Clanton, Nancy E. "Scotopic, Mesopic and Photopic Ranges," [6]

Viewing environment for cultural heritage capture

Human vision is malleable, and many factors alter the perception of a particular scene. Thus, understanding the operators' modus operandi of visual processing can enhance and maintain sharp, accurate, and consistent observation.

According to the third edition of the Federal Agencies Digital Guidelines Initiative (FADGI), the viewing environment should match the displayed imagery on monitors during capture sessions [10]. The guidelines also offer detailed suggestions on how to adjust and calibrate both environment and device settings for optimal production performance.

A FADGI-compliant physical work environment should be light-controlled with no natural light flooding into the working space [10]; the lighting should be consistent to minimize fluctuations in perception processing since imaging relies on human judgment and the numerical measurements of light and color patches. The space should have the following [10]:

a. Painted in a neutral gray with 60% reflectance
b. Room illuminance temperature of roughly 5000k
c. Monitors positioned away from light sources to avoid reflections.
d. Separation of imaging stations

e. Calibrate the monitor to synchronize with the physical environment
f. Color monitors are set to a neutral mid-gray background.

Digital imaging requires an acute observation of non-spectral hues, including neutral tones that range from light to dark brown shades. The difference between the color space modals is evident when comparing physical items to images when progressing during capture sessions. For instance, when imaging an atlas or book, the depth of field and the object's distance from the lights may change slightly; in these cases, colors and tones may change.

The eye in different conditions

The eye adapts to brightness far quicker than it adapts to darkness. It takes an observer at least half an hour to almost completely adjust to darkness after bright light exposure, e.g., sunlight [11]. Longer duration of sunlight exposure necessitates a longer eye recovery time to absorb faint illuminance in latter conditions. The retina contains rhodopsins (also known as visual purple)— protein receptors attached to rods that process light, transforming photons into electrons that the brain processes. The visual purple gives the retina a purplish tint when it is in a fully recovered state. However, when the retina is exposed to intense luminance, it becomes bleached and opaque. The damage to the retina that occurs in such conditions temporarily blinds the observer until the rods are functional [5]. Thus, it may be best to minimize sunlight exposure when operating in ambient lighting to reduce the length of retinal recovery.

The discussed structure of the eye is based on average statistics of a healthy system. There are multiple contributors to color perception, both physiologically and psychologically, such as age, genetics, color literacy and adaptation, and cultural influence.

Age

The damage and transformation of the eye's lens occur either as one age, an ocular disease that impacts color perception and light detection, or even due to environmental pollutants. As the eye degrades, the lens's yellowing can occur, disrupting the absorption of blue light that disables the observer from experiencing saturated short wavelengths of light [12]. Pupils shrink over time for some individuals. The shrinkage disables light from reaching the photoreceptors—colors will appear darker, and pastel tones become difficult to separate. Furthermore, affected observers will see blues and purples as black, and certain shades of yellow will appear brown [1]. Due to the sensitivity of the S cone, the likelihood of a decrease in function over age is very high; in contrast, the L and M cone counts remain unchanged throughout one's lifetime [12]. There are many causes of eye damage due to age, such as sun exposure, cataracts, glaucoma, and other diseases that spread to the eye. Being aware of one's overall optical wellness will ensure traceable changes. Age is not always a factor in altering visual perception, as there are cases of younger individuals with visual abnormalities due to genetic disposition.

Genetics

Males tend to be more at risk of color deficiencies due to a single X chromosome in the genetic composition; females have two X chromosomes [13]. Females can compensate for losing an X chromosome, which makes up 0.5% of the female population impacted by color blindness. In contrast, 8% of males have some form of color deficiency (either protanopia or deuteranopia) [14]. Hereditary mutations can also cause gene arrangements based on familial genealogy and disrupted restructuring during female meiosis [13]. The combined male and female population with some degree of color perception impairment equals roughly 663 million worldwide.

Color literacy

Color literacy is subjective in nature, and, as a result, measuring an individual's ability to distinguish a vast amount of tints and shades is nearly impossible. Designers, physicists, artists, chemists, and other professionals are trained to observe minute changes in hue and chroma– the skills of these professionals accumulate over a long period and are often recognized as *experts* in their field. An average observer may need to gain the necessary vocabulary and skills to employ when deciphering nearly similar tones.

Color adaptation

Color adaptations occur from frequent exposure to certain levels and hues of colors, similar to the subconscious adaptation effect of cultural influence. Yet, color adaptation is often associated with luminance and technical measurements. A group of researchers from the University of Leeds utilized this method to reset their subjects' chromatic vision to measure *unrelated colors in photopic and mesopic conditions* [15]. In theory, adaptation has a long and short-term definition. Short-term adaptation is equivalent to visual calibration, and long-term adaptation targets the internal wiring of color perception. Metaphorically, it is like comparing an individual who had life-long acclimation to spicy foods to someone drinking milk to mitigate the effect of the spice.

Cultural influence

Individuals who are exposed to high levels of hues throughout their lives, based on their socio-cultural environments, may view certain colors differently. For example, a Scandinavian individual may have a neutral palette as part of their daily color consumption. In contrast, an individual from India may have a far more diverse, saturated hue exposure.

This difference plays a role in subconscious hardwiring, where the recollection of color levels differs. Moreover, the regional lexicon heavily alters a person's perception based on material association and environmental conditioning. Carl Ratner studied the effect of social perception in relation to the natural form of color perception. He found subjects' reactions towards certain values to relate in opposition to collective agreement by labeling colors as "dull" or "pretty" [16]. Hypothetically, cultural influence can be retrained if dissociated from social demand.

Result and conclusion

Despite the numerous factors contributing to the rewiring of chromatic perception, the brain is adaptable. Nevertheless, understanding the multiple variables of structure, processing, and environmental contributors to vision helps operators take necessary measures to maintain eye health, shorten training periods, and rationalize varied production outcomes.

Every imaging project will require setting lights at different heights and varied intensities. To prepare the eye to function optimally in indirect or ambient lighting, one should allow the eye to adapt to such conditions for at least 30 minutes to an hour before engaging in image capture sessions and even more during visual editing.

Another option would be to allow the recalibration of the eye to adapt to the working light condition while preparing for the initial set-up of the Lens Cast Correction (LCC) process in the Capture One program or other software that corrects lens and lighting falloff.

Low-light working environments activate rod cells more than cone cells due to restricted illumination, leading to decreased visual acuity for some individuals. In such cases, operators, with the aid of their doctors, can find prescription glasses that compensate for low vision acuity [17].

Vitamin A deficiency is the degeneration or lack of opsin proteins that latch onto the outer segment of a rod cell. Minor deficiency can be recovered within two to three hours after consumption of vitamin A, improving night vision. However, if the deficiency is too severe, then the cell structure is compromised, eating away the inner lining of the rods further, making them irreparable. Also, the study states that changes occur in the central rods before affecting the peripheral. There are natural sources of vitamin A supplements, but consuming the liver may be the best medicine [18].

Here are additional suggestions that may benefit digital imaging practitioners long-term:

1. Maintaining eye health to keep track of the possibility of degression of either the pupil or the cornea
2. Including vitamin A intake in dietary supplements to strengthen night vision.
3. Allowing the eye adequate rest before work by minimizing intensive lighting before sleep
4. Recognize signs of dry eyes and/or fatigue, and apply moisturizing eye drops as needed.

Finally, space brightness is not always an issue as available tools in the market measure the lumens and color temperatures, known as light and color meters, of a workspace for comfort on the eye and enough illumination for safe handling. For collective benefit, there are plans in the works for developing a formal survey to gather feedback from colleagues on their experiences working in low light, provide a platform for an informal discussion and sharing resources on the impact of working in low light conditions, and collaborate with experts to create a monthly visual color test to enhance color literacy and tonal differentiation.

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Author Biography

Nora Ibrahim has been experimenting with photography since 2015, and preparing for her MRes in the studies of Comprehension and Perception of Color at the beginning of 2020. She has been working for the Osher Map Library and Smith Center for Cartographic Education's Digital Imaging team since 2018. Her academic goal is to better understand the correlation between light and subconscious processing.