Building and Environment 127 (2018) 148–156

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Saturation based color appearance of objects: A comparison between healthy elderly, young adults, and young adults wearing goggles simulating cataract

Asha L. Hegde*, Nicholas Bishop

School of Family and Consumer Sciences, College of Applied Arts, Texas State University, 601 University Drive, San Marcos, TX 78666, USA

A R T I C L E I N F O

Keywords:
Aging eye
Cataract
Color perception
Color appearance
Color preference
Color saturation

A B S T R A C T

Proper use of light and color in the built environment benefits all users, especially ones with reduced visual functioning such as older adults and low vision individuals. In this study, differences in saturation based color appearance of objects were compared between young eyes, old healthy eyes, and young eyes wearing foggy/yellowing goggles simulating cataract. Four color—Red, Green, Blue and Purple—and three saturation levels were manipulated when holding illuminance and value within each of the 4 colors constant. The perceived value of donning simulation goggles by the young was also assessed. Results indicated that there were no significant differences on saturation based color appearance between the young and the older healthy eye in the test situations. Young subjects wearing goggles rated all color appearance characteristics higher for color red than the young without goggles at all three levels of saturation, indicating that the goggles simulated the yellowing deficiency well. Regardless of visual conditions the color blue was perceived the best in high saturation, but in low saturation, the reverse was true where blue was rated low with regards to color appearance characteristics. Color purple which is more of reddish purple was perceived the best in low saturation. This study indicates that when considering color in the built environment, specifying color only by name (i.e. red, blue etc.) can be problematic. Saturation of the color is an important component and its application can provide individuals of all age groups and visual capabilities a supportive visual environment.

1. Introduction

The U.S is entering a period in which there will be unprecedented numbers of elders in the population, increasing from around 43.1 million in 2012 to an estimated 83.7 in 2050 [1]. This trend is also reflected globally. With progressing age, structures of the eye change due to biological senescence and "wear and tear", including increases in blue-light absorption due to accumulation of yellow pigments in the eye lens [2], affecting visual functioning such as visibility, decreased contrast sensitivity, and color perception [3,4]. In the built environment, color and light play an important role in providing the right ambience, enabling one to see, helping to move through the space safely, providing wayfinding cues, and affecting the overall wellbeing of the individual [5]. While all people can benefit from applications of good light and color in the built environment, it becomes even more critical to consider good visual cueing through light and color to enable normal healthy elderly who have reduced visual functioning and people with low vison to experience the built environment safely and with confidence [6]. It is imperative that designers, architects, environmentalists, planners, gerontologists, and others who make decisions about the composition of the interior environments occupied by elders clearly understand the effects of aging on color and light perception. Equally important is for young adults (architecture, design, and interior environmental professionals and students) who design for the older population to get better insights to how individuals with reduced visual capabilities see color and appearance of objects. The health professions have long used simulation based learning successfully in academic as well as professional settings [7]. Similarly, using simulation goggles that emulate compromised visual capabilities (such as cloudy and yellowing lens/cataract) can benefit young designers by emulating the visual experience of color as seen by the older eye.

The study's two main objectives were: First, to study what colors and saturations provide the best visual perception of object color for users of diverse visual abilities including young and the old. Second, to identify whether donning goggles that simulate yellowing and cloudy crystalline lens conveyed the experience of "blue blindness" and cataract associated with the aging eye. The results from the first objective relate to the idea of the 'inclusive design' approach [8,9] where the

* Corresponding author.
E-mail addresses: ah16@txstate.edu (A.L. Hegde), nicholas.bishop@txstate.edu (N. Bishop).

https://doi.org/10.1016/j.buildenv.2017.11.007
Received 19 July 2017; Received in revised form 16 October 2017; Accepted 5 November 2017
Available online 06 November 2017

findings will provide some understanding of what colors and color attributes have an effect on color appearance of objects that might benefit many users including healthy elderly and low vision populations that have *reduced visual* functions, making the built environment safer and less frustrating to negotiate. Additionally, academicians will gain insights to the possible value of incorporating simulation based learning experiences in the design curricula.

2. Literature review

We depend on light and vision to negotiate our environments and it is important to study how light in conjunction with color effects the overall visual perception of objects and space. Light is radiant energy that is capable of exciting the retina (which contains photoreceptors), creating visual sensations [10]. With progressing age one experiences physical, social, and cognitive changes, many of which are characterized by senescence and decreasing function. Similarly, the aging eye experiences physiological changes in the retina. Changes in pupil size and yellowing and thickening of the lens reduce the amount of light and short wavelengths reaching the retina [3,4]. These changes adversely affect visibility, color discrimination, contrast sensitivity, and adaptability [10].

It seems prudent to study how the aging eye views color and its various dimensions (hue, value, and saturation) and what aspects of color provide the best visibility to the aging eye. It is up to the architect/designer and planners to make meaningful choices about color with regard to selection and application of surfaces such as walls, floor, furniture, signage, and wayfinding for both indoor environments as well as outdoor spaces. To compensate for visual problems, it is believed that increased color contrast and an ability to discern color appearance of objects, helps the older adult see and negotiate the built environment more effectively. Bright at al [6]. state that color plays an important role in the movement and safety of all people in environments but that color considerations become even more important for people with low vision and visual impairment. To compensate for visual problems, attention to environmental factors of color and lighting can positively impact the sense of well-being of low vision individuals as they use the environment (ibid.).

Most color research falls under either color preferences or color discrimination. Color preference research [11] suggests a rank order of color preference, with blue being the most preferred, followed by green, red, violet, orange, and yellow. Dittmar [12] investigated color preferences by using color names among young adults and older adults. Overall participants ranked the colors blue, green, red, and yellow from most to least preferred. Further, results in age-group differences indicated that with advancing age, preference for the color blue decreased while the preference of green and red increased. Beke et al. [13] also examined the relationship between color preference and age of observer where they found that long term compensation of preferred hues for the aged was consistent with lifelong color constancy. Beke et al. [13] also found that the aged need more chroma than the young to match a reference stimulus, especially in the color blue region, followed by similar tendencies in the color red. Age effects on color emotion and preference [14] suggests that while the 'relative' values of color appearance regarding chroma did not change much for the aged, the 'absolute' value of attributes such as 'colorfulness' declined.

When pictorial content and images are used in color preference and color perception studies, findings indicate that color and chroma preference of simple contextless images (such as small squares of color) differ significantly from that of images [13]. The Ecological Valence Theory—EVT [15] states that color preferences of liking/disliking are a combination of events associated with a particular color. Schloss et al. [16] examined color preferences for specific objects and found that people preferred saturated colors for contextless squares, but not for actual objects. For the most part, people preferred objects such as cars, clothing, couches, and pillows to be darker, with the exception of things like walls. Schloss, Strauss, and Palmer [16] speculate that this may be related to differences in functionality of the objects—for example, lighter walls make a room look bigger, thus causing people to prefer lighter colors for that object. Color preferences may also be related to the image that people want to project through the use of an object such as a car, or to colors that are more commonly found for certain objects. Experiments conducted by Strauss and colleagues [17] regarding color preferences of colored objects indicate that the preferences are deeply influenced by affective experiences with colored objects and its existing associations. Further, Schloss and Palmer [18] suggest factors such as symbolic associations, and use of color in particular object design or applications contribute to color preference.

Research on color discrimination by the aging eye using the Lanthony Color Test indicates that as age increases, the number of errors in color judgment increases [19], especially at the lower levels of saturation [19,20]. Hegde and Woodson [21] studied the effects of light, light level, and color (red, green, yellow, and purple-blue) on measures of visual clarity in young adults and found that the color yellow resulted in the poorest visual clarity, while green was evaluated as having the best visual clarity.

Suzuki et al. [22] studied reaction time and subjective evaluation for low contrast color presented on cathode ray tube (CRT) displays among elderly, young adults, and young adults wearing visual filters simulating yellowing of the lens typical of an older eye. Their results indicated that the filters worn by the young adults were effective in simulating the visual perception of the older adults. Another study by Suzuki et al. [23] found that both young adults without visual filters and older subjects rated blue and grey color stimuli lower, though the older adults took a significantly longer time to rate the color stimuli. These results suggest that the yellowing of the optical lens negatively influences the reaction time on color evaluation among older adults. The extra time taken to evaluate color contrast is attributed to the decreased motor and cognitive processing of the older adults.

In their study of color appearance and visual performance, Ikeda et al. [24] used foggy goggles to simulate the cataract (cloudy crystalline lens) experienced by older adults. Their results indicated that the larger the size of the area used to display the color (they used color patches in their experiment), the less the environmental light from the surrounding area had an effect on the color perception and desaturation of the color, leading to greater overall perception of the color presented. The scatter of light from the foggy goggles showed that the color appearance is desaturated by environmental light scatter. It is believed the size and visual distance from the color patch play an important role in color perception since the focus of the foggy filter (eye) is on the color and is therefore influenced less by the scatter of light on the lens.

3. Current study and research questions

The current study builds on previous color appearance and saturation-based color research. If young designers, architects, and planners are tasked with choosing the colors used in the built environment, what methods can be used to effectively mimic the visual limitations experienced by older adults? To answer this question, knowing how users of interior spaces with diverse visual capabilities see and rate color appearance of objects is necessary. Second, does wearing cataract simulation glasses by young adults mimic the visual limitations experienced by the aging eye adequately? If so, simulation goggles could be used as a tool to sensitize the designer to the diversity of human visual abilities and limitations, making their designs respond to the needs of many users in an environment.

In an earlier experiment, sixty elderly subject's subjective visual clarity evaluation of four colors (red 5R, blue 5B, green 5G, and purple 10P) in three saturation levels (high, medium, low) under two commonly used light sources—warm white (3000 K) and cool white (4150 K) fluorescent lamps—were compared on five measures of color appearance [25]. In order to compare age differences in preferences of