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Senescent Effects on Color Perception and Emotion

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Abstract Senescent effects are the gradual deterioration of function caused by biological aging. Senescent effects on color vision are not clearly understood even after considerable researches. Part of the reason is that the color vision is a complex phenomenon resulting from various factors such as organic systems, and the physical (neuro-optical) and the psychological (experiential) processes of color perception. We performed a field experiment on color perceptional differences due to aging vision. Our experiment was applied to two different groups in South Korea: an experimental group (46 subjects of over the age of 61 years) and a control group (49 subjects in their twenties). The experimental tools are comprised of (1) six gradual yellowing detector board (40%, 50%, 60%, 70%, 80%, 90%); (2) pairs of vivid-strong, vivid-deep, grayish-deep, deep-dull, and bright-light tones of Blue (B) and Purple (P) colors; (3) Red (R), Yellow (Y), Green (G), Blue (B), and Purple (P) colors of dull-tones and pale-tones; and (4) a questionnaire on the semantic differential scales of the color images and color differences. A diagnosis system of gradual yellow vision, developed by the authors for this study, was adapted to generate the color detecting boards. The results are as follows. (1) There are significant differences between the two groups in detecting colors that simulate 40% and 50% of yellow vision. (2) As to the color difference detecting ability between similar tones, the experimental group shows difficulties in pairs of vivid-strong tones and deep-dull tones of the B color. And (3), the emotional responses to the dull tone and the pale tone are not stable in the red, the yellow, blue, and purple. Thus, we empirically demonstrate the specific differences in color perception between the old and young groups.

Keywords: Color vision, Light transmission, Color difference detection, Color emotional response

1. INTRODUCTION

A color used in a built environment has an impression, a function, and a meaning. The effects of colors, even in the same context, could produce different responses depending on the viewer's visual ability, which is called color vision. Color vision is a complex phenomenon resulting from specific organic systems, and physical (neuro-optical) and psychological (experiential) processes (Shinomori et al., 2001; Knoblauch et al., 2001). Aging is one of the most important variables related to differences in color perception. Most studies (Boettner et al., 1962; Norren and Vos, 1974; Pokorny et al., 1987; Weale, 1986; Kessel et al., 2010) have shown that the colors experienced by the aged are perceived differently compared to those experienced by the young under the same conditions. However, some researchers (Werner, 1982; Wright, 1988) are more cautious in suggesting that aging vision changes simply because of senescent effects on ocular media.

Among several reasons attributed to senescent color vision (such as the ocular system, retina, optic nerve, and brain stage), lenticular change has been accepted as the major factor. Older eyes transmit less light, especially at shorter wavelengths, since the crystalline lens becomes denser and yellow pigments in the lens increase (Boettner and Wolter, 1962; Pokorny et al., 1987; Weale, 1986; Kessel et al., 2010). However, the difference between young and old observers is mitigated because color perception is also affected by the compensation during the process (Werner and Craft, 1994, 1999). In fact, the viewers commonly perceive colors with good constancy despite the apparent evidence of lenticular senescence (Weale, 1988), sensitivity losses in cone mechanisms (Werner and Steele, 1988), neuronal cell losses, and morphological changes (Kilbride et al., 1986).

Therefore, the senescence in normal color vision should be examined with caution because there could be complex reasons caused by the ocular media, or by the receptoral and the postreceptor process of light. In this study, we focus on changes in color vision using the viewer's responses, color perception, and emotion. The ultimate purpose of using colors in an environment

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(the environmental color design) is not only to transfer the proper functions and meanings, but also to make a good impression on the users. Our experiments for comparing the response of the aged and the young were applied to two different groups in South Korea: the experimental group (46 subjects over the age of 61) and the control group (49 subjects in their twenties). Technical tools, color stimuli, and scales were designed for a color appearance test and for the environmental color design. These include a distorted color perception detector system, a color emotion measurement scale that is composed of the pale tones and dull tones of red, yellow, green, blue, and purple.

2. THE AGING OF COLOR VISION AND ENVIRONMENTAL COLOR DESIGN

In a built environment, color makes an impression on its users, causes an emotional response, and consequently affects the usage of the space. Responses to environmental colors depend on the individual and the context, and also have commonalities with respect to culture, age, and class (Cho and Lee, 2008; Kim, H., 1995; Kim, M., 2010). With the rapid growth of an older population, researches on the senescence effects of color vision have increased. It has been proved that the aged have different color perception, and demand special color controls that work for their color vision (Cho & Chang, 2006; Chung et al., 2003; Ou et al., 2012; Yoshida & Hashimoto, 1989).

2.1 Aging and color vision changes

Factors that can affect color vision include the lenticular senescence, the sensitivity losses in the cone mechanism, the neuronal cell losses, and morphological changes (Werner, 1996). Although the changes in color vision due to age are complex (Norren and Vos, 1976), it is commonly accepted that macular pigment and the yellowing of the lens mainly affects the perception and the response to the aging of color vision (Pokorny et al., 1987; Weale, 1986). These changes cause different absorption of light with respect to the spectral wavelength. Subsequently, the user experiences the environment with a different color appearance. There are two different opinions on whether the lens density changes prior to the age of 20 (Said and Weale, 1959) or 30 (Norren and Vos, 1976, p.1241), or changes constantly during an entire lifetime (Werner, 1982). It is certain that the increase in the density accelerates after the age of 60, as proved from psychophysical, photographic, and physical studies (Fig. 1, Fig. 2).

In most cases of human behavior and environmental design studies, interest in the aging of color vision has concentrated on the yellowing of the lens (Akashi & Nakagawa, 2012; Cho & Chang, 2006; Chung et al., 2003). Researchers have tested whether the color appearance and the color preference of the elderly are affected by yellowing. Tests showed that the yellowing of the lens could be related to color preference of the elderly; that their emotional responses are different from those of the young (Cho & Chang, 2006; Jun & Cho, 2006; Cho & Lee, 2008); and that the yellowing affected visual performance (Akashi and Nakagawa, 2012). Simulation using an artificial yellow lens showed that the environmental sign system seen every day on the streets or at the subway stations would not work efficiently to the yellowing eye (Fig. 3).

Several psychophysical approaches support the constancy of color appearance based on calculating the effects of the ocular media for an achromatic point, and by demonstration that there is no significant change in the achromatic loci (Werner and Schefrin, 1993a, 1993b; Werner, 1996). The fact that a constant achromatic locus occurs through aging shows that the changes in the retinal stimulus are adjusted for lenticular senescence. Ou et al. (2012) also states the following: "As one ages, there is a decline in transmittance of the crystalline lens for short-wavelength light due to increase in ocular media density (OMD). While this may imply that the same color is perceived as more yellowish by older people than by younger adults, evidence has shown this might not be the case. The visual system seems to be able to adapt itself to age-related changes so that lights and surfaces retain relatively consistent appearances across the lifespan (Ou et al., 2012, p92-93)."

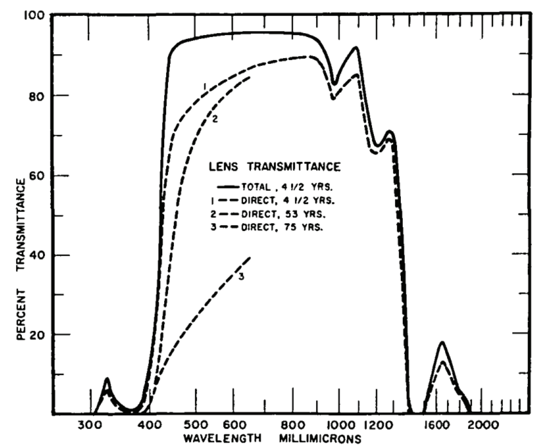


Figure 1. Transmittance of the lens
(Scource: Boettner & Wolter, 1962, p.779)

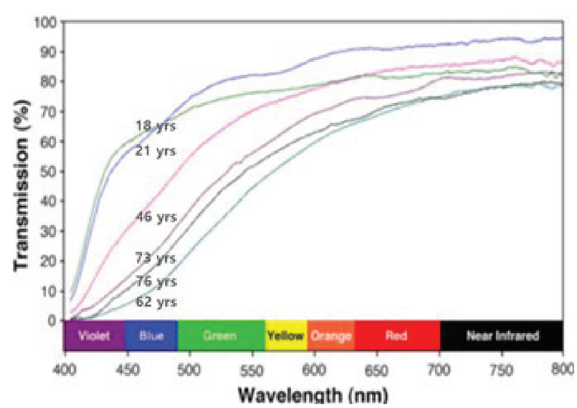


Figure 2. Spectral transmission in vitro of human donor lenses aged 18,21,46,62,73, and 76 years (Scource: Kessel et al., 2010)

Figure 3. The directional sign board photographed with a YA3 filter
(a substitute lens for vision of 75 years old)
(Source: Japaness Institute of Architects)

2.2 Color control for the aged

Studies related to color control or color design for the aged are categorized into two representative streams: one is the color preference of the old, and the other is color appearance including yellowing. The former varies from a preference for simple unique colors (Jun & Cho, 2006; Kim, H. 1995) to a color combination of two or more colors (Song, 2008; Cho & Lee, 2008). These studies mostly measured the preference using numbering scales, and sometimes evaluated emotional scales using functional or aesthetic adjectives (Ou et al., 2012; Park, 2011). The latter concerns the senescence of the ocular system and the perceptual changes of colors in the elderly (Cho & Chang, 2006; Chung et al., 2003). The hypotheses of these studies are based on the fact that color vision changes with age mainly because the density of the crystalline lens becomes higher and the yellow pigments in the lens increase.

2.3 Behavioral approaches used to measure senescent color vision factors

2.3.1. Distorted color perception by yellowing

Yoshida & Hashimoto (1992) considered the yellowing of a crystalline lens to be the main cause of color vision changes in the aged. They measured the subjects' (age 65-94 years) color perception ratio through seven color samples, each reflecting a yellowing percentage (0, 20, 40, 50, 60, 80, and 100%). The subjects were asked to select the 100% yellowed color, and almost one-half of those in their 80s and 90s were reported to have selected the wrong answer. In a similar experiment performed by the Japan Interior Industry Association (2001) using blue and yellow colors, 33% of the aged compared to 57% of the young responded correctly to blue, and 50% of the aged compared to 75% of the young responded correctly to yellow. These results prove that distorted color perception becomes severe in the blue realm because the yellowing lenses transmit less blue light at the short wavelength.

Schefrin and Werner (1993) used color naming to find age-related changes in color appearance. The observers, which were comprised of 15 younger subjects (mean age of 21 years) and 15 older subjects (mean age of 72 years), were asked to scale (in terms of percentage) each fundamental hue: red, green, yellow, and blue. The results failed to reveal any significant overall differences between hue-naming percentages for the younger and older subjects (Werner, 1997, p. 624). As a psychophysical approach, color-matching experiments were adapted to calculate an achromatic point. Although the experiments were based on the hypothesis that there is an age-related change in the stimulus perceived as achromatic, there was no significant change in the achromatic loci as a function of age.

In this study we adapted a behavioral approach using a yellowing level detector and similar tones of the short wavelength colors (blue and purple).

2.3.2 Color emotion

Colors affect the viewer; for example, they can cause excitement, energy, or calmness. This has been referred to as color meaning (Wright and Rainwater, 1962; Taft, 1997), color image (Kobayashi, 1981), and color emotion (Ou et al., 2004, 2012). Kobayashi (1981) used the semantic differential method to transform colors into images and images into colors with technical and statistical analysis. He devised a color image scale that has three dimensions of color emotion comprised of warm-cool, soft-hard, and clear-grayish axes. Ou et al. (2012) measured the color emotions of 20 young subjects (mean age of 24.5 years) and 20 older subjects (mean age of 64.8 years) with three word pairs corresponding to the three principal dimensions of color emotion (warm-cool, heavy-light, and active-passive) and a color preference scale (like-dislike), which also identified a significant dimension of color emotion.

While Ou et al. (2012) chose the scales and analyzed them through a quantitative process, Park (2011) selected eight pairs of adjectives corresponding to three physical attributes of color through the qualitative approach using a professional panel, including a Korean linguist, and three colorists. The eight pairs are warm-cool (hue), bright-dark (value), clear-dull (value, saturation), hard-soft (value, saturation), lush-austere (saturation), pleasant-gloomy (saturation), active-passive (saturation), and strong-mild (value, saturation).

Seven word pairs were chosen from recent studies to compare color emotion between the young and the old, considering the universal color-emotion factors (Table 1): ***warm-cool, clear-dull, light-heavy, active-passive, soft-hard, bright-dark, and like-dislike.***

Table 1. Color emotional scale by color attributes and color preference

Color Attributes	Hue	Warm-Cool
	Value	Bright-Dark Light-Heavy
	Value, Saturation	Vivid-Dull Soft-Hard
	Saturation	Dynamic-Static
Color Preference	Like-Dislike	

3. METHODS

We compared the perceptual responses for the color stimuli between two groups: an experimental group and a control group. 46 subjects of the experimental group and 49 of the control group participated the experiment and answered a questionnaire.

3.1 Color stimuli

The color stimuli are composed of two parts: one for the measurement of color appearance distortion, and the other for the measurement of color emotion.

Color appearance distortion was scaled by using a yellowing detector and a similar tone detector. A diagnosis system of gradual yellow vision was developed in a previous study (Kim et al., 2013). The degree of yellow vision was simulated using transmission data of a Y2 yellow filter, and the color differences between a normal vision (before applying yellow filter) and a yellow vision (after applying yellow filter) were calculated. The system selects and presents color combinations in the last phase that are distinguishable in a normal vision but indistinguishable with a yellow vision.

Six color patches were designed to detect a yellowing level form 40% to 90%. Random numbers from one to nine were written on the patches. The color combinations of backgrounds and numbers were selected by the diagnosis system. A similar tone detector was designed using blue and purple of similar tones: vivid-strong, vivid-deep, grayish-deep, deep-dull, and bright-light tone.

Color emotion was scaled using five basic colors and two tones: dull tones and pale tones of red, yellow, green, blue, and purple (Table 2). Instead of using identical colors such as vivid tones, dull tones and pale tones were selected because these tones are commonly and widely used for environmental design, and can effectively represent the influence of lightness, chroma, and hues on color emotion.

All the color stimuli were presented on 9 x 9 cm color patches through a computer display at a viewing angle of 10°.

Table 2. Munsell notation of color emotion stimuli

Tone	Color				
	R	Y	G	B	P
Pale	5R 8/4	5Y 8.5/4	5G 8/4	5B 8/4	5P 8/4
Dull	5R 5/6	5Y 5/4	5G 5/4	5B 5/4	5P 4/6

3.2 Subjects

The subjects were grouped into an experimental group and a control group, in order to compare functional changes in color vision due to aging. The ages of the experimental group are distributed from 62 to 81 with a mean value of 71.3, and the control group ranged from 19 to 29 with a mean age of 22.6. Five in the experimental group (10.9%) and ten in the control group (20.4%) are males.

3.3 Settings

The experiment was carried out in a casual interior space with dimensions of 4 x 4 m, illuminated by both natural and artificial lighting from 10:00 am to 4:00 pm. Direct daylight and the luminance level were controlled. The ambient lighting level was set from 700 to 900 lux. Generally, the results of the subjects' color responses differed by eye condition adapted to light or dark; therefore, conducting the experiment under a normal environment was important in order to obtain proper results. Thus, a casual ambient lighting room was chosen in our study, although most color vision tests are performed in dark rooms. The computer models and the monitor were calibrated using a Spyder 4 ELITE display calibration system. The luminance level for the display peaks was white 250 cd/m2, with chromaticity coordinates of (0.3130, 0.3290). This is close to the D65, standard illuminant (0.31271, 0.32902).

3.4 Procedure

The subjects were exposed to three color stimuli, and answered the questionnaire on color differences and their emotional responses. Three trained assistants worked with the experimental group. Only subjects who had taken the Farnsworth Munsell 100 hue test and obtained the appropriate qualification participated in the experiment as the control group. Twelve pairs of color patches to detect yellowing form 40 % to 90 %, ten pairs of two different tones of B and P color patches, and ten color patches comprised of five colors of two tones were presented in order.

4. RESULTS AND DISCUSSION

4.1 Progress of yellowing vision

The yellowing of vision that a human experiences with advancing age has been simulated using optical yellow filters such as Y2 and YA (Cho & Chang, 2006; Hashimoto, 1991). Measuring the yellowing, however, should be considered to be a gradual progress because it is a gradual change of visual function and not an immediate symptom.

In this experiment, a gradual yellowing filter was used to apply a certain amount of transmittance from 0 to 100%, and was adapted to measure the subjects' color vision. An algorithm for simulating yellow vision was developed based on physical attribution of the Y2 filter in a prior study (Kim et al., 2013). Pairs of colors that could detect yellowing from 40% to 90% were picked through this diagnosis system of gradual yellow vision. They are used for the colored patch and random numbers on it. The subject had to answer a correct number that were placed on a pair of squares (Fig. 4).

All the subjects of the control group gave the correct answer (100%) for any percentage of yellowing detector. Some subjects of the experimental group could not distinguish colors of a number and a patch presented with the 40% and 50% yellow filter. Fifteen subjects (32.6%) and fourteen subjects (30.4%) of the experimental group could not answer correctly to the detector boards of 40% and 50%. No subject of the experimental group gave wrong answers with the 60% detector board; five subjects gave wrong answer with the 70% detector board; four subjects gave wrong answers with the 80% detector board; and one subject gave wrong answers with the 90% detector board. These results suggest that less than one-half of the subjects in their sixties and seventies experienced 40% or 50% of yellowing (Fig. 5).

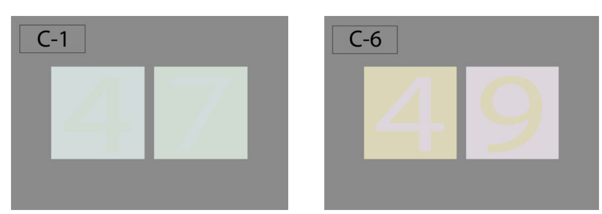


Figure 4. The sample tools to measure progress of yellow vision

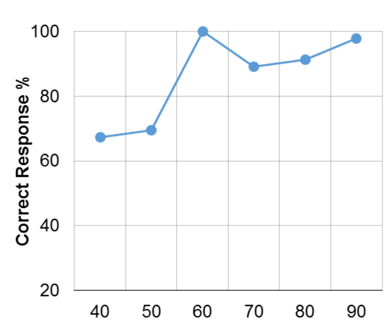


Figure 5. Response rate to yelloing detector of experimental group

4.2 Perceptional difference for short wavelength colors, B (blue) and P (purple)

The light transmittance of the human eye decreases with age, and is worse in the short wavelengths. Melanopsin in the crystalline lens (with an absorption peak at 480 nm) is one of the main causes. Thus, blue (450 to 489 nm) and purple (440 to 449 nm) are frequently mentioned when comparing the difference in color perception between young and old adults. We chose similar tones of blue and purple such as *vivid-strong, vivid-deep, grayish-deep, deep-dull, and bright-light* and asked the subjects how different the pairs of colors seemed. The scale was varied in four steps: 4-very distinguishable, 3-somewhat distinguishable, 2-rarely distinguishable, and 1-undistinguishable.

Significant differences were found in the vivid-strong pair ($p < .05$) and the deep-dull pair ($p < .05$) of blue between responses of the experimental group and those of the controlled group. Responses to any pair of purple colors did not show a significant difference between two groups. The mean value of the experimental group for the vivid-strong pair is 3.41 (SD= .80), and that of the control group is 3.35 (SD = .75). The mean value of the experimental group for the deep-dull pair is 3.80 (SD = .59) and that of the control group is 3.65 (SD = .69). The experimental group distinguished well between less saturated tones of blue, but did not do well between more saturated tones, compared to the control group (Fig. 6, Fig. 7).

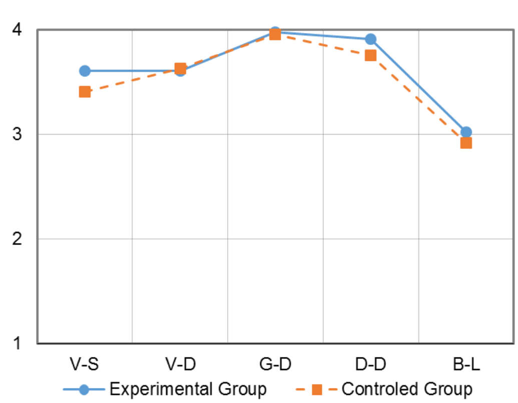


Figure 6. Color differentiation between similar tones of blue.

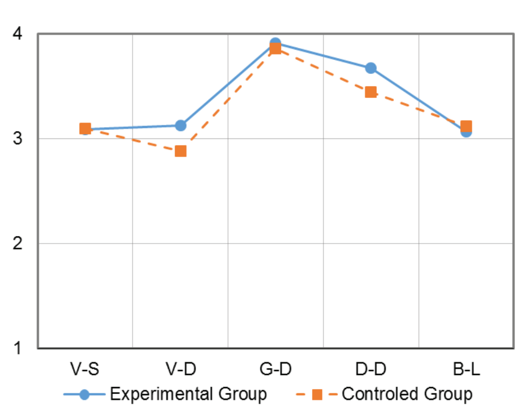


Figure 7. Color differentiation between similar tones of purple.

4.3 The color emotional difference

The subjects' color emotion in response to pale and dull tones of five basic colors was measured using the seven color emotion factors: *warm-cool, clear-dull, light-heavy, active-passive, soft-hard, bright-dark, and like-dislike*. The difference in the subject group's color emotional responses were validated using t-test analysis (Table 3).

The subjects' responses for pale red and dull red differed significantly between the experiment group and the control group. Responses for pale red showed the statistical difference with respect to the clear-dull factor with a significance probability of $p < .001$; the light-heavy factor with $p < .01$; and the active-passive factor with $p < .05$. The responses for dull red also showed statistical differences with respect to the light-heavy, the active-passive, and the bright-dark factors with $p < .001$. The experimental group answered that the pale red sample was clearer, lighter, and more active, and the dull red sample was less heavy, less passive, and less dark compared to the answers of the control group.

The responses to the pale yellow showed statistical differences with respect to the clear-dull, the light-heavy, and the active-passive factors with $p < .001$. The responses to dull yellow showed statistical differences with respect to the light-heavy and the active-passive factors with $p < .001$, and the bright-dark factor with $p < .05$. The experimental group answered that the pale yellow was clearer, lighter, and more active, and the dull yellow was less heavy, less passive, and less dark compared to the answers of the control group.

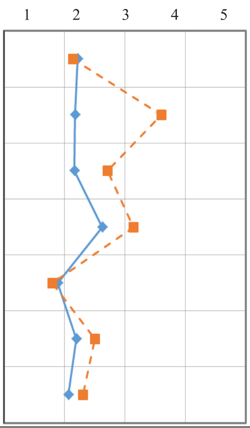
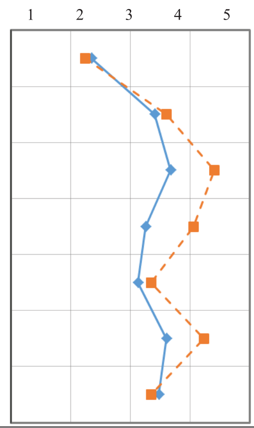
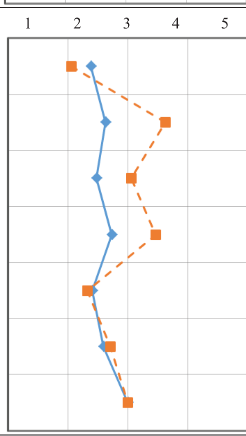
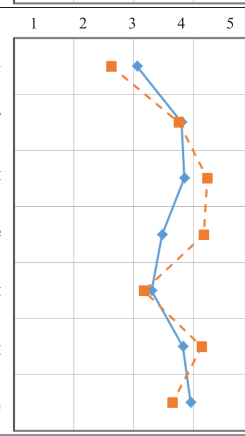
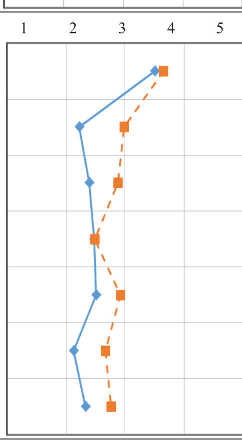
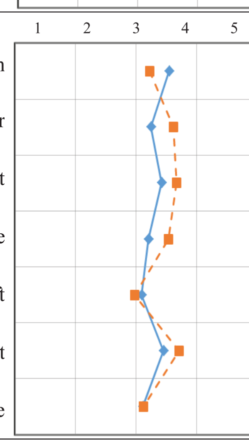
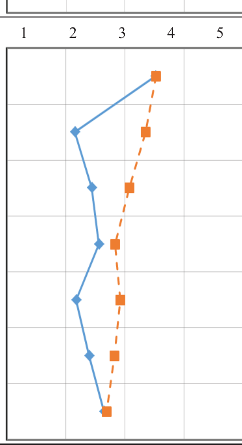
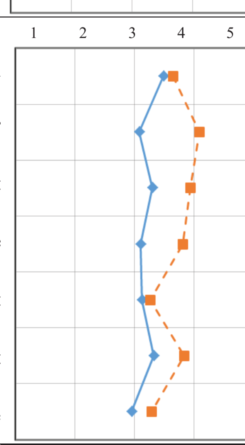
The responses to the pale green showed statistical differences with respect to the clear-dull with a significance probability of $p < .001$, the light-heavy and the bright-dark factors with $p < .01$, and the soft-hard factor with $p < .05$. The answers to the dull green did not show any significant differences. The experimental group answered that the pale green was clearer, lighter, brighter, and softer compared to the control group.

The responses to the pale blue showed statistical differences with respect to the clear-dull, the light-heavy, and the soft-hard factors with a significance probability of $p < .001$ and the bright-dark factor with $p < .05$. The responses to the dull blue showed differences in the clear-dull, the light-heavy, the active-passive, and the bright-dark factors with $p < .001$. The experimental group answered that the pale blue was clearer, lighter, softer, and brighter, and the dull blue was less dull, less heavy, less passive, and less dark compared to the control group.

The responses to pale purple showed differences in the clear-dull, the light-heavy, the active-passive, the bright-dark factors with $p < .001$, and the soft-hard and like-dislike factors with $p < .05$. The responses to the active-passive factor for the dull purple were differentiated in two groups with $p < .001$.

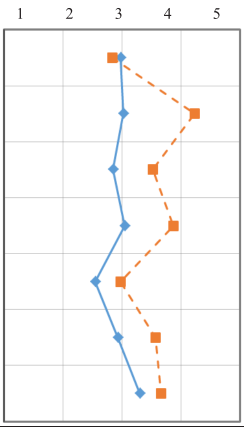
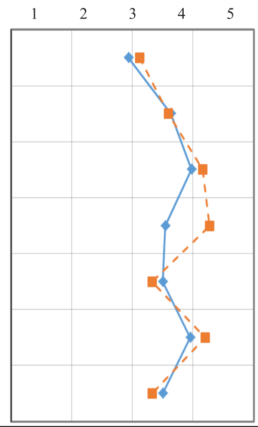
The differences between two groups were magnified for the pale tone colors compared to the dull tone colors, as a whole. The experimental group perceived the colors with high values as being clearer and lighter. The responses to the longer wavelength colors such as red and yellow showed similar patterns: the experimental group perceived the pale tone of two colors as being clearer and lighter, whereas the dull tones were seen as less heavy and less passive. Similar patterns were not found for the short wavelength colors. Color emotion with respect to the blue colors were the greatest, both in the pale and in the dull tones, compared to any

Table 3. Color emotional difference

Color	Pale tone			t-value	Dull tone			t-value
Red	Warm		Cool	0.47	Warm		Cool	0.54
	Clear		Dull	-8.09***	Clear		Dull	-0.76
	Light		Heavy	-2.85**	Light		Heavy	-4.79***
	Active		Passive	-2.47*	Active		Passive	-4.01***
	Soft		Hard	0.50	Soft		Hard	-0.98
	Bright		Dark	-1.39	Bright		Dark	-3.68***
	Like		Dislike	-1.17	Like		Dislike	0.56
				t-value				t-value
Yellow	Warm		Cool	2.15*	Warm		Cool	2.43*
	Clear		Dull	-5.79***	Clear		Dull	0.24
	Light		Heavy	-2.98**	Light		Heavy	-2.99**
	Active		Passive	-3.81***	Active		Passive	-4.08***
	Soft		Hard	0.43	Soft		Hard	0.56
	Bright		Dark	-0.63	Bright		Dark	-2.13*
	Like		Dislike	0.00	Like		Dislike	1.55
				t-value				t-value
Green	Warm		Cool	-0.89	Warm		Cool	1.72
	Clear		Dull	-3.61***	Clear		Dull	-1.98
	Light		Heavy	-2.73**	Light		Heavy	-1.44
	Active		Passive	-0.06	Active		Passive	-1.62
	Soft		Hard	-2.10*	Soft		Hard	0.58
	Bright		Dark	-2.96**	Bright		Dark	-1.43
	Like		Dislike	-2.00*	Like		Dislike	-0.05
				t-value				t-value
Blue	Warm		Cool	-0.04	Warm		Cool	-0.91
	Clear		Dull	-6.72***	Clear		Dull	-5.79***
	Light		Heavy	-3.77***	Light		Heavy	-3.45**
	Active		Passive	-1.30	Active		Passive	-3.84***
	Soft		Hard	-4.58***	Soft		Hard	-0.71
	Bright		Dark	-2.26*	Bright		Dark	-3.10**
	Like		Dislike	-0.21	Like		Dislike	-1.61

Experimental Group, Controled Group, * p<.05, **p<.01, ***p<.001

Table 3. Color emotional difference (continued)

Color		Pale tone		t-value		Dull tone		t-value
Purple	Warm		Cool	0.68	Warm		Cool	-0.88
	Clear		Dull	-6.64***	Clear		Dull	0.19
	Light		Heavy	-3.24**	Light		Heavy	-1.26
	Active		Passive	-3.89***	Active		Passive	-4.37***
	Soft		Hard	-2.00*	Soft		Hard	0.84
	Bright		Dark	-3.17**	Bright		Dark	-1.56
	Like		Dislike	-1.96	Like		Dislike	0.80

, * p<.05, **p<.01, ***p<.001

other colors. Our results did not show significant differences in the warm-cool and the like-dislike scale at a level of over $p < .01$. That is to say, the color emotional responses did not differ by hues for the pale and the dull tones since the warm-cool scale is more associated with the hue among the physical attributes of colors, and the age effect on color emotion is more significant than the individual color preference for the color control.

5. CONCLUSION

The color perception and the color emotion of elderly subjects were compared to the responses of the young of the normal vision with respect to the environmental color design. The senescence of color vision was reviewed through the literature from various disciplines. Experiments were carried out with technically elaborate devices developed on the basis of color theory to measure the gradual progress of the yellowing of vision. Our major findings and conclusions are as follows.

Although psychophysical and empirical evidence exists to support the constancy of color vision across a lifespan, this study shows that yellowing of the lens and its effect on color vision are gradual aging phenomena. Less than one-half of the subjects in the aged group showed that they have experienced less than 50 % of yellowing.

The elderly's color vision should be discussed with respect to color attributes to foster the prior findings related to color vision of the aged, which focused on a decline in transmittance of the lens for short wavelength light. The aged group showed that the visual function of distinguishing similar tones for the short wavelength colors was slightly low compared to the young group. They responded less accurately to vivid-strong and deep-dull pairs of blue, while they responded as accurately as those of the younger group to any pairs of purple color.

The elderly's color emotion seems to be changed by the attenuation of light transmission for all spectral colors, even if it is slightly stable in the long- and mid-wavelength colors compared to short wavelength colors. The responses to color-emotional factors show significant differences between the aged and the young group for pale and dull tones of five colors (red, yellow, green, blue, and purple), except dull green. Subjects in the aged group tended to perceive the pale tone of the basic five colors as clearer and lighter, and tended to perceive the dull tones of the basic five colors as less heavy and less passive. These results partially support Wright's introspection for color constancy. An individual perceives colors with his/her own color palette, which changes with age and differs depending on physical color attributes. Color attributes such as values and chroma are significantly affected by the senescence of color vision, although the balance of hues seems to be constant. In conclusion, we propose the detection method of subtle changes in the color vision of our elderly subjects that are caused by a complex functional attenuation of yellowing in aging vision and light transmission. Although this study has limitations in the experimental setting and in the subjects' age variance, our results allow us to suggest more sophisticated criteria to apply to the changes of aging vision with respect to environmental color design practice.

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