ORIGINAL ARTICLE

The Effects of Aging and Illuminance on Perceived Saturation: Direct Scaling and Paired Comparison Scaling

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Abstract: Color perception in older individuals is affected by the aging of the ocular system. Previous studies have explored the effects of aging on perceived saturation by asking study participants to assign a proportion of overall chromatic content to each stimulus in a series (direct scaling). This investigation aimed to (1) reveal differences in perceived saturation between younger and older observers based on two different scaling methods, namely conventional direct scaling and paired comparison scaling; and (2) examine the effects of three different illuminance levels on perceived saturation. The results indicate that when using direct scaling for high-saturation colors, older observers perceived less saturation than younger subjects. This difference was not observed for trials with low-saturation colors. When paired comparison scaling was used, perception of saturations for yellow and blue, or blue-green, in older observers was different from that in younger observers. Illuminance did not influence perceived saturation in either group.

Keywords: *Color appearance, Aging vision, Perceived saturation*

1. INTRODUCTION

Color perception in older individuals is affected by reductions in intensity at the retina due to age-related increases in optical density in the ocular media, which affects the absorption of short wavelength light by the lens [1]. Many studies have explored color perception in older adults by investigating color discrimination or color appearance. Kinnear & Sahraie (2002) have suggested that chromatic discrimination performance varies as a U-shaped function with age, with the best color discrimination achieved at 19 years of age [2]. Chromatic sensitivity reaches its zenith at around 20 to 30 years of age [1,3]. The sensitivities of chromatic mechanisms across life are not uniform [4]: both the red-green (RG) and yellow-blue (YB) thresholds increase in a gradual and linear manner throughout life [1,5].

In contrast, aspects of color appearance, such as the perception of hue, saturation, and lightness, or color naming properties, are relatively stable across life despite age-related changes that lead to elevated thresholds for chromatic sensitivity. There are no significant changes in achromatic perception as a function of age [6]. Categorical color naming also remains relatively constant in normal aging [7-9]. The absence of differences between younger and older subjects may be associated with the compensation of color vision by the latter's use of a general chromatic adaptation process [10]. This compensation underlies the general expectation for "good vision" throughout our lifetimes [11, 12].

As for the perception of saturation, Scheffrin & Werner (1993) found evidence that, in comparison to younger participants, older participants perceive less chromatic content [7]. In addition, the authors reported that the differences in the perceived saturation of test stimuli between the two age groups progressively increased as the lightness and luminance of color samples decreased. Kraft & Werner (1999) measured age-related changes in the perception of desaturated color; they found that older observers scale short-wave stimuli as more saturated than do younger observers [8]. Okajima et al. (2002) found that chromatic sensation in older subjects was lower than that in younger observers for high-saturation colors, while it was higher in older individuals than in younger subjects for low-saturation color stimuli. The authors suggested that age-related changes may depend on the saturation of color, and that the practical range of color appearance observed may be narrower in older observers than in younger subjects [9]. However, there are no studies to confirm these results. Additionally, the studies described above have explored perceived saturation using the direct scaling method: participants were instructed to assign a number to represent the percentage of overall chromatic content for each stimulus. Gordon & Abramov (1988) standardized this psychophysical scaling technique, and several studies to date have used it to measure color appearance [13]. Although the direct scaling method is easy to perform experimentally, it is likely difficult for participants who are not familiar with color dimensions or attributes to properly assign a number representing chromatic content to each stimulus. The current study therefore investigates

the effects of aging on perceived saturation using two scaling methods: conventional direct scaling and paired comparison scaling. In the latter, participants simultaneously compare two color samples to determine which color sample contains greater chromatic content. The comparative scaling method may reveal different aspects of chromatic sensation than those found in previous studies that exclusively employed direct scaling.

The current study also investigates the effect of illuminance levels on color perception in older individuals; it is estimated that adults above 50 years of age need twice as much light as young adults for comfortable work [14]. Lowering illuminance levels impairs color discrimination in older individuals more than in younger subjects [15, 16]. In contrast, Okajima et al. (2002) have suggested that there is no significant difference in perceived saturation across ages. Few studies to date have examined the effect of illuminance level on perceived saturation in older individuals [9].

This study aimed to compare perceived saturation between younger and older observers under three different illuminance levels (50, 500, and 1,000 lx), using two different scaling methods. Specifically, 20 colors from the TOYO INK color chips comprised of high and low saturation samples of ten hues were used. In the first experiment, ten young adults (the younger group) and ten older observers (the older group) who had normal color vision rated the chromatic content of each color sample. In the second experiment, the present study conducted paired comparison scaling with five younger and five older observers. The results of the two experiments allowed us to assess the effects of aging and illuminance on perceived saturation.

2. EXPERIMENT 1

2.1 Materials and Methods

1) Subjects:

The participants included ten younger observers and ten older observers; all of the subjects were Japanese. Ages in the younger and older groups ranged from 20 to 23 years and 66 to 83 years, respectively; the mean ages were 21.6 (standard deviation [SD]=0.80) years for the former and 71.9 (SD=5.61) years for the latter. All participants were tested using Ishihara pseudoisochromatic plates. Written informed consent was obtained from all participants, and the experimental protocol was approved by the Ethics Committee of Kagawa University (approval no. 28-005). The subjects participated voluntarily; each was given a gift certificate in compensation.

Table 1: Munsell values for the 20 color chips

	Low-saturation set			High-saturation set		
	Hue	Value	Chroma	Hue	Value	Chroma
R	5.4	5.5	1.8	5.1	5.4	16.8
YR	5.2	6.9	4.4	5.8	7.3	14.8
Y	5.5	8.9	1.9	5.2	8.7	11.2
GY	5.2	7.4	4.9	4.8	8.4	13.5
G	4.3	6.8	2.9	5.2	5.2	12.1
BG	5.7	5.8	3.7	5.4	6.0	11.3
B	4.4	7.0	3.9	4.1	7.1	9.0
PB	4.4	4.5	4.7	5.4	5.1	12.4
P	5.1	5.2	3.8	5.8	4.3	15.0
RP	4.6	7.1	4.9	4.9	6.3	12.8

2) Equipment and stimuli:

Arranged based on the Munsell color scale, the stimuli included 20 color chips from the TOYO COLOR FINDER 1050 (TOYO INK CO., LTD.); the colors featured low-saturation and high-saturation samples of ten hues: red (R), yellow-red (YR), yellow (Y), green-yellow (GY), green (G), blue-green (BG), blue (B), purple-blue (PB), purple (P), and red-purple (RP). The Munsell values for the 20 color chips are shown in Table 1. The experiment was carried out in a dark room under D65 ceiling lighting. With the vertical luminance on the desk, one of three illumination levels were randomly assigned to each session: approximately 50, 500, or 1,000 lx. The color chips were presented as rectangular patches at a size of 24 mm×36 mm. The participants observed the test color samples on an N5 gray background with binocular natural viewing.

3) Procedure:

The participants spent the first five minutes adapting to the illumination level. The test color samples were presented at random, after which the participants assigned a number to represent the percentage of overall chromatic content of each test color sample per our instructions. The participants completed this task as quickly as possible for 20 color samples with roughly one-minute intervals between tasks. The 20 rating tasks amounted to one session. The session was repeated twice more at the illumination levels remaining to be tested, with 10-minute intervals between sessions. We repeated the experiment to gather a second set of measurements per subject. Depending on the participant, the entire experiment lasted roughly two hours.

2.2 Results

In order to confirm the reliability of the ratings, correlation coefficients were calculated between the first and second ratings for the 20 color samples under the three illuminance conditions. Reliabilities for the younger and older age groups were significant (younger: $r=0.84$, $p<.001$; older: $r=0.63$, $p<.001$).

A mixed-model analyses of variance (ANOVA) was used to assess differences between the proportions of the chromatic contents of the color samples that the two groups reported. A mixed-model ANOVA was used with the saturation level (i.e., low and high), the three illuminance levels (i.e., 50, 500, and 1,000 lx), the 10 hues (i.e., R, YR, Y, GY, G, GB, B, BP, P, and RP), and the two groups (i.e., younger and older). The analysis revealed significant interactions between group and saturation level ($F_{(1,18)}=18.26, p<.001$, generalized $\eta^2=0.17$), as well as saturation level and hue ($F_{(4,27,76.93)}=5.81, p<.001$, generalized $\eta^2=0.04$). As shown in Figure 1, a simple effects analysis for the interaction between group and saturation level revealed a group difference in the color samples with high saturation ($F_{(1,18)}=8.40$,

Figure 1: Averaged chromatic contents

$p<.01$, generalized $\eta^2=0.24$), while no differences were found for the low-saturation set ($F_{(1,18)}=1.13, n.s.$). The other interactions were not significant.

To provide an adequate basis of comparison between the results of this experiment and those of experiment 2, the individual ratings for 20 color samples under the three illuminance conditions were normalized by the mean of all of the responses given by all the subjects of both groups under each illuminance condition; the normalized values of the rating scores were thereby obtained. ANOVAs were used to assess the main effects of the 20 color samples for each group under the three illuminance conditions (i.e., younger observers at 50 lx, 500 lx, and 1,000 lx; and older observers at 50, 500, and 1,000 lx). The analyses revealed significant main effects in all conditions (younger at 50 lx: $F_{(19,171)}=28.52, p<.001$; younger at 500 lx: $F_{(19,171)}=32.07, p<.001$; younger at 1,000 lx: $F_{(19,171)}=20.33, p<.001$; older at 50 lx: $F_{(19,171)}=8.22, p<.001$; older at 500 lx: $F_{(19,171)}=12.56, p<.001$; older at 1,000 lx: $F_{(19,171)}=9.11, p<.001$). To find means significantly different from one another, a multiple comparison test according to the Shaffer method was performed for each group under the three illuminance conditions. Figure 2 shows the normalized average chromatic contents for the younger (A) and older (B) groups under the three illuminance conditions.

Figure 2: Normalized average chromatic contents of each color for the younger group (A) and older group (B) under the three illuminance conditions

3. EXPERIMENT 2

3.1 Materials and Methods

1) Subjects:

Among the participants from experiment 1, five were recruited from both the older and the younger groups. Years of age in the younger and older groups ranged from 20 to 23 and 66 to 75, respectively; the mean ages were 21.4 (SD=0.9) for the former, and 69.8 (SD=2.3) for the latter. As in experiment 1, written informed consent was obtained from all participants, and the subjects were provided with gift certificates as compensation.

2) Equipment and stimuli:

The same equipment and stimuli used in experiment 1 were used here.

3) Procedure:

The participants spent the first five minutes adapting to the illumination level, after which the participants were presented simultaneously with randomly matched paired color samples. As instructed, the participants then rated dissimilarities of perceived saturation between all possible pairs of the 20 color samples – amounting to a total of 190 pairs – on a scale from -10 to 10 as quickly as possible. Taking colors A and B as an example, -10 indicates that A is perceived to be much less saturated than B, 0 that A and B have the same saturation level, and 10 that A is perceived to be much more saturated than B. A given session encompassed scaling tasks for the 190 pairs under one of three illuminance levels. The tasks were repeated for the remaining two illuminance levels for a total of three sessions separated by 10-minute intervals. The order of the illuminance conditions across sessions was randomized among subjects. All sessions were carried out twice. Depending on the subject, the entire experiment required roughly four hours.

3.2 Results

The correlation coefficients between the first and second ratings of the 190 color samples were significant for both groups under the three illumination conditions (younger: $r=0.79$, $p<.001$; older: $r=0.73$, $p<.001$).

For all color pairs, the average values of the rating scores by the subjects were calculated and the relative values of perceived saturation for each color sample were obtained. ANOVAs were used to assess the main effects of the 20 color samples for each group under the three illuminance conditions (i.e., younger observers at 50, 500, and 1,000 lx, and older observers at 50, 500, and 1,000 lx). The analyses revealed significant main effects in all conditions (younger at 50 lx: $F_{(19,684)}=323.22$,

$p<.001$; younger at 500 lx: $F_{(19,684)}=346.73$, $p<.001$; younger at 1,000 lx: $F_{(19,684)}=429.77$, $p<.001$; older at 50 lx: $F_{(19,684)}=301.95$, $p<.001$; older at 500 lx: $F_{(19,684)}=344.72$, $p<.001$; older at 1,000 lx: $F_{(19,684)}=396.26$, $p<.001$). To find means that were significantly different from one other, the multiple comparison test according to the Tukey-Kramer method was performed for each group under the three illuminance conditions. Figure 3 shows the averaged perceived saturation levels for the younger (A) and older group (B) under the three illuminance conditions.

4. DISCUSSION

In a study conducted by Scheffrin & Werner (1993), 15 broadband colored surfaces were used as test stimuli with free viewing; their results suggested that older subjects perceive all stimuli as having less chromatic content than younger observers [7]. Okajima et al. (2002) used a larger set of 75 color chips and reported that older participants assigned lower values for chromatic contents when presented with high-saturation color samples than did younger subjects; for low-saturation stimuli, older participants assigned higher values relative to younger subjects. The authors suggested that age-related changes may depend on the saturation of the colors presented [9].

The results of experiment 1 indicated a significant difference in the values reported in response to high-saturation stimuli between younger and older participants; a disparity absent when the subjects were shown low-saturation samples. These findings partially agree with those of Okajima et al. (2002) [9]. Our results regarding the effect of luminance levels were also consistent with those of Okajima et al. (2002): no difference was observed between the color appearance perceived by older at two illuminance levels (50 and 500 lx); though the current study included an additional level of illuminance (1,000 lx), no significant effect was found.

The results of experiment 1 obtained by the direct scaling method, which asks observers to measure the absolute chromatic content of a color sample, did not reveal a significant difference in the perceived saturation between hues at either saturation level. As aforementioned, it is difficult for participants who are not familiar with color dimensions or attributes to assign chromatic content. In fact, the rating data obtained from the direct scaling method was widely spread.

The current study used the paired comparison scaling in experiment 2, wherein the participants simultaneously compared two color samples to determine which color

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Figure 3: Averaged perceived saturation levels for the younger (A) and older group (B) under the three illuminance conditions

sample had a greater chromatic content. As shown in Figure 3, the results of experiment 2 indicate that the two groups differed primarily in their assessments of low-saturation colors under the lowest illuminance level. In the older group, relative differences in perceived saturation between the low-saturation test stimuli seemed to decrease with the illuminance level. Knoblauch et al. (1987) found that lowering the illuminance level impaired color discrimination more in older individuals than in younger subjects, indicating that significant reductions in retinal illuminance can lead to large increases in discrimination error [15]; illuminance levels may affect the perceived saturation of low-saturation color samples in older observers, but not in younger observers.

The paired comparison scaling test revealed interesting differences in perceived saturation between younger and older observers (Figure 3): regardless of illuminance

level, younger observers found the difference in perceived saturation between the low-saturation yellow and blue colors, but not between high-saturation yellow and blue colors; older observers perceived low-saturation yellow and blue colors to have the same saturation, while they reported high-saturation yellow and blue colors to have different saturation levels. These observations remained consistent when yellow and blue-green color samples were paired. With the exception of younger participants reporting the low-saturation yellow as having the lowest chromatic content, experiment 1 did not show these differences (Figure 2).

The disparity in the perceived saturation of yellow and blue (or blue-green) colors (YB) – indicated by the results of experiment 2 – between the younger and older groups might be due to decreases in YB sensitivity with age. This line of reasoning is consistent with that of previous studies: Knoblauch et al. (1987) have

reported that YB discrimination may be deficient in older observers [15]; and Kinnear & Sahraie (2002) have suggested that YB sensitivity deteriorates more than RG sensitivity in observers older than 40 years, as assessed using the 100-hue test [2]. The way in which saturation is perceived in the paired comparison scaling conducted in experiment 2 may also be related to changes in an underlying discrimination mechanism: investigating chromatic discrimination using the Cambridge Color Test, Paramei & Oakley (2014) found that sensitivity declines in all chromatic systems and is more pronounced in the tritan system after the age of 60 years [3]. This may be due to receptor or post-receptor dysfunction associated with the aging of neurons involved in color discrimination: there are greater reductions in the contribution of short-wavelength light to retinal illuminance with increasing age, which results in a more rapid increase in the YB threshold [1]; in addition, Shinomori et al. (2001) have suggested that post-receptor alterations account for age-related changes in wavelength discrimination [17].

Color appearance, such as the perception of hue, saturation, and lightness, also depends on the post-receptor combinations of cone signals; they give rise to blue-yellow, red-green, and black-white dimensions of color appearance, with each pair of colors organized in an opponent manner [18]. Page & Crognale (2005) have suggested that the chromatic and achromatic visual pathways age differently [5]. The perceived saturation properties of low-saturation yellow and blue, or blue-green, in older observers are likely to be rooted in the age-related post-receptor changes aforementioned.

It has been suggested that there are neural processes that are responsible for maintaining relatively constant hue perception across much of life, despite age-related changes that take place at the receptor and post-receptor levels. Okajima & Takase (2001) have suggested that the neural balance of the YB opponent color channel may change in order to compensate for age-related changes in the human lens [10]. A recent study on color constancy indicated that yellow, red, green, and blue illumination are equally well-compensated for in older observers relative to younger subjects [19]. These findings provide a possible explanation for the results of experiment 2: age-related compensatory mechanisms in human vision may account for older participants having distinguished more differences in saturation between paired color samples in the high-saturation set than did younger participants (Figure 3).

5. CONCLUSION

This study used both the conventional direct scaling and the paired comparison scaling to explore differences in perceived saturation between younger and older adults under three different illuminance conditions. The two experiments conclude that (1) when using direct scaling, older observers perceive high-saturation colors as less saturated than do younger observers; (2) the difference noted in the prior conclusion is not evident for low-saturation colors; (3) When using paired comparison scaling, perception of saturations for yellow and blue, or blue-green, in older observers is different from that in younger observers; and (4) illuminance does not influence perceived saturation in either group. The comparative scaling method revealed different aspects of chromatic sensation from those revealed by previous studies using the direct scaling method.

Though the older participants in the current study had normal color vision, it is difficult to separate the effects of diseases that affect the retina from the gradual decline attributed to normal aging [1]; Paramei & Oakley (2014) have reported greater variability in color detection thresholds with an increased scatter for subjects older than 60 years [3]. The findings of the current study further indicate sample size and distribution issues for the group of older participants. It is necessary for future research to recruit larger groups and extend the study to larger color sample sets. Our study does, however, provide preliminary evidence for a compensation mechanism that may be partially responsible for the differences observed in perceived saturation.

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