Experiment of Color Schemes for the Elderly in Apartment Bathrooms

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Abstract
Suggested color combinations and actually existing color combinations for apartment bathrooms are empirically examined in this experiment to test the levels of color discernment for both normal and elderly vision. A YA3 filter was employed for simulating yellowed eyesight that commonly affects the color vision of the elderly. Results of the study imply most color combinations in apartment bathrooms found in Korea today are difficult to discern for both the elderly and young adults with normal vision. In elderly vision, the high discernment levels of the suggested combinations support the efficiency of the color schemes developed in the previous study. The color schemes were complemented and improved through analysis of other combinations, which showed low discernment levels in normal or elderly vision. In conclusion, with the perspective of universal design in mind, this study suggested color schemes that are easily discernable for both elderly and normal vision while maintaining the original mood.

Keywords: color perception; color scheme; the elderly; universal design

1. Introduction
Recently, the elderly population in Korea has been growing rapidly. In the aspect of housing, the welfare of the elderly along with the concept of 'Aging in Place' has become very important. This concept refers to enabling the elderly to continue living in the community they are familiar with. Among these familiar spaces, housing is recognized as one of the most important, and the bathroom can be seen as the most crucial. It is the usability of the bathroom that can distinguish the difference between the independent and dependent users (Mullick, 2001). ADL (Activities of daily living) of the elderly is largely affected by visual function loss after health-related factors. The loss of contrast sensitivity and the loss of visual acuity are both considered forms of visual impairment, but the loss of contrast sensitivity is more closely associated with effecting everyday activity (Burmedi et al., 2002).

In Korean residential buildings, research confirms that bathrooms are where the most number of accidents occur for the elderly. It is also a space that most often requires alterations to be made in order to fit the needs of the elderly and users with wheelchairs (Han et al., 2000; Kwon et al., 2007). To meet these demands, studies focusing on accessibility by means of dimension and fixture layouts in bathroom spaces have been conducted consistently (Ju et al., 2006; Kang et al., 2007); however, there is an insufficient amount of study that takes into consideration the color vision changes effecting the elderly and how they perceive the visual environment.

Due to the present conditions, color schemes for the elderly had been suggested based on results from studies on color perception of the elderly. Surveys of actual color schemes for bathrooms in apartments, the most popular residential dwelling type in Korea, were also conducted (Kang, Bae, and Lee, 2008). In the perspective of universal design, the study suggested color schemes to be more discernable for the elderly while still maintaining its original mood.

The purpose of this study is to empirically examine the efficiency of the schemes suggested in Kang et al.’s study (2008). Research questions for the present study are as follows:
· In the view of the elderly, are the suggested color combinations easier to distinguish compared to the present field conditions in apartment bathrooms?
· What are the characteristics in the color combinations that are most easily discernable for both normal and elderly vision?
· What color combination characteristics create the different levels of discernment between normal and elderly vision?

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2. IRI Color System

2.1 IRI Hue & Tone System  
In Korea, IRI Hue & Tone System was developed by IRI (Image Research Institute Inc) in the year 2001. Taking color sensitivity of Korean culture into consideration, the IRI Hue & Tone System classified color and color combinations based on the Munsell color system and ISCC-NBS color notation to create combinations that can adhere to a global audience. The term tone indicates a certain range of chroma and value in the Munsell notation and refers to the degree of vividness-dullness or lightness-darkness. IRI Tone System consists of 11 tones: V(Vivid), S(Strong), B(Bright), P(Pale), Vp(Very Pale), Lgr(Light Grayish), L(Light), Gr(Grayish), D(Dull), Dp(Deep), and Dk(Dark) (Fig.1. (a)). The IRI Hue & Tone 898 System, which consists of 880 chromatic colors (40 hues, 22 tones) and 18 neutral colors, was used to analyze and suggest color combinations (Fig.1. (b)).

2.2 IRI 24 Keyword Image Scale  
IRI 24 Keyword Image Scale is a method expressing the characteristics and feelings of a color combination through the use of a common keyword by positioning the combination along two basic psychological axes: soft-hard and dynamic-static. The dictionary of color combination made up of 24 keywords in ‘The Color for Designer’ (IRI, 2004) was used to analyze color image keywords for an apartment bathroom (Fig.1. (c)).

3. Area of Color Confusion for the Elderly  
The arrangement method is one of several different types of color vision tests. In this test the observer is required to arrange color caps by similarity in a sequential color series. The color caps have the same value and chroma but are different in hue. Therefore Table 1. The Value and Chroma of Color Caps in Each Arrangement Test

| Test                  | Value | Chroma |
|-----------------------|-------|--------|
| Farnsworth-Munsell 100-Hue Test | 5     | 5      |
| Farnsworth Dichotomous Panel D-15 | 5     | 4      |
| Lanthony Desaturated D-15 | 8     | 2      |
| Lanthony New Color Test | 6     | 6      |
|                       | 6     | 4      |
|                       | 6     | 2      |

Table 1. The Value and Chroma of Color Caps in Each Arrangement Test

with arrangement tests, evaluation of one's ability in hue discrimination and the identification of areas where one hue is confused with other hues of similar tones or grays can be studied. According to a study on age-related decline in color discrimination using Farnsworth-Munsell 100-hue test, as one grows older his or her color perception become more tritanlike (Knoblauch et al., 1987).

Several arrangement tests were developed with differences in the value and chroma of the color caps for each test. Employing these tests (Table 1.), several authors identified characteristics of color perception of the elderly and in tritan (Cooper et al., 1991; Kinnear and Sahraie, 2002; Lanthony, 1978a; Lanthony, 1978b; Linksz, 1966; Woo and Lee, 2002).

Optical simulations are another method of analyzing color vision in older adults. The yellowed crystalline lens of the elderly decrease the transmittance of light in short wavelength(400~450nm) and reduce sensitivity in the hues G, B, and P. In order to simulate the color vision of a person, camera lens and/or filters equivalent to each age group are employed. Yoshida et al. (1991 cited in Cho and Jang, 2006) used a Y-2 filter for ages 60~70 and a YA3 filter for late 70's. Using a Y-2 filter, Cho and Jang (2006) investigated the color perception of the elderly based on the IRI Color System. Fig.2. visualizes the transmittance crystalline lens of a 75-year-old, Y-2 filter, and YA3 filter.

From the results of several arrangement tests and optical simulations, Kang et al.(2008) suggested...
confusion areas (Fig.3.) experienced by the elderly based on the IRI Color System as seen below.

3.1 Hue Confusion among Colors of Similar Tone

In Fig.3. 880 chromatic colors of IRI Hue & Tone system are positioned in Munsell's hue circle. Hues in the same concentric circle are similar in tone starting from the center of hue circle: Dk, Dp, Dl, Gr, Lgr, Vp, P, B, S, and V, respectively. The areas separated by a dark thick line designate tones that are confused as the same by the elderly. Therefore, colors within this area should be treated as one color. Colors in the area from G to B or from RP to R are commonly confused but the exact range of confusion varies among tones. Especially, circles in the Vp, Lgr, Gr, and Dk tones, having no separated areas of confusion, make the entire area vulnerable to confusion and should be treated as one color. Placement of adjacent colors found within the circle must be avoided.

![Fig.3. Color Confusion Area of the Elderly](image)

3.2 Color Confusion with Neutral Colors

The areas separated by dashed lines around Y and PB in Fig.3. are areas that can be confused as neutral colors for the elderly who experience yellowed eyesight. Therefore, placing Y, PB and neutral colors of similar values together must be avoided.

3.3 Tone Confusion among Colors of the Same Hue

According to Cho and Jang (2006), different tones in fixed hue and value (e.g. S and V tones in the hue of R) are confused with each other. Especially in the hue of PB, all but Lgr tones are confused with one or more tones. Therefore, color combinations of the same hues and values, even if there is a difference in tone, should be avoided. If a color combination in the hue PB must occur, the value difference between the colors must be maximized to reduce confusion.

4. Color Combination in Apartment Bathrooms

A field survey (Kang, Bae, and Lee, 2008) investigated the color combination of 17 apartment bathrooms found in Korea. The colors mainly used are Y, YR in hue with high value and low chroma and N9.5 (white). When comparing the field survey findings to the identified color confusion areas of the elderly, difficulty in differentiating the color of the wall, floor, sanitary fixture, and door from each other is highly expected. There was only one case where the colors were easily discernable for the elderly (A1 in Table 3.). In the 24 Keyword Image Scale by IRI, the image cases from the field study sorted into 4 keyword images represented by shaded figures in Fig.1.(c): 'Peaceful', 'Unpretentious', 'Natural', and 'Pure'.

Table 2. Color Distribution in Apartment Bathrooms (%)

| Hue | Value | Chroma |
|-----|-------|--------|
| N   | 21.6  | 67.6   | 10.8  |
| Y   | 28.8  | 71.2   | 4 or  |
| YR  | 71.2  | 28.8   | above  |
| Below 7 | 88.3 | 11.7 |

5. Methods

5.1 Experiment Settings and Experiment Tools

Only Northern daylight through windows from 10 a.m. to 3 p.m. was used to illuminate the space for this experiment. Illuminance of the experiment table was distributed between 300 and 931 lx (mean value: 435.5 lx).

Color combinations for the experiment consisted of 4 colors designating the 4 crucial parts found in a bathroom that need to be easily distinguished from one another (Fig.4.). 5 test combinations are made up for each one of the four keyword images. One of the color combinations was found in the field survey, but the remaining 4 combinations are selected from the dictionary of color combinations based on the color schemes suggested by Kang et al. (2008) that identified easily distinguishable color combinations for the elderly. These color schemes focused on the hue discrimination of the same tone and tone discrimination of the same hue. To make them even more accurate, combinations with colors different in both hue and tone are included in the present study. Table 3. shows colors used in each color combination.

Test samples are 180 mm × 130 mm in size and printed with Fuji Xerox Apeos Port C6550(300dpi). These samples are placed on a background gray (N5) to minimize outside color interference during the experiment. For simulating the color vision of the elderly, glasses are made of YA3 filter that Yoshida et al.

Table 3. Colors Used in Each Color Combination

| Image | Keyword | Sample | Wall | Floor | Door |
|-------|---------|--------|------|-------|------|
| A.    |         |        |      |       |      |
| Peaceful | A1* | 9YR 6/2 | 10YR 8/4 | 7YR 8/4 |
| A2    | N8.5   | 3G 8.5/3 | N6   |
| A3    | N8.5   | N7     | 8G 8.5/2.5 |
| A4    | N8.5   | 6.5YR 7.5/3.5 | 10Y 7.5/3.5 |
| A5    | N8.5   | N6     | 4Y 7.5/3.5 |
| B.    |         |        |      |       |      |
| B1*   | 6.5YR 8.5/1 | 9YR 8.5/1 | 9R 4.5/7.5 |
| B2    | N7     | 6.5GY 6.5/2.5 | 4Y 7.5/3.5 |
| B3    | N8.5   | N7     | 10Y 7.5/3.5 |
| B4    | 4Y 7.5/3.5 | 9.5RY 6/4.5 | 3.5YR 4/5.8 |
| B5    | N8.5   | 4Y 7.5/3.5 | 9.5RY 6/4.5 |
| C.    |         |        |      |       |      |
| Natural | C1* | 4.5Y 9/2.5 | 3Y 8.5/1 | 5Y 2.5/6.5 |
| C2    | 1.5GY 9.5/3.5 | 10Y 7.5/3.5 | 9.5RY 6/4.5 |
| C3    | 1.5GY 9.5/3.5 | 7.5Y 6/5.5 | 0.5Y 4/7 |
| C4    | 1.5GY 9.5/3.5 | 10Y 7.5/3.5 | 7YR 2.5/5.5 |
| C5    | 1.5GY 9.5/3.5 | 7.5Y 6/5.5 | 9.5RY 6/4.5 |
| D.    |         |        |      |       |      |
| Pure  | D1*    | 3.5GY 9.1 | 3Y 8.5/1 | 6.5YR 8/4 |
| D2    | 3.5Y 9.1 | 5GY 9/5.5 | 4RP 6/3.5 |
| D3    | 1.5GY 9.5/3.5 | 6.5BG 8.5/1.5 | 8.5GY 9.2/5 |
| D4    | 8.5GY 9.2/5 | 8.5BG 7.5/5 | 6.5BG 8/1.5 |
| D5    | 8.5GY 9.2/5 | 9.5BG 8/2.5 | 9YR 9/2.5 |

* Actual combinations used in apartment bathrooms
6. Results

Table 4. The Types of Color Combination

| Type | Characteristics of colors | A            | B            | C            | D            |
|------|---------------------------|--------------|--------------|--------------|--------------|
| 1    | 2 neutral and 1 chromatic colors | A2, A3, A5   | B3           |              |              |
| 2    | 1 neutral and 2 chromatic colors | A4           | B2, B5       |              |              |
| 3    | 3 analogous colors         | A1           | B1, B4       | C1, C2, C3   | C4, C5       |
| 4    | Other 3 chromatic colors   |              |              | D1, D3, D4   | D2, D5       |

6.1 Type 1: Combination of 2 Neutral and 1 Chromatic Colors

- Discernment levels in normal vision

As seen in Table 5. and Fig. 6., the score for discernment in normal vision was higher when \( \Delta V \) between the 3 colors in the combination is large. Color combination A5 had a \( \Delta V \) that was larger than 1 among all 3 colors justifying its highest score within type 1. In the two cases of A2 and A3, the chroma, referring to the vividness of the hue, in G was 3 and 2.5 respectively, and the \( \Delta V \) between G and N8.5 was zero because the value for both G and N was 8.5. The low \( \Delta V \) and low chroma of G indicated the difficulty in distinguishing colors from each other that also contributed to the low scores found in both A2 and A3. For B3, the chroma of Y of 3.5 is higher than the chroma for G in A2 or A3. The \( \Delta V \) between Y and N7 is 0.5, but this difference was larger than the difference between G and N8.5 in A2 and A3 that ultimately explained the higher score of B3.

- Discernment levels in elderly vision

Compared to the scores for normal vision, scores for A2 and A3 both increased to 5 or above with elderly vision. It is because the short wavelengths of G are perceived darker than N8.5 of the same value that made it easier to discriminate between the two colors. Especially A2, where the chroma of G is higher than A3 by 0.5, indicated a very high score of 6.13. Therefore, it is expected that if the chroma of G increased or the

(1991 cited in Cho and Jang, 2006) employed.

5.2 Subjects

42 subjects (28 males and 14 females) majoring in architecture between 20 and 40 years old (mean age: 25.5) participated in this experiment. Before the experiment, all subjects took the Ishihara test to confirm normal color vision.

5.3 Procedure

Fig.5 outlines the experiment procedure. Each subject measured the level of color discernment for 2 sessions with a filter and 2 sessions without a filter. In the experiment, the condition wearing glasses represented elderly vision and the condition without glasses represented normal vision. In the first session, 5 samples of the keyword image ‘Peaceful’(A1~A5) were randomly arranged on the table and subject without glasses had to rearrange samples according to the levels of discernment and score them on a scale of 1 to 10 with 1 as the least distinguishable and 10 as the most distinguishable color combination. Subsequently, samples of the remaining keyword images ‘Unpretentious’(B), ‘Natural’(C), and ‘Pure’(D) were evaluated in the same manner.

After completing the first session, subjects wore glasses and listened to an explanation about the filter for 5 minutes. This gave them time to adjust to the filtered glasses. In the second session, they were asked to do the same task in the given order of A, C, D, and B with the filtered glasses. The third session required the subjects to follow the order of the first session with the filtered glasses. In the last session, the order of the second session was repeated without the filtered glasses.

6. Results

Sessions 1 and 2 and sessions 3 and 4 made up two score groups for evaluating the results. Correlation analysis of the scores was conducted between these two groups with each subject. 7 Subjects whose data showed low correlation coefficients below 0.6 were excluded from the analysis. As a result, data from 35 subjects were chosen for further analysis and the correlation coefficient ranged from a high of 0.867 to a low of 0.647(mean value: 0.734). Fig.6. and Table 5. show the mean score of each sample. The results of the paired-sample T-test, the difference between the score with filter and without filter, are presented in Table 5. In all of the samples, the color of sanitary fixtures is N9.5(white) and its position is fixed on the left-hand side (Fig.4.); therefore, it became obsolete to the experiment. Excluding the color of the sanitary fixtures, the colors of the wall, floor, and door are left for discernment level analysis. Samples were classified into 4 combination types according to the characteristic of colors composed in the combination seen in Table 4. The colors whose hue difference is below 25, which is 1/4 of Munsell 100 hue circle, are classified as analogous colors. The concept Index of fading formula (Nickerson, 1936 cited on Moon, 2005), which explains color difference (\( \Delta E \), from here on) is affected most by the difference in value (\( \Delta V \), from here on), then the difference in chroma (\( \Delta C \), from here on), and lastly by the difference in hue (\( \Delta H \), from here on), is employed to explain the differences in the scores between samples.

Table 4. The Types of Color Combination

| Type | Characteristics of colors | A            | B            | C            | D            |
|------|---------------------------|--------------|--------------|--------------|--------------|
| 1    | 2 neutral and 1 chromatic colors | A2, A3, A5   | B3           |              |              |
| 2    | 1 neutral and 2 chromatic colors | A4           | B2, B5       |              |              |
| 3    | 3 analogous colors         | A1           | B1, B4       | C1, C2, C3   | C4, C5       |
| 4    | Other 3 chromatic colors   |              |              | D1, D3, D4   | D2, D5       |
value of G decreased, the level of discernment would increase in both normal and elderly vision.

The score of B3 decreased to 4.26. Due to the yellowed eyesight of the elderly, Y was perceived with less hue and became difficult to distinguish from N7 that had a similar value. The Y in A5 was perceived with less hue, but the score was still a high of 7.26 because the ∆V was 1 or above between all 3 colors regardless of the reduction in the color cue of Y.

- **Color schemes of Type 1**

Based on the results, color combination schemes composed of 2 neutral colors and 1 chromatic color could be summarized as seen below: (1) to set a gap between the values of each color as much as possible and especially make the ∆V 1 or greater among neutral colors and between a neutral color and Y or PB, which the elderly would perceive with less hue, (2) if the chromatic color whose ∆V with the neutral colors do not exceed 1, set the chroma of the color at 3.5 or higher.

- **Levels of discernment in normal vision**

All three samples for normal vision had high scores of 5 or above. Combinations obtained scores of 7 or above as seen in A4 and B5, which kept the ∆V 1 or greater between the 1 neutral color and the 2 chromatic colors and also revealed that there were ΔH and ∆V between the 2 chromatic colors.

Compared to B3 in type 1 and A4, both have the same combinations except N7 in color combination B3 and YR with a value of 7 in color combination A4. With that one difference, A4 had the higher score. In the same way, B3 in type 1 compared to B2 are the same combinations except N8.5 in B3 and GY with a value of 6.5 in B2, yet there was no significant difference in the score. Therefore, it could be said that if the ∆V between 2 colors is lower than 1, the combination of 2 chromatic colors, which are different in hue, would be more easily discernable than the combination of 1 chromatic color and 1 neutral color.

- **Levels of discernment in elderly vision**

In the cases of A4 and B5, both had high scores in normal vision. The score of B5 continued to stay high at 7.13, but the score of A4 decreased to 5.59.

Although the color cue of Y in B5 is reduced by elderly vision, the score was still high because the ∆V between the 2 chromatic colors was 1 or above. When compared to A5 in type 1 and B5, they have the same combinations except YR with a value of 6 in B5 and N6 in A5, but the scores are very high in both B5 and A5. Therefore, it can be stated that the colors whose ∆V is 1 or greater is easily discernable regardless of whether the color is chromatic or neutral.

In A4, the ΔH between YR and Y created the high score regardless of the small ∆V for normal vision, but the score decreased for elderly vision. The reduction of the perceived color cue for the Y series made the combination less discernable. In this case, YR can become darker by increasing the chroma or decreasing the value that would keep the score high as in B5. In B2, similar to B3 in type 1, the color hue of Y was reduced in elderly vision because it was harder to distinguish N7 that had a similar value.

- **Color schemes of Type 2**

Based on the results, color combination schemes composed of 1 neutral color and 2 chromatic colors could be summarized as seen below: (1) to set a gap between the value of each color as much as possible, and make ∆V 1 or greater between a neutral color and Y or PB, which the elderly would perceive with less hue, (2) if the chromatic colors whose ∆V with the neutral colors does not exceed 1, set the chroma of the color at 3.5 or higher, (3) if the chromatic colors whose ∆V with the neutral color does not exceed 1, the chroma of the color needs to be 3.5 or higher, (3) if the chromatic colors whose ∆V between the colors does not exceed 1, make them different in hue or chroma.

- **Levels of discernment in normal vision**

As seen in Table 5., combinations where the ∆V between all 3 analogous colors is 1 or greater (A1, B4, C2, C3, and C4) ended up with high scores. Also, combinations composed of colors with similar high values (D3 and D4) obtained high scores by making colors different in chroma. Especially D4, where the
color with the lowest value also had the highest chroma obtained a higher score than D3, whose color with the highest value had the highest chroma.

In D1, where the range of value distribution is similar with D4, all colors are different in hue, but the score recorded a low of 3.77. It is because the chroma of all the colors is below 3 and the ΔC between Y and GY is zero. Therefore, it was difficult to distinguish one color from another by the ΔH or ΔC.

**Levels of discernment in elderly vision**

Similar to normal vision results, combinations with a large difference in value between colors (A1, B4, C2, C3, and C4) and combinations where there was a difference of chroma and hue between colors received high scores of 5 or above with elderly vision.

Comparing A1 with B4, which are similar to each other in value distribution, the score of B4 continued to have a high score of 6.77, but the score of A1 decreased to 5.80 with elderly vision. When comparing D3 and D4, which also have similar hue and chroma distribution, the score of D3 did not change much and came out to be 5.41, but the score of D4 increased to 7.80. In comparison with A1 and D3, the characteristic of B4 and D4, which indicated very high score in elderly vision, are as follows: (1) there is chroma difference among all colors and (2) lower the value of color, higher the chroma becomes.

The Y and YR in C5 are similar in tone and could be distinguished from each other by the elderly, but the score was 4.97 and when compared with other combinations, it is relatively low. Comparing D5 in type 4 with C5, these combinations are similar because they use 2 colors that have similar value and chroma, i.e. same tone. Although the range of value distribution in C5 is wider than D5, the score of C5 is lower by 2.34. When colors have the same tone and the values are below 6, the elderly are highly likely to have a difficult time distinguishing colors.

There is a significant correlation between the score of normal vision and elderly vision for the 11 combinations in type 3 (Pearson's r=0.927, α=0.01). And the result from the paired-sample T-test have no significant difference between the scores of normal vision and elderly vision; therefore, in the case of type 3, the difference in scores between normal and elderly vision is smaller than any other combination type. The reason is the similar wavelengths in analogous colors in conjunction with the change of color perception as an outcome to yellowing lens affecting elderly vision.

In conclusion, with the combination of analogous colors, the difference of value and chroma (i.e. tone) are the main factors affecting the color combination discernment levels other than hue.

**Color schemes of Type 3**

Based on the results from above, color scheme combinations composed of 3 analogous colors could be summarized as follows: (1) to set a gap between the value of each color as much as possible, and specifically adjust the ΔV to equal 1 or greater among the analogous colors Y-Y and PB-PB, which the elderly perceive with

| Table 5. Value of Color and Discernment Levels in Each Color Combination |
|--------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Type | Color Combination | 2.5 | 3 | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 | 6.5 | 7 | 7.5 | 8 | 8.5 | 9 | 9.5 | w/o filter | w/ filter | Diff. |
| 1 | A2 | N** | G/3 | N | N | G/2.5 | 4.16 | 6.13 | 1.97* |
| | A3 | N | Y/3.5 | N | Y/3.5 | N | 3.70 | 5.26 | 1.56* |
| | A5 | Y/3.5 | N | Y/3.5 | N | 7.29 | 7.26 | .03 |
| | B3 | Y/3.5 | N | Y/3.5 | N | 5.64 | 4.26 | -1.39* |
| 2 | A4 | YR/3.5 | Y/3.5 | N | 7.01 | 5.59 | -1.43* |
| | B2 | GY/2.5 | N | Y/3.5 | 5.74 | 4.83 | -1.91* |
| | B5 | YR/4.5 | Y/3.5 | N | 7.06 | 7.13 | .07 |
| 3 | A1 | YR/4 | YR/2 | YR/4 | 6.86 | 5.80 | -1.06* |
| | B1 | R/7.5 | YR/1 | YR/1 | 3.23 | 3.26 | .03 |
| | B4 | YR/8 | YR/4.5 | Y/3.5 | 7.00 | 6.77 | -.23 |
| | C1 | YR/6.5 | Y/1 | Y/2.5 | 3.66 | 3.57 | -.09 |
| | C2 | YR/4.5 | Y/3.5 | GY/3.5 | 6.30 | 5.97 | -.33 |
| | C3 | Y/5.5 | Y/3.5 | GY/3.5 | 7.83 | 7.64 | -.19* |
| | C4 | Y/5.5 | Y/3.5 | GY/3.5 | 7.73 | 7.86 | .13 |
| | C5 | Y/5.5 | YR/4.5 | GY/3.5 | 5.27 | 4.97 | -.30 |
| | D1 | YR/3 | Y/1 | GY/1 | 3.77 | 4.59 | .81* |
| | D3 | BG/1.5 | GY/2.5 | GY/3.5 | 5.74 | 5.41 | -.33 |
| | D4 | BG/1.5 | GY/2.5 | GY/2.5 | 6.94 | 7.80 | .86* |
| 4 | D2 | RP/3.5 | B/1 | GY/3.5 | 6.60 | 2.37 | -4.23* |
| | D5 | BG/2.5 | GY/2.5 | YR/2.5 | 5.59 | 7.31 | 1.73* |

* α=0.05
** Neutral color is represented as N, and chromatic color as its Hue/Chroma.
a lack of hue, (2) when the value of colors are similar, select the color with the lowest value and increase its chroma above the others, (3) when the tone of the colors are similar, set their value at 6 or above.

6.4 Type 4: Combination of 3 Chromatic Colors which are Not Analogous

- Levels of discernment in normal vision

Both D2 and D5 are composed of colors whose values are 8 or above. In D2, the value of the colors is similar but the hue and the chroma are different. In D5, the chroma of the colors is the same, but there are differences of hue and value. As a result of these differences, D2 and D5 show higher discernment levels.

- Levels of discernment in elderly vision

In D2, which showed a high score in response to the difference in hue and chroma for normal vision, there was a remarkable decrease in the score to 2.37 for elderly vision. Comparing colors B with GY in D2, the chroma is 1 and 5.5 respectively, and the value of both colors is 9, i.e. B is paler than GY. Although colors in general for the elderly become dimmer, the dimness in hues with shorter wavelengths is intense due to yellowed eyesight. Therefore, B whose wavelengths are shorter than GY is perceived similar in value and chroma to each other by elderly vision and caused the score to decrease significantly.

In D5 the chroma of all colors equaled 2.5 and the BG, whose wavelengths are shorter, had the lowest value. The degree of change in the darkening of hues is high in the order of BG, GY, and YR in elderly vision. As a result, BG with the lowest value was perceived much darker than the others and the combination became easier to distinguish. The score increased to a remarkable 7.31.

- Color schemes of Type 4

The colors used in type 4 are not analogous. Separate colors have different wavelengths that affect how they are perceived by elderly vision.

Fig.9. illustrates the change of color brightness perceived by the elderly. (a) and (b) are color combinations composed of one color with a short wavelength (S) and one color with a long wavelength color (L). Both combinations have an equal color difference (ΔE) between L and S in terms of normal vision, but in terms of elderly vision, the color difference (ΔE') differ significantly. In combination (a), where S is darker than L, the color difference is much larger because S' is perceived much darker than the L' by the elderly; therefore, the level of discernment between L' and S' is larger than L and S. In combination (b), L is darker than S; therefore, the color difference decreased, making it harder for the elderly to distinguish the 2 different colors. Although it is desirable to make colors different vary in hue, value and chroma, the degree of change felt by the elderly and their perception of color must be taken into consideration.

Based on the results, color combination schemes composed of 3 chromatic colors that are not analogous could be summarized as follows: (1) to set a gap between the values of each color as much as possible, in specific, make ΔE' 1 or higher among colors Y-Y, PB-PB, and Y-PB, which the elderly recognize with little hue, (2) when colors have similar tones, make sure the value is 6 or above, (3) when the chroma of the colors is the same, select a color that has a shorter wavelength and reduce the values below the other colors, (4) when the value of the colors is the same, select a color with a short wavelength and increase its chroma above the others.

7. Discussion

As suspected, results indicated that most color combinations (B1, C1, and D1) found in field study, excluding color combination A1, are difficult for elderly vision to discern as well as the young adults with normal vision. This outcome can only confirm the lack of importance placed on color combination discernment for apartment bathrooms in Korea.

Most of the scores for elderly vision had results of 5 or above, therefore, supports the efficiency of the distinguishable color schemes suggested by Kang et al. (2008).

However, not all the suggested combinations had high discernment results, e.g. A2 and A3 for normal vision and B3, B2, C5 and D2 for elderly vision. Color schemes can be complemented in the following manner: (1) even if a color is not Y nor PB, that can easily be confused with neutral colors, a value difference under 1 between a color and a neutral color needs to set the color's chroma to 3.5 or above (from A2 and A3), (2) when using the color Y or PB, whose color cue is reduced by elderly vision, make its value difference with neutral color 1 or above regardless of its chroma (from B3 and B2), (3) when using colors from the same tone, set the value to 6 or above (from C5), (4) when using colors with different wavelengths, increase the chroma of the colors that have short wavelengths and reduce value in comparison to the other colors (from D2).

The characteristics of the combinations that had a relatively high score of 6 or above for both normal and elderly vision can be summarized as follows: (1) when the value difference between colors is 1 or above, the chroma of the color with a low value was increased above the other colors (A5, B5, B4, C2, C3, C4), (2) when the value difference is lower than 1, the color
value with the short wavelengths was reduced below the others or the chroma was increased (D4, D5).

Different levels of discernment between normal and elderly vision are caused mainly by (1) the difference in the degree of change in brightness between non-analogous colors, (2) and the loss of hue in Y and PB perceived by the elderly with yellowed eyesight.

8. Color schemes for the normal and elderly vision

Based on the empirical findings of the present study, the color schemes suggested in the previous study could be complemented for both normal and elderly vision as follows:

1) treat colors in confusion areas as one color.
2) create a large value difference between colors. Especially with the 6 possible hue combinations of Y and PB and neutral, produce a value difference of at least 1 or above.
3) when the value difference is below 1 between a chromatic color and colors with the hue Y or PB or neutral, increase its chroma to 3.5 or above.
4) when analogous colors with same tone are used, change their value to 6 or above.
5) when the value difference is under 1 among non-analogous colors, increase the chroma of color with the short wavelength above the others.
6) when the chroma difference is under 1 among non-analogous colors, reduce the value of the color with the short wavelength below the color with the lowest value present.

9. Conclusion

In the perspective of universal design, the present study empirically examines the efficiency of the suggested color schemes and check to see if it fits the needs of both normal vision and elder vision suffering from yellowed eyesight. Therefore, the consideration for not only image scale in space, but also the level of color discernment in a space is required.

In some cases the discernment levels for certain colors are higher for elderly vision than normal vision. This indicates that yellowed eyesight of the elderly is not always an unfavorable condition for distinguishing colors. According to the concepts of universal design, the change of eyesight in the elderly is more of a characteristic as opposed to impairment. If there is an effort to try and understand the characteristics involved in normal and elderly vision, it is possible to design within the same image scale for both users.

In analyzing and suggesting color combinations, this study is centered on the actual image scale of the bathroom. Color combinations not commonly used in bathrooms are not included in this study but are listed below: (1) colors are lower than 5.5 in values, (2) the colors are high in both value and chroma, (3) colors Y and PB or just PB are the only hues, etc. The suggested color schemes may be complemented by additional examinations of these combinations listed above. In the visual environment of the bathroom, discernment levels of different colors on the walls, floor, and door were investigated. The study of the overall environment including other visual components such as the lighting, the shape and material, etc. would be the next step. Findings in this present study could be used as basic material for further investigation.

Endnotes
1) Natural northern daylight from 3 hours after sunrise to 3 hours before sunset without any interference from surrounding colors can be used for the test (Korean standards association. (2005) KS A 0065, Methods of visual comparison for surface colors. Seoul: Korean standards association.)
2) The majority of researchers would consider 100 lx to be a minimal level for screening purpose. Screening-test results are not affected by change in level of illumination between approximately 100 and 1,000 lx (Committee on vision, National research council. (1981) Procedures for testing color vision. Washington, D.C.: National Academy of Sciences.).
3) It is recommended to limit analogous color schemes to a 90 degree range defined the color circle (Pile, J.F. (1997) Color in interior design. New York: McGraw-Hill.).
4) \( \Delta E = 2/5 \times \Delta C + \Delta V = \Delta H/6 \Delta V + 3 \Delta H \) could be explained approximately as \( 3 \Delta H = 1 \Delta V = 2 \Delta C \) (Moon, E.B. (2005) Understanding and application of colors. Seoul: Ahn Gracius).

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