THE JOURNAL ON TECHNOLOGY AND PERSONS WITH DISABILITIES

Secure Color Combinations of Stairs for Senior Citizens

Hiroyuki Nakamura
Shibaura Institute of Technology
nkmr@shibaura-it.ac.jp

Abstract

This study aims to promote safety in using stairs in public places among an aging population. In this study, the author focuses on how tread and nosing (an edge of a tread) of each step on a staircase can be painted in colors of greater visibility for older adults who experience cataracts or age-related yellowing of the lens of their eyes. The author investigated the effects of ambient light on the color combination of stairs in public spaces where color guidelines strongly recommend color choices. Furthermore, the focus of this study is not on detecting the presence of stairs but instead perceiving where the stair steps are so that a person approaching the stairs does not take a wrong step. This study suggests that the color combination of Munsell Values 5YR6/2 for tread and 10R4/6 for nosing is the most visible color scheme for older adults in the stairs at Tamachi Station in any ambient light. The color scheme of Munsell Values 10YR2/2 for tread and 5Y9.5/10 for nosing is also a safe color combination, particularly in evening light on a cloudy day.

Keywords

Older adults, aging, color combination of a staircase, ambient light, visibility, wayfinding

Introduction

Aging weakens our physical and cognitive functions. Color changes with age (Shinomori, 2003), and yellowing of the lens affects our daily lives (Ishihara, 1998). Due to aging, reduced visual function, cataracts, and lens yellowing can cause older adults to stumble and fall in the evening and at night (Cabinet Office, 2010). Stairs, in particular, are places where older adults face danger. When older adults see a step from the top of a staircase, it is difficult for them to recognize the edge of the step in the evening or at night.

The global community is aging. It is especially critical in Japan. The number of people aged 65 and over accounts for 29.0% of the population and is still increasing (Statistic Bureau, 2021). This phenomenon causes various issues, such as the confinement of older adults and the lonely death of living alone (Cabinet Office, 2019). Physical, psychological, and social environmental factors make older adults confined. Many of them feel insecure about their connection to the community. They should have specific roles in society, community, and family and participate in society (Cabinet Office, 2019). Transportation and urban environments need to be friendlier for older adults who go out into the community searching for income or development of opportunity. In particular, public facilities should become more critical. This background let the Japanese government enact the so-called “New Barrier-Free Law” in 2007 to ensure accessibility of transportation systems and buildings. Since this law came into effect, efforts have been made to increase the visibility of stairs in stations by painting the edges of the treads in different colors.

On the other hand, the central government of Japan enacted the “Landscape Law” in 2004. This law strongly encourages local governments to create their landscape plans, including the color guidelines of building facades, especially in public places. Since Japan is a centralized country, about one-third of the local governments (1,718 municipalities) have followed this directive and then made their plans. However, the recommended colors for urban areas tend to be low in saturation (Kametani et al., 2000, Kobayashi 2013) and difficult to distinguish for older adults.

We can find several studies in architecture, urban planning, and ergonomics. Some studies examined the relationship between the colors of urban landscapes and the color vision characteristics of older adults (Tonosaki, 2012, Ohgai, 2004), and others examined the effectiveness of safety colors defined by the Japanese Industrial Standards (JIS) for older adults (Ochiai et al., 2021). We can find some studies on color combinations of stairs (color schemes for tread and nosing) that match the visual characteristics of older adults (Ministry of Land, 2003, Mijy, 2009). However, these studies do not consider the effects of ambient light. Since Mijy uses a method of presenting color chips on a PC screen to simulate easy-to-see colors, it remains difficult for subjects to evaluate actual spaces and stairs.

Therefore, in this study, the authors investigated the effects of ambient light on the color combination of stairs in public spaces where color guidelines strongly recommend color choices. Furthermore, the focus of this study is not on detecting the presence of stairs but instead perceiving where the stair steps (and the boundaries between tread and nosing) are so that a person approaching the stairs does not take a wrong step.

Methods

In order to select the color scheme for stairs that is easily visible to older adults, it is best to experiment with painting actual stairs. As it is not impossible, but it is certainly unsafe for participants in a study. Therefore, it is common to use photographs for the simulation. However, the space is compressed into a single plane in an ordinary two-dimensional photograph, so it is impossible to recognize depth. Therefore, when looking down from the top of a staircase, it is not easy to distinguish each staircase step.

In this research, we simulated using stereo images. We selected the stairs of Tamachi Station in Tokyo, where an accident involving older adults occurred. We define the horizontal part (step) of each staircase as “tread” and the edge of a tread as “nosing” (Fig. 1). The authors experimented in two stages: preliminary and main experiments.

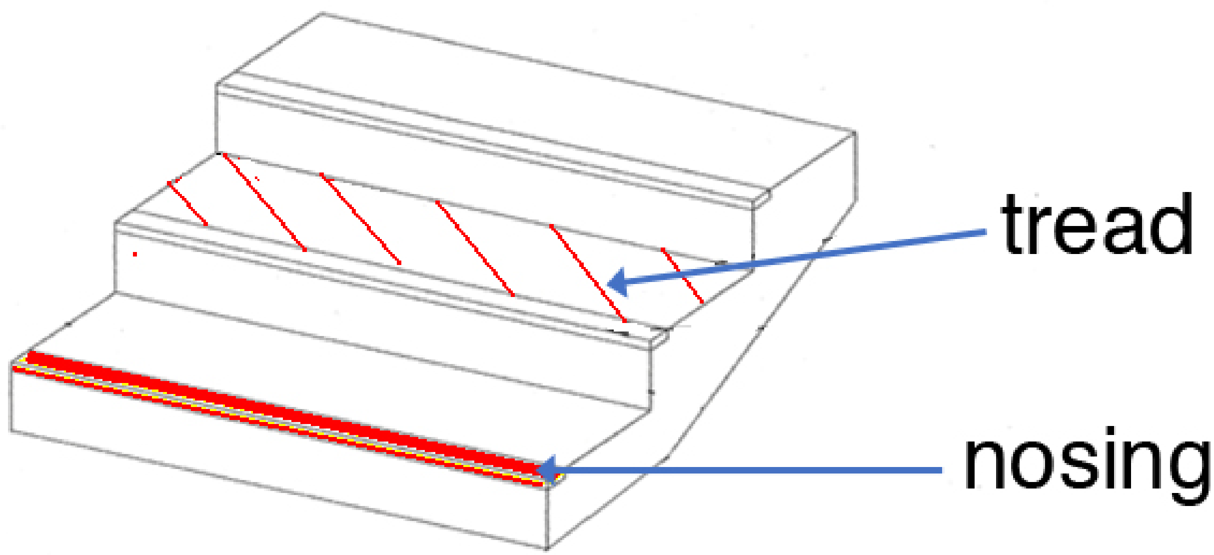

Fig. 1. Structure of a Stair: Tread and Nosing.

Preliminary Experiment

The subjects were 40 students. The age range is 21-22. We used simulation software (“aDesigner” from the ECLIPS Foundation) to simulate the vision of people in their 70s approximately. The subjects viewed the images projected on the screen from the 3D projector with polarized glasses and evaluated them.

It is natural to wonder about the color space reproducibility of the projector and the color change when viewed through polarized glasses. We used a color calibrator (x-rite's i1) to make proper corrections, and we confirmed in a previous study that almost no significant color shift occurs (Nakamura 2005).

Main Experiment

The subjects were 51 people aged 65 years or older. The age range is 65-84. The average was 73.7. 17 with cataracts. The subjects wore a VR viewer (GOOICE VR-PARK) to view and evaluate the images. The images were presented using a smartphone (SONY XZs SO-03J). The color calibrator corrected the color reproduction.

Table 1. Color Combination of Tread and Nosing in Munsell Values.

Note: Color scheme B is Brick Color and D is Yellow Color.

Color Scheme	Munsell Value of Tread	Munsell Value of Nosing
A	2.5Y8/1	2.5Y5/3
B (brick color)	5YR6/2	10R4/6
C	N5.5	N0.5
D (yellow color)	10TR2/2	5Y9.5/10

In this research, the following four ambient lights were selected. They are “daytime sunny” (5500K), “evening sunny” (3500K), “daytime cloudy” (6500K), and “evening cloudy” (7000K). The four combinations of colors were selected based on previous studies (Ministry of Land, 2003, and Mijy 2009.) The color guideline of Minatku, where Tamachi Station locates, includes these colors (Table 1.) Each image was modified in color according to the white balance to simulate each ambient light by Adobe Photoshop (Fig. 2.).

Fig. 2. The Camera Used in the Main Experiment.

The camera used to photograph pictures in the main experiment is tilted downward slightly to emulate human sight to look down at the stairs.

For the stereo images, the simulation tool developed by the authors (Nakamura et al., 2005 and 2010) was used in the preliminary experiments, and the tool using a VR viewer was used in the main experiment instead.

Two compact digital cameras (SONY P-200) were placed in parallel in the preliminary experiment for photography. One digital camera (CANON 6D) was moved to the left and right in the main experiment. In both cases, the distance between the optical axes of the left and the right lenses was 65mm. 65mm is the average distance of human eyes. The color temperature of the ambient light was measured with a color thermometer (SEKONIC C-500) and used for calibration. The lens's focal length is approximately 45mm in 35mm format equivalent. This focal length makes about 50 degrees of view angle, close to the effective field of view when gazing. The camera was set at 150 cm from the ground, assuming the average height of Japanese people to be 160 cm. The camera was tilted downward from the top of the stairs (Fig. 3.)

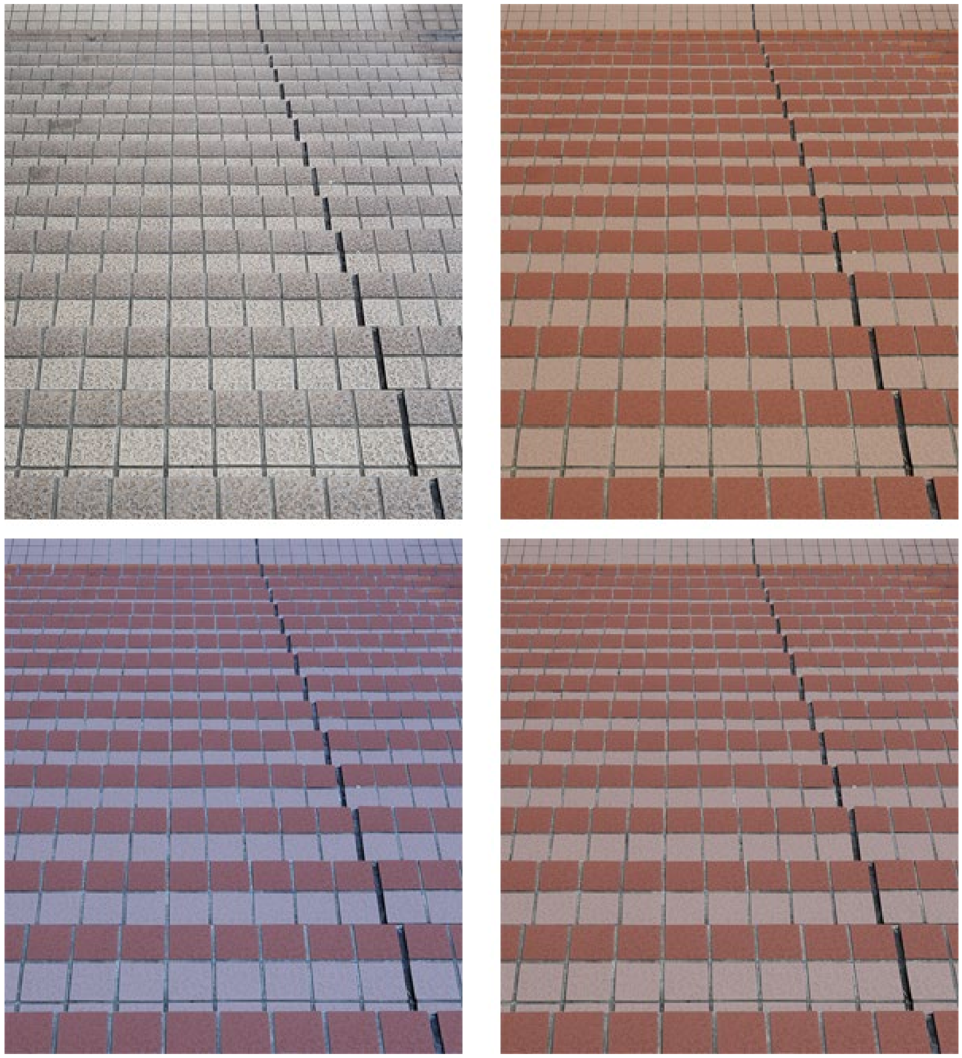

Fig. 3. Color Combination of Stairs in Three Ambient Lights (Munsell value is 5YR6/2 for tread and 10R4/6 for nosing). Pictures are only in standard 2D format and only a half of stereo images (the right half of the stereo images) because it is impossible to view them without viewers. Top Left: Reference image (current combination) in 5500K. Top Right: Simulated image in ambient light 3500K (Munsell value is 5YR6/2 for tread and 10R4/6 for nosing). Bottom Left: Simulated image in 7000K (same Munsell value). Bottom Right: Simulated image in 5500K (same Munsell value).

In the preliminary experiment, the images were projected on the 140inch screen from a distance of 4m. This screen size and the distance provide a nearly equal angle to the effective field of view. In the main experiment, the images are viewed with a VR viewer. The distance is similar to the typical distance from a person's eyes to a staircase when they are about to step on them. The virtual distance when viewing a VR viewer in the main experiment is also this distance. The subjects tilted slightly downward to simulate standing at the top of the stairs.

In both the experiments, two items are evaluated: "whether nosing is easy to recognize" and "which images look relatively dangerous." Subjects evaluated in nine grades (-4,-3,-2,-1,0,1,2,3,4) in the preliminary experiment and seven grades (-3,-2,-1,0,1,2,3) in the main experiment. When the visibility of the simulation image is equal to the reference image, a grade is zero. Positive grades are given when the simulation image is superior to the reference image.

After a brief explanation, the subject puts on the polarized glasses in the preliminary experiment. While standing, they viewed the images in the following order: stereo adjustment image, reference image, color neutralization image, and simulation image. Here, the adjustment image is an image to confirm the stereoscopic view. The reference image is an image of the current nosing and tread. The color adjustment image is a neutral gray image to reset the color adaptation. The simulation image is with different color combinations. The procedure for the main experiment is similar, but instead of polarized glasses, a VR viewer is worn.

Results

Table 2. T-Test Results on the Scores of Color Combinations in the Preliminary Experiment.

Note: Color Scheme B is Brick Color and D is Yellow Color.

Ambient Light	Color Scheme	Average Score	t-value	p-value	Significance
Daytime Sunny	B	7.7	17.68	1.35 ^ -8	1%
Daytime Sunny	C	7.0	2.93	8.41 ^ -3	1%

Ambient Light	Color Scheme	Average Score	t-value	p-value	Significance
Evening Sunny	B	8.0	11.12	2.97 ^ -7	1%
Evening Sunny	C	7.6	6.80	2.38 ^ -5	1%
Evening Sunny	A	7.3	5.30	1.72 ^ -4	1%
Daytime Cloudy	B	7.2	11.00	8.05 ^ -7	1%
Daytime Cloudy	C	6.6	2.85	9.51 ^ -3	1%
Evening Cloudy	B	7.9	8.22	1.79 ^ -5	1%
Evening Cloudy	C	7.2	5.55	2.71 ^ -4	1%
Evening Cloudy	D	7.6	6.78	7.02 ^ -5	1%

Table 3. T-Test Results on the Scores of Dangers in the Preliminary Experiment.

Note: Color Scheme B is Brick Color and D is Yellow Color.

Ambient Light	Color Scheme	Average Score	t-value	p-value	Significance
Daytime Sunny	B	4.1	11.00	8.05 ^ -7	1%
Evening Sunny	A	3.0	2.89	8.10 ^ -3	1%
Evening Sunny	B	4.1	3.18	4.87 ^ -3	1%
Daytime Cloudy	A	3.7	2.33	2.22 ^ -2	5%
Daytime Cloudy	B	3.0	3.18	4.87 ^ -3	1%
Evening Cloudy	C	3.0	2.51	1.53 ^ -2	5%
Evening Cloudy	D	3.0	-2.51	1.53 ^ -2	5%

We used four different color schemes of stairs considered excellent visibility characteristics for older adults and four ambient lights in the preliminary experiment. Of these 16 combinations, t-tests were conducted on the results of nosing's visibility evaluation. The results of the t-test were compared with the reference image (the current color scheme) at a significance level of 5% (indicated *) or 1% (indicated **) (Table 2). A t-test was also conducted to evaluate the danger (Table 3.) The following were clarified:

1) The color combination of Munsell values (tread 5YR6/2, nosing 10R4/6) is legible under any ambient light compared to the current scheme.

2) The Munsell values (tread 5YR6/2, nosing 10R4/6) are near-safe colors that do not present any danger under any ambient light.
3) The combination of Munsell values (tread 10YR2/2, nosing 5Y9.5/10) is a more legible and safer color for recognizing nosing in the evening light of a cloudy day.

Table 4: The t-test result on the scores of color combination in the main experiment

Note: Color Scheme B is “brick color” and D is “yellow color” in the main experience.

Ambient Light	Color scheme	Average Score	t-value	p-value	Significance
Daytime Sunny	B	1.1	1.74	5.26 ^ -2	10%
Daytime Sunny	D	1.1	1.80	4.80 ^ -2	5%
Evening Sunny	B	1.9	4.60	2.51 ^ -4	1%
Evening Cloudy	B	0.9	1.72	5.44 ^ -2	5%
Evening Cloudy	D	1.3	2.65	1.00 ^ -2	5%

In the main experiment, we used the two combinations of colors to consider the subject's burden and three ambient lights such as “daytime sunny” (5500K), “evening sunny” (3500K), and “evening cloudy” (7000K). The results of the t-test are shown in Table 4. The differences from the current color scheme were found at a significance level of 5% (indicated *) or 1% (indicated **). Figure 4 shows the average scores of each color combination in each ambient light.

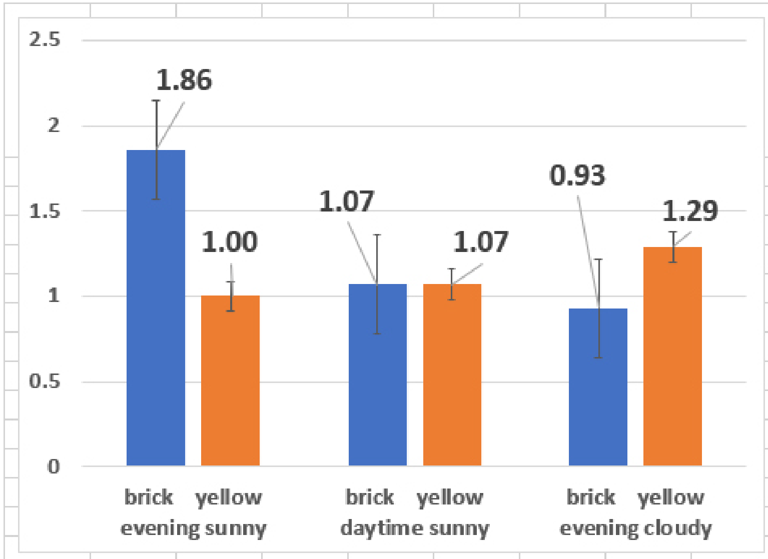

Fig. 4. Average Score of Each Combination of Colors and Ambient Lights.

The results were divided into two age groups: 28 people (65-74) and 23 people (75 older). In the color scheme (tread 5YR6/2, nosing 10R4/6), there was 1% significance in younger seniors on the "evening sunny." In the color scheme (tread 10YR2/2, nosing 5Y9.5/10), there was 1% significance on "evening cloudy." From the above, the following were clarified.

1) The color scheme with a Munsell value (tread 5YR6/2, nosing 10R4/6) is safe on "daytime sunny," "evening sunny," and "evening cloudy."
2) This color scheme is less dangerous among the three types of ambient light.
3) After the experiment, the subjects were asked to write freely. About 70% of the subjects pointed out that yellow, widely understood as characteristic and reassuring, is "too conspicuous" and "tires the eyes."

Discussion

The main experiment results showed a positive difference in the visibility of nosing for brick color (tread 5YR6/2, nosing 10R4/6) at the 1% significance on "evening sunny." The yellow color (tread 10YR2/2, nosing 5Y9.5/10) showed a positive difference at the 5% significance on “evening cloudy.” This result is the same as that of the preliminary experiment.

In each ambient light, the brick color tended to show the edges of the stairs more clearly than the yellow color on the “evening sunny” condition. The yellow color tended to show the nosing more clearly than the brick color on the “evening cloudy.” The brick color was relatively noticeable on the “evening cloudy” because of the ambient light conditions. However, on the “evening sunny,” the brick color tended to be more noticeable than the yellow color because of the orange tint of the surroundings. In the same way, the yellow color was not noticeable on the “evening sunny” because of the ambient light conditions. However, on the “evening cloudy,” the yellow color was more noticeable and straightforward to recognize because of the dim surroundings.

When the visibility of nosing was compared between men and women, no significant difference was found. In comparison with the reference image, on “evening sunny,” there was a positive difference at the 5% significance for women and a positive difference at the 1% significance for men in the brick color stairs. Therefore, we believe that the visibility of stairs tends not to change much between men and women.

There was no significant difference in the visibility of nosing between the two age groups at “evening sunny” and “daytime sunny.” on “evening cloudy,” there was a 5% significance between the age groups to recognize nosing. In the case of “evening cloudy,” there was a 5% significance between age groups in the visibility of the yellow color stairs.

In comparison with the reference image, in the case of “evening sunny,” there was a positive difference at the 1% of significance for the relatively younger seniors in the brick color stairs. In the case of “daytime sunny,” there was a positive difference at the 1% significance for the relatively older seniors on the brick color stairs. In the case of “evening cloudy,” the yellow color stairs showed a positive difference at the 1% significance for the older adults.

Although the visibility of nosing changes depending on the ambient light and the viewer's attributes, it is suggested that both brick and yellow color schemes are apparent on the stairs of Tamachi Station.

However, in terms of “which image felt more dangerous,” the results were opposite for brick color and yellow color. For the brick color, the reference image (the current color scheme) tended to be perceived as more dangerous in all ambient light conditions. On the other hand, for yellow, the comparison image tended to be perceived as more dangerous.

In addition, many of the free descriptions of the brick color were positive, such as “calming color” and “reassuring color.” However, many yellow descriptions were negative, such as “the yellow color distracts people from paying attention to the surroundings” and “yellow is an easy color to see, but it stands out more than other colors.”

Incidentally, although there was no statistically significant difference in which image was dangerous, women tended to find the stairs in the reference image (the current color scheme) more dangerous in the cloudy evening light. In contrast, men tended to find the yellow color stairs slightly more dangerous. We speculate that this may be partly due to differences in the way men and women see colors. In a color test, “Men need slightly longer wavelengths than women to perceive the same hue across almost the entire visible spectrum (Israel Abramov, 2012.) As a specific example, the fruit orange may appear slightly redder to men than to women. Similarly, green grass may almost always appear greener to women and slightly yellow to men. This research suggests that differences in color distinction may have led to differences in the perception of danger.

When comparing the two groups of older adults, there was no significant difference in the visibility of nosing in either “evening sunny” or “daytime sunny.” However, relatively young subjects perceived the brick color stairs on “daytime sunny” as dangerous. In contrast, relatively old subjects tended to perceive the stairs in the reference image (the current color scheme) as dangerous. In the yellow color staircase, the younger seniors perceived the staircase in the current color scheme as more dangerous than the older seniors.

These results suggest that brick color stairs are a less dangerous color scheme than yellow color stairs in Tamachi Station. However, the visibility of nosing changes depending on the ambient light and the viewer's attributes. In addition, it was confirmed that yellow, which is considered a JIS safety color, is a noticeable color. Nevertheless, the main experiment suggested that yellow should not be used for the entire edge of the stairs.

Conclusion

From this research, the authors conclude the following:

1) The brick color (tread 5YR6/2, nosing 10R4/6) stairs and yellow color (tread 10YR2/2, nosing 5Y9.5/10) stairs are considered to be color schemes with high visibility for nosing in any of the three types of ambient light: “evening sunny,” “daytime sunny,” and “evening cloudy.”
2) In the three types of ambient light, brick color stairs are less dangerous than yellow ones.
3) Yellow, considered a JIS safety color, should not be used for a wide range of nosing.
4) There is no difference in the visibility of brick color stairs depending on the gender or age of older adults, and there is a tendency to perceive the brick color scheme as less dangerous.

From the above, we can suggest that the brick color (tread 5YR6/2, nosing 10R4/6) scheme is the most visible color scheme for older adults in the stairs at Tamachi Station in any ambient light.

This study also suggests the following:

1) The colors listed by the color guidelines are prevalent in many cities in Japan, North America, and modern parts of Europe. Therefore, the results are adaptable to Japan and many cities and public spaces worldwide.
2) In the cataract simulation used in this study, a similar color combination is noticed in the younger and older age groups. This result suggests that the cataract simulation software such as aDesigner can be used to a certain extent to evaluate the color combination of stairs. However, since the viewing conditions we utilized in the preliminary and the main experiments in this research are different, further verification is needed.

Works Cited

Abramov, Israel, et al., Sex and vision II: color appearance of monochromatic lights. Biology of Sex Differences, Vol. 3, No. 21, 1-15, 2012.

Cabinet Office, An aged society white paper, 2010 and 2019.

Ishihara, Keiko, et al., Affects of age-related yellowing crystalline lenses on daily life, Ergonomics, Vol.34, No.1, 9-16, 1998.

Kametani, Yoshihiro, et al., Mode of Appearance of Color in Building Exterior Materials, Transactions of AIJ. Journal of architecture, planning and environmental engineering, No. 533, 97-104, 2000.

Kobayashi, Miran, A Basic Study on Commonality and Regional Characteristics of Landscape Color Guidelines, Graduation thesis, Shibaura Institute of Technology, 2013.

Mijy, Kwon, et al, Color Coordination for Stairways with High Visibility for the Elderly People: For Prevention of Falling Accidents, The design study research Vol. 56, No. 3, 99-108, 2009.

Ministry of Land, Infrastructure and Transport, The color plan investigation report of the public space in an aging society, 2003.

Nakamura, Hiroyuki and KAWAMURA, Kenji, Evaluation of Color Environment for the Elderly and the Color Blind -3D Color Accessibility Simulator-, Proceedings of Socio Information Studies, Vol. 20, 90-95, 2010.

Nakamura, Hiroyuki, et al., Evaluation of Color Environment for the Elderly and the Color Blind -3D Color Accessibility Simulator-, Human Interface, Vol. 7, No. 5, 33-38, 2005.

Ochiai, Nobuhisa, and KONDO, Hiroyuki, Investigating the Reproducibility of Hazard Perception among the Elderly for Safety Colors in Japanese Industrial Standards using Test–Retest Method, The Japanese Journal of Ergonomics, Vol. 57, Supp., 1F2-1, 2021.

Ohgai, Akira, et al., Evaluating Walk Space from the Viewpoints of Safety and Town space, The AIJ Journal of Technology and Design, No. 20, 313-318. 2004.

Shinomori, Keizo, Aging Effects on Color Vision, Journal of the Color Science Association of Japan, vol.27, No. 3, 216-223, 2003.

Statistical Bureau of Japan, Census, 2021.

Tonosaki, Kochi, Measurement of Comfort in Urban Landscape Using the Ratio of Vertical Green Coverage by Chromaticity, Landscape Research Japan Online, Volume 5, Pages 47-54, 2012.