Study on the threshold of judgment of different age groups on the depth of green in the green color system

Qiyang LIN[1,†] and Yujie ZHOU[2]

[1] *Qiyang LIN*
[2] *Yujie ZHOU*
[†] *These authors contributed equally to this work*

Abstract

The relationship between human color discrimination threshold and increasing age has always been a major subject of study. It is commonly believed that older populations have a higher color discrimination threshold than younger ones, meaning young people can more rapidly identify subtle color differences. However, some argue that with the advancement of display technology, the difference in color discrimination across different age groups has gradually disappeared. To investigate whether the current young population has superior color discrimination abilities compared to the middle-aged group, this study employed both the method of limits and the method of constant stimuli to conduct a color discrimination threshold survey among people aged 20-30 and 30-40. By asking participants to determine whether there is a difference in the depth of color in the provided green color blocks, the study analyzed the color discrimination threshold intervals of different age groups and compared the differences in experimental results between the two populations. Ultimately, this study confirmed the conclusion: the younger group possesses better color discrimination abilities than the middle-aged group, but the color discrimination thresholds of both groups are similar, corroborating the excellent auxiliary effect of technological progress on human vision.

1. Introduction

Color difference, defined as the perceptual discrepancy between different colors, is a fundamental aspect of visual experience that influences various domains, including design, marketing, and human-computer interaction[8] . It plays a critical role in how individuals perceive and interact with their environment. Understanding color difference is essential not only for enhancing aesthetic appeal but also for improving functionality and usability in applications ranging from digital displays to product design. Research indicates that individuals exhibit variability in color discrimination abilities, which can be influenced by factors such as age, ambient lighting conditions, and the characteristics of display technology[9].

Threshold experiments are a widely used methodology for assessing color discrimination, aiming to determine the minimum perceptible difference in color that a viewer can detect [3]. These experiments typically involve presenting participants with stimuli that gradually change in color, and participants are tasked with identifying the point at which a change becomes noticeable. The significance of threshold testing is underscored by studies such as those conducted by[1], which examined the effects of different display technologies on color perception. These findings highlight the impact of hardware quality on individuals' ability to perceive color differences, emphasizing the need to explore contemporary advancements in display technology.

Most of the research on the colour discrimination threshold of the human eye in China and abroad has been conducted using CRT display devices.In order to study the colour discrimination properties of the human eye, Wang[6] used a CRT monitor to formulate colour stimuli based on the five basic colour centres and used the grey scale method to evaluate the colour difference data. Ethan[2], [7] used a CRT monitor to generate colour stimuli to study visual threshold chromatic aberration. Xu[4]–[6] investigated the effect of differences in visual scale on colour visual discrimination by using the cross-stepping method and the constant stimulus method.

In this study, we hypothesize that, under current high-quality display conditions, such as those provided by the iPhone 15 compared to the iPhone X, the color discrimination thresholds of young adults (ages 20-30) and middle-aged adults (ages 30-40) will exhibit minimal differences. This hypothesis is grounded in the understanding that advancements in display technology have enhanced color representation and clarity, potentially reducing age-related disparities in color perception. To investigate this hypothesis, we will conduct threshold tests using two distinct methodologies: one involving direct color comparison and the other employing color matching tasks. By analyzing the sensitivity of both age groups to variations in color depth, we aim to contribute to the growing body of literature on how technological advancements influence color perception across different demographics.

2. Overview

This study investigates the impact of color difference on the color discrimination abilities of two age groups: young adults (ages 20-30) and middle-aged adults (ages 30-40). Color difference is crucial for various applications, influencing how individuals interact with their environment and perceive visual stimuli. To assess color discrimination, we will employ threshold experiments, which measure the smallest detectable differences in color perception.

Our hypothesis posits that advancements in display technology, particularly in devices like the iPhone 15 compared to the iPhone X, will minimize the differences in color discrimination thresholds between the two age groups. We will conduct two types of threshold tests to evaluate the sensitivity of both groups to variations in color depth. The results of this research aim to deepen our understanding of how technology influences color perception across different demographics, with potential implications for design, marketing, and visual ergonomics.

3. Methods

3.1. Preparation and Conditions

This study employs visual experiments to assess the color discrimination thresholds of participants, utilizing RGB color blocks generated through MATLAB software. The visual stimuli are displayed on a uniform screen at 50 brightness within a controlled, enclosed lighting environment. This setup minimizes the influence of external factors, ensuring consistent color perception across trials.

- In this study, all experiments were conducted through visual observation. The smartphone displaying the experimental images was placed on a stand at the center of the experimental setup. Observers were asked to sit upright and maintain, as much as possible, an observation distance of 55 cm. Observers were

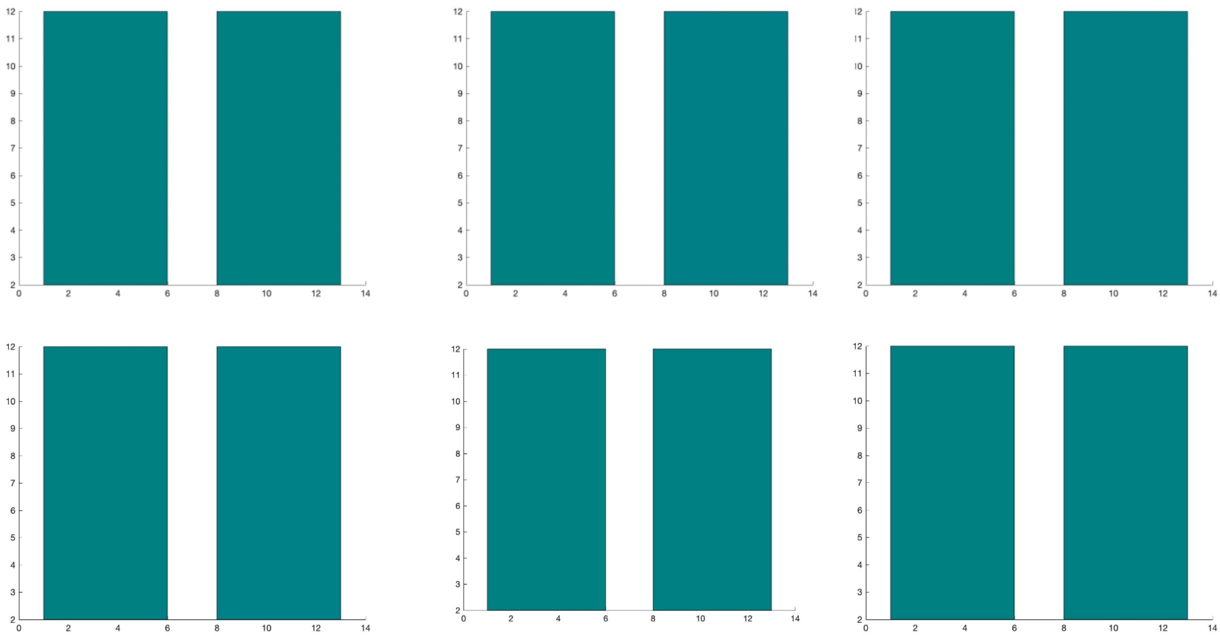

Figure 1. Different Color with different threshold.

then asked to make observations and respond to the following question based on their first instinct: "Is there a noticeable difference in color depth between the image on the left and the image on the right?" Responses were based on the observers' intuitive judgment. If the observer perceived no difference between the two, it was recorded as a numerical value of "0". Conversely, if a difference was perceived, it was recorded as a numerical value of "1". Each observer's judgments were recorded for each instance and this data was used to analyze the threshold.

- Experimental Image Generation: Using MATLAB software, green rectangular color blocks were generated with an RGB baseline color value of (0, 0.5, 0.5). Subsequently, by increasing the B value incrementally, different shades of green rectangular color blocks were created. The baseline color block and the adjusted color blocks were placed within the same image for export and compilation. During the experimental process, all images were uniformly displayed on a MacBook at 50% brightness in a controlled lighting environment, with similar image sizes and resolutions, and without any quality compression.
- Participant Selection: Participants are chosen based on strict criteria to ensure accurate results. Only normal trichromats—individuals who are neither color-blind nor color-deficient—are included. Furthermore, all participants must have normal vision or corrected vision using appropriate eyewear.
- Training: Prior to the experiments, all observers undergo a training session designed to enhance their subjective color judgment skills. This training involves familiarizing participants with color discrimination tasks, ensuring they understand the experimental requirements.
- Testing Environment: During testing, participants are instructed to refrain from wearing tinted glasses, sunglasses, or colored contact lenses, as these can interfere with color perception. Additionally, participants must not consume any strong or recreational drugs before the experiment. To reduce potential biases, observers are required to wear neutral-colored clothing and avoid any reflective jewelry that could distract or influence their responses.
- Time Management: To mitigate visual fatigue and ensure focus, each participant's observation time is limited to a maximum of 30 minutes, with breaks permitted as needed. This structure helps maintain participants' attention and reduces the risk of errors due to fatigue.
- Age Grouping: Participants are divided into two distinct age groups: the Young Adult Group (ages 20-30) and the Middle-Aged Adult Group (ages 30-40). Each group consists of six members with a diverse age range and no gender restrictions, providing a comprehensive comparison of color discrimination abilities across different age demographics.
- Experimental Environment and Background Selection Requirements: The experiment was conducted in a light-proof chamber, with external light blocked by opaque gray curtains. Inside, no other light sources were present except for the observation light source. The walls and surroundings were devoid of any large areas of intense color. Indoor illumination was provided by a single LED bulb. All participants conducted the observation experiments in the same room and within similar time frames. To minimize the impact of background brightness and color on the experiment, a neutral gray background was chosen.

3.2. Method

3.2.1. Method of Limits

The method of limits is utilized to ascertain the color discrimination thresholds of the participants. Each participant is presented with a series of color blocks that vary incrementally in hue, saturation, or brightness. During each trial, observers are prompted to indicate when they first perceive a difference between two presented colors. This response is meticulously recorded to establish the threshold of color detection for each individual.

For the RGB images, set the minimum increment value for the B value to 0.01 and the maximum increment value to 0.1, with an increment step of 0.005. This means the color stimulus variation experimental group consists of nine data points: 0.01, 0.015, 0.02, 0.025, 0.03, 0.035, 0.04, 0.045, and 0.05. Observers are instructed to view the displayed images and judge the differences in color depth. A response of '0' is recorded for no perceived difference, and '1' for a perceived difference. The images are presented in ascending order, indicating a gradual increase in stimulus intensity. Finally, based on the collected data, the interval of the color discrimination threshold for the experimental population is determined.

To ensure reliability, the experiment is conducted multiple times for each participant, allowing for the calculation of an average threshold for each color variation. After the completion of the tests, the collected data undergoes statistical analysis to determine the significance of any observed differences in color discrimination thresholds between the young and middle-aged groups. This rigorous approach not only ensures controlled experimental conditions but also facilitates a comprehensive analysis of age-related differences in color perception.

3.2.2. Method of Constant Stimuli

The method of Constant Stimuli is a classical technique used in psycho-physics to measure the sensory threshold of an observer by presenting stimuli of fixed intensities in a random order and defining absolute threshold as the intensity value that elicits "perceived" responses on 50% of the trials. Here in this study, according to the information from the result of method of limits, as the range of color discrimination thresholds of the experimental population mainly lies between 0.02-0.07, 6 kinds of color difference setting block are prepared as constant stimuli(0.03, 0.035, 0.04, 0.045, 0.05, 0.055), and each participant is presented with a series of these color block in a quasi-random order. During each trial, observers also have to indicate when they first perceive a difference or similarity between the two presented color block.

In order to collect reliable data and more precise threshold discrimination, the method is utilized and each kind of color block is presented by 20 times randomly to avoid serendipity and failure judgement. The frequency and percentage of the times that observers recognize the difference will be counted and calculated. By plotting a curve of constant stimuli versus percentage of recognition, the absolute threshold can be confirmed based on the 50% recognition percentage in the curve. This kind of methods can provide a more accurate estimate of the sensory threshold.

3.2.3. Participant Grouping

For this study, participants were divided into two age-based groups to enable a detailed comparison of color discrimination thresholds between younger and middle-aged individuals. The Young Adult Group (ages 20-30) consisted of six participants with evenly distributed ages of 20, 22, 24, 26, 28, and 30. This range was selected to ensure gradual variation across young adulthood, offering insight into potential changes in color perception within this demographic.

Similarly, the Middle-Aged Group (ages 30-40) included six participants aged 31, 33, 35, 37, 39, and 40, representing a spectrum of middle-aged individuals. Both groups comprised participants with normal or corrected vision, and there were no gender restrictions, allowing for a balanced mix of male and female participants.

The age distribution within each group was designed to capture subtle differences in color discrimination that may occur with age, providing a comprehensive analysis of visual perception across different life stages. This approach ensures the study can effectively investigate how aging influences color sensitivity under controlled experimental conditions.

4. Result

4.1. Method of Limits

As shown in Table, the ability to distinguish colors declines progressively as the threshold value decreases across all age groups. For all participants, 100% were able to distinguish colors at higher thresholds (0.1 to 0.07), but this percentage dropped to 38.46% at the lowest threshold (0.01).

For the 20-30 age group, 100% of participants maintained the ability to distinguish colors from threshold 0.1 to 0.06. At lower thresholds, this capability decreased, with 76.92% at 0.03, and 61.54

In the 30-40 age group, 100% of participants could distinguish colors at thresholds 0.1 to 0.07. However, their ability decreased more sharply at lower thresholds, with only 46.15% at 0.03 and 15.38% at 0.01

Threshold	All ages	30-40 years old	20-30 years old
0.1	100.00%	100.00%	100.00%
0.09	96.15%	100.00%	92.31%
0.08	100.00%	100.00%	92.31%
0.07	100.00%	100.00%	100.00%
0.06	96.15%	92.31%	92.31%
0.05	92.31%	92.31%	92.31%
0.045	92.31%	92.31%	92.31%
0.04	69.23%	76.92%	92.31%
0.035	61.54%	76.92%	46.15%
0.03	42.31%	38.46%	46.15%
0.025	30.77%	38.46%	23.08%
0.02	30.77%	46.15%	15.38%
0.015	30.77%	46.15%	15.38%
0.01	38.46%	61.54%	15.38%

Table 1. (Distinguishing colors across age groups)

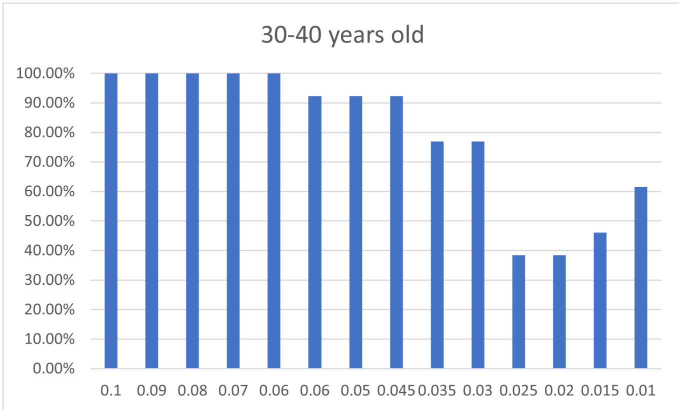

Figure 2. 30-40 years old.

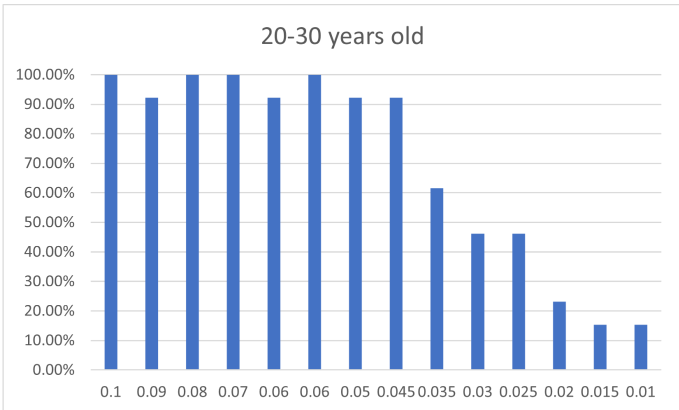

Figure 3. 20-30 years old.

Figures 3 and 2 compare the percentage distributions of a specific metric across two age groups: 20-30 years old (Figure 2) and 30-40 years old (Figure 3). Both figures display the percentages for a range of values from 0.1 to 0.01, with noticeable differences between the two groups as the values decrease.

In Figure 3, which represents the 20-30 years old group, the percentages are consistently high (above 90%) for values between 0.1 and 0.06, indicating that most individuals in this age group fall within this range. As the values decrease from 0.05 to 0.01, the percentages decline steadily, dropping sharply after 0.05 and reaching approximately 10%-20% at the lower end (0.01). This pattern suggests that the majority of individuals in this group maintain high metric values, with a gradual but consistent drop-off as the values decrease.

In contrast, Figure 2, which shows the 30-40 years old group, follows a similar trend at the higher values, with percentages above 80% from 0.1 to 0.06. However, the decline becomes more pronounced from 0.05 onwards, with the percentage dropping below 50% by the time the values reach 0.03. Notably, unlike the 20-30 years old group, the 30-40 years old group exhibits a marked increase in percentages at the lower end (0.01 and 0.02), with the percentage rising sharply at 0.01. This indicates that while the distribution in this group is also skewed toward higher values, a significant proportion of individuals exhibit lower values, leading to a distinct upward shift at the lower range.

In summary, the 20-30 years old group shows a more uniform decline as values decrease, with a consistent downward trend. The 30-40 years old group, however, displays greater variability, particularly at the lower end, where a significant rebound in percentages occurs, suggesting a wider distribution of metric values in this age group.

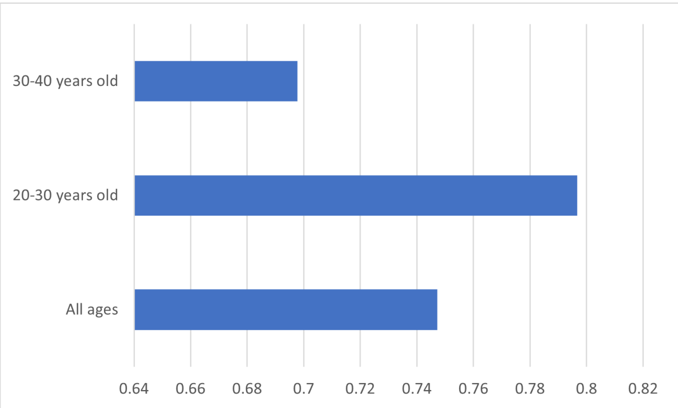

Figure 4. Contrast different ages.

The figure 4 bar chart compares the values of a certain metric across three groups: "20-30 years old," "30-40 years old," and "All ages." The "20-30 years old" group has the highest value, nearing 0.80, while the "30-40 years old" group shows the lowest value at approximately 0.70. The "All ages" group falls in between, with a value around 0.74.

This indicates that the 20-30 years old group performs better on this metric compared to both the 30-40 years old group and the general population, suggesting that younger individuals may have a stronger performance or outcome in the given context.

4.2. Method of Constant Limits

Sample data of the experimental population in the young-adult and middle-aged groups are shown in the table 2-5, and the psychometric function curve of the sample data is shown in the figure 5.

Stimulus Intensity	Frequency	Percentage
0.030	0	0%
0.035	6	30%
0.040	11	55%
0.045	17	85%
0.050	20	100%
0.055	20	100%

Table 2. (Sample Data 1 of Young-Adult Group)

Stimulus Intensity	Frequency	Percentage
0.030	1	5%
0.035	5	25%
0.040	12	60%
0.045	17	85%
0.050	19	95%
0.055	20	100%

Table 3. (Sample Data 2 of Young-Adult Group)

Stimulus Intensity	Frequency	Percentage
0.030	0	0%
0.035	3	15%
0.040	9	45%
0.045	14	70%
0.050	19	95%
0.055	20	100%

Table 4. (Sample Data 1 of Middle-Aged Group)

Stimulus Intensity	Frequency	Percentage
0.030	2	10%
0.035	4	20%
0.040	10	50%
0.045	14	70%
0.050	20	100%
0.055	20	100%

Table 5. (Sample Data 2 of Middle-Aged Group)

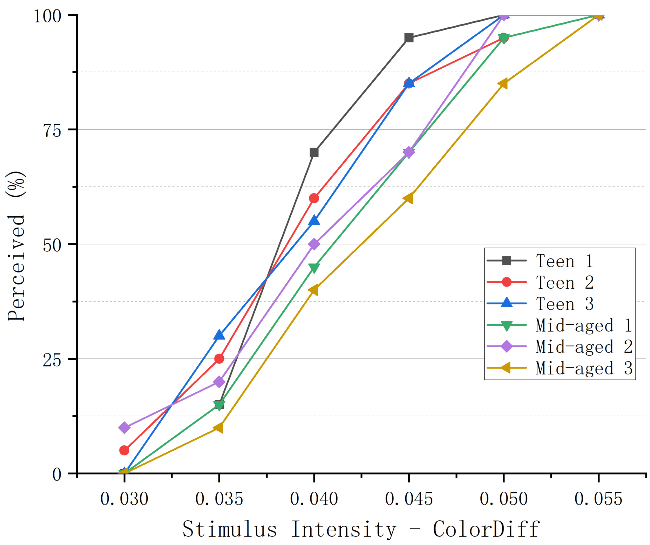

Figure 5. Psychometric Function Curve

According to the tables and figure,

1. After several repetitions of the randomized experiment, it was determined that the color discrimination thresholds of the young-adult and middle-aged groups were mainly located in the range of 0.0375-0.0425, which is a more precise location of the thresholds compared to the limit method's result;
2. For the young people in the 20-30 age group, color depth changes are almost imperceptible when the Color difference growth value is less than or equal to 0.03, and almost 100 percent detectable when the color difference growth value is greater than 0.045, the absolute thresholds obtained from the statistical analysis in the illustrated case are 0.0376, 0.0383, 0.039;
3. For middle-aged people in the 30-40 age group, when the

color difference growth value is less than or equal to 0.03, the color depth change is almost undetectable, and when the color difference growth value is greater than 0.05, the color depth change can be detected with nearly 100 percent chance, the absolute thresholds for color discrimination in the illustrated case obtained after statistical analysis are as follows 0.04, 0.041, 0.043;
4. Comparing the number of detection between the young and middle-aged populations, when the color difference growth values are 0.03 and 0.055, the two groups have the same ability to discriminate colours, but when the Color difference growth values are in this range and the values are the same, the number of detection of the young population is more than that of the middle-aged population, which means the young population's discriminatory ability is better than that of the middle-aged population;
5. Comparing the absolute thresholds of color discrimination between the young-adult population and the middle-aged population, it can be seen from the data of the curves in the figure that when the discrimination success rate is the same as 50%, the corresponding color difference growth value of the young-adult population in each curve is smaller than that of the middle-aged population, which means the young population has smaller absolute thresholds, and this phenomenon suggests that the young-adult population is able to identify weaker color changes compared to the middle-aged population, which proves that young ones have more excellent color discrimination ability.

5. Conclusion

The findings of this study highlight significant differences in color discrimination abilities across age groups. Participants aged 20-30 demonstrated superior performance, with consistently higher color discrimination thresholds compared to those in the 30-40 age group. This suggests that younger individuals retain a more robust ability to perceive color differences, particularly at lower thresholds where the performance of the middle-aged group notably declines. The overall trend indicates that aging is associated with a gradual decline in color sensitivity, particularly for finer distinctions, as shown by the lower percentages in the older age group at thresholds below 0.05.

6. Discussion

These results align with existing literature on age-related decline in visual sensitivity, specifically in color perception. The 20-30 age group maintained higher performance across all thresholds, while the 30-40 group exhibited a sharp drop-off at lower thresholds, likely due to the natural deterioration of visual processing capabilities with age. Interestingly, the 30-40 group showed variability in their ability to detect color differences at lower thresholds, which might be attributed to individual differences in the rate of visual aging or other factors such as environmental influences or health conditions.

The controlled testing conditions minimized the impact of external variables on participants' color perception, ensuring that the observed age-related differences are attributable to physiological changes rather than external influences. Future studies could explore the underlying causes of this decline further, possibly incorporating a broader age range to examine how these changes progress throughout different stages of life. Additionally, research could investigate potential interventions or visual aids that might mitigate the decline in color discrimination abilities as individuals age.

References

[1] J. C. Fish, ?Colour as sensation in visual art and in science,? *Leonardo*, **pages** 89–98, 1981.

[2] Y. Qiao, R. Berns, L. Reniff **and** E. Montag, ?Visual determination of hue suprathreshold color-difference tolerances,? *COLOR RESEARCH AND APPLICATION*, **jourvol** 23, **number** 5, **pages** 302–313, **october** 1998, ISSN: 0361-2317. DOI: 10.1002/(SICI)1520-6378(199810)23:5<302::AID-COL6>3.0.CO;2-\#.

[3] K. Ishihara, S. Ishihara, M. Nagamachi, S. Hiramatsu **and** H. Osaki, ?Age-related decline in color perception and difficulties with daily activities–measurement, questionnaire, optical and computer-graphics simulation studies,? *International Journal of Industrial Ergonomics*, **jourvol** 28, **number** 3-4, **pages** 153–163, 2001.

[4] H. Xu, H. Yaguchi **and** S. Shiroiri, ?Testing CIELAB-based color-difference formulae using large color differences,? *OPTICAL REVIEW*, **jourvol** 8, **number** 6, **pages** 487–494, **november** 2001, ISSN: 1340-6000. DOI: 10.1007/BF02931740.

[5] H. Xu, H. Yaguchi **and** S. Shioiri, ?Correlation between visual and colorimetric scales ranging from threshold to large color difference,? *COLOR RESEARCH AND APPLICATION*, **jourvol** 27, **number** 5, **pages** 349–359, **october** 2002, ISSN: 0361-2317. DOI: 10.1002/col.10081.

[6] H. Xu **and** H. Yaguchi, ?Visual evaluation at scale of threshold to suprathreshold color difference,? *COLOR RESEARCH AND APPLICATION*, **jourvol** 30, **number** 3, **pages** 198–208, **june** 2005, ISSN: 0361-2317. DOI: 10.1002/col.20106.

[7] R. Huertas, M. Melgosa **and** E. Hita, ?Influence of random-dot textures on perception of suprathreshold color differences,? *JOURNAL OF THE OPTICAL SOCIETY OF AMERICA A-OPTICS IMAGE SCIENCE AND VISION*, **jourvol** 23, **number** 9, **pages** 2067–2076, **september** 2006, ISSN: 1084-7529. DOI: 10.1364/JOSAA.23.002067.

[8] M. D. Fairchild, *Color appearance models*. John Wiley & Sons, 2013.

[9] G. J. Privitera, *Research methods for the behavioral sciences*. Sage Publications, 2024.