Optimized light sources for enhancing color discrimination in people with low vision

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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อนุกูล รัดสำโรง : แหล่งแสงที่เหมาะที่สุดสำหรับการเพิ่มการแยกแยะสีในคนสายตาเลือนราง . (Optimized light sources for enhancing color discrimination in people with low vision) อ.ที่ปรึกษาหลัก : รศ. ดร.พิชญดา เกตุเมฆ, อ.ที่ปรึกษาร่วม : รศ. ดร.อิริค ดิเนต,ดร.วนิตา กาลวารี

งานวิจัยนี้แบ่งเป็น 2 ส่วน ส่วนแรกมีวัตถุประสงค์เพื่อศึกษาอิทธิพลของระดับความสว่างและอุณหภูมิสีต่อการเคลื่อนไหวและความแม่นยำในการทำกิจกรรมในผู้ที่มีสายตาเลือนรางเทียบกับผู้สูงอายุ ส่วนที่ 2 มีวัตถุประสงค์เพื่อหาแสงสว่างที่เหมาะสมในการช่วยแยกแยะสีได้ดีในคนสายตาเลือนรางจากการผสมแสงที่มีการกระจายพลังงานต่างกัน กระบวนการวิจัยในส่วนแรกจัดให้มีสภาวะแสงต่างกัน 7 สภาวะ และให้ผู้ที่มีสายตาเลือนรางและผู้สูงอายุเดินผ่านเส้นทางภายใต้สภาวะแสงเหล่านั้นให้เร็วที่สุดและไม่สัมผัสกับสิ่งกีดขวาง ความเร็วในการเดินและคะแนนการสัมผัสสิ่งกีดขวางเป็นตัวบ่งชี้การเคลื่อนไหวภายใต้สภาวะแสง นอกจากนี้การทดสอบความแม่นยำในการทำกิจกรรมเป็นส่วนหนึ่งในการศึกษาการเคลื่อนไหวโดยให้ผู้เข้าร่วมทดสอบเทน้ำชาลงในถ้วยให้มีระดับน้ำตามที่กำหนด ผลการทดสอบการเคลื่อนไหวพบว่าระดับความสว่างและอุณหภูมิสีในการทดลองไม่ส่งผลต่อความเร็วในการเดินและคะแนนการสัมผัสในผู้ที่มีสายตาเลือนรางและผู้สูงอายุที่ใส่แว่นจำลองสายตาเลือนราง อย่างไรก็ตาม ความเร็วในการเดินของผู้ที่มีสายตาเลือนรางแบบต่างกันจะไม่เท่ากันที่ระดับความสว่างต่ำ และความเร็วในการเดินของผู้สูงอายุใส่แว่นตาจำลองช้ากว่าคนสายตาเลือนราง ความแม่นยำในการทำกิจกรรมชงชาในคนสายตาเลือนรางสูงกว่าผู้สูงอายุใส่แว่นตาจำลอง สำหรับผู้สูงอายุที่ไม่ใส่แว่นตาจำลองพบว่ามีการเคลื่อนไหวได้เร็วกว่าคนสายตาเลือนราง วิธีวิจัยในส่วนที่ 2 ให้ผู้เข้าร่วมที่ใส่แว่นตาจำลองสายตาเลือนราง 2 แบบ ได้แก่ แบบฝ้าขุ่น (CVG) และแบบไม่คมชัด (BVG) ที่มีความคมชัดของสายตา 0.08 และ 0.06 ตามลำดับ โดยทำการแยกแยะความแตกต่างสีของตัวอย่างภายใต้แสงจากแอลอีดี 14 ช่องสัญญาณแสง และเลือกช่องสัญญาณจากช่องที่ผู้เข้าร่วมแยกความต่างสีได้จำนวนมากที่สุด หรือได้เร็วที่สุดหรือมีขีดเริ่มเปลี่ยนต่ำที่สุด จากนั้นนำช่องสัญญาณที่ดีที่สุดในช่วงความยาวคลื่น สั้น กลาง และยาวมาผสมกันให้เป็นแสงขาวก่อนไปทดสอบความสามารถในการแยกแยะสีตัวอย่าง 200 คู่สีโดยผู้ที่สวมแว่นตาจำลองสายตาเลือนรางทั้ง 2 แบบ พบว่าช่องสัญญาณแอลอีดีที่ทำให้แยกความต่างสีได้เร็วที่สุดในช่วงความยาวคลื่นสั้นได้แก่ 410, 420 และ 430 นาโนเมตร 555 นาโนเมตร ในช่วงความยาวคลื่นกลาง และ 615, 630, 600 นาโนเมตร ในช่วงความยาวคลื่นยาว ส่วนช่องสัญญาณที่ทำให้แยกแยะคู่สีที่มีความต่างสีต่ำได้ดีได้แก่ 475 และ 495 นาโนเมตร ในช่วงความยาวคลื่นสั้น 595 และ 540 นาโนเมตร ในช่วงความยาวคลื่นกลางและ 700 และ 660 นาโนเมตร ในช่วงความยาวคลื่นยาวสำหรับแว่นแบบฝ้าขุ่น ส่วนแว่นแบบไม่คมชัด ช่องสัญญาณ 435 และ 495 นาโนเมตร ในช่วงความยาวคลื่นสั้น 525 และ 595 นาโนเมตร ในช่วงความยาวคลื่นกลาง 660 และ 615 นาโนเมตร ในช่วงความยาวคลื่นยาว ทำให้แยกคู่สีที่มีความต่างสีต่ำได้ดี นอกจากนี้ยังพบว่าสามารถหาสภาวะแสงที่ดีที่สุดได้และให้ผลการแยกสีที่ดีกว่าแสงจากแอลอีดีสีขาว โดยที่แหล่งแสง ซีวี- แอล (475, 595 และ 700 นาโนเมตร) สามารถเพิ่มการแยกแยะสีช่วงสีแดง-ม่วงแดง-ม่วง และ ช่วงสีน้ำเงินเขียว-เขียว แหล่งแสง บีวี-แอล (425, 525 และ 660 นาโนเมตร) เพิ่มการแยกสีช่วงสีเหลือง-เหลืองแดง และช่วงสีม่วงน้ำเงิน-น้ำเงิน เนื่องมาจากลักษณะการกระจายพลังงานของแหล่งแสงที่ไม่ต่อเนื่องทำให้สามารถเพิ่มความสามารถในการแยกแยะสีได้และแหล่งแสงทั้งสองมีค่าเฉลี่ยของความต่างสีที่เริ่มมองเห็นต่ำว่าแสงจากแอลอีดีขาวทั่วไปและเมื่อเปรียบเทียบการใช้แสงที่ดีที่สุดทั้ง 3 ชุดกับผู้ที่มีสายตาเลือนรางพบว่าขีดเริ่มเปลี่ยนความต่างสีใกล้เคียงกันมาก

สาขาวิชา	เทคโนโลยีทางภาพ	ลายมือชื่อนิสิต	....
ปีการศึกษา	2562	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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Anukul Radsamrong : Optimized light sources for enhancing color discrimination in people with low vision . Advisor: Assoc. Prof. PICHAYADA KATEMAKE, Ph.D. Co-advisor: Assoc. Prof. Eric Dinet, Ph.D., Vineetha Kalavally, Ph.D.

This research was divided into 2 parts. The aim of the first part was to investigate if illuminance level and correlated color temperature (CCT) had an effect on mobility performance in people with low vision compared to the elderly wearing simulated low vision glasses and the elderly with naked eyes. We also compared their mobility in pouring liquid to a specified level. The second part's aim was to optimize combinations of light emitting diode (LED) channels that increased the discrimination of color in people with low vision. The research procedure of the first part involved 7 lighting conditions, with different illuminance levels and CCTs, and walking course with an obstacle. The participants walked along the walking course at their normal speed and avoid contacting the obstacles. The walking speed and contact score indicated mobility performance. We found that the illuminance levels and the CCTs, in the experiment, did not influence the walking mobility of the low vision and the elderly with low vision glasses. However, the walking speed obtained from a different type of low visions differed under low illuminance level. Moreover, the walking speed of the elderly with low vision glasses was slower than the low vision. The deviation of the specified scale in pouring liquid by the low vision was less than by the elderly with low vision glasses. The elderly with naked eyes had better mobility performance than the low vision. The research procedure of the second part involved color discrimination in colored pairs under 14 LEDs individually, having different spectral power distribution (SPD), by the participants wearing cloudy and blurred simulated low vision glasses (CVG and BVG). The selected channels yielded the lowest color difference (ΔE^*_{ab}) between the pairs determined in psychophysics experiment. The least color difference of the colored pairs, that could be enhanced, indicated the performance of the SPD or LED channels. We combined the optimized SPDs from 3 regions (short, medium and long) of wavelength, obtained from CVG and BVG, and made white light from them for testing color discrimination of 200 colored pairs. Finally, the optimized white lights were tested by participants with simulated low vision glasses and the patients with low vision. The results were indicated that R-RP-P pairs and BG-G pairs were enhanced by CV-L and Y-YR pairs and PB-B pairs were enhanced by BV-L because of the different SPD of lighting. The proposed combinations of SPDs showed better performance and gave the lower average color difference threshold than the commercial white light. Comparison of 3 of proposed lighting by simulated low vision observers and the low vision patients showed that the color difference (ΔE^*_{94}) thresholds were similar.

Field of Study:	Imaging Technology	Student's Signature ....
Academic Year:	2019	Advisor's Signature ....
		Co-advisor's Signature ....
		Co-advisor's Signature ....

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I am grateful to all of those with whom I have had the pleasure to work during this and other related experiments. I would also like to thank members of my Dissertation Committee, Assistant Professor Dr. Chawan Koopipat, Associate Professor Dr. Aran Hansuebsai, Assistant Professor Dr. Chanprapha Phuangsuwan and Dr. Kuntinee Suvarnakich for provided me extensive personal and professional guidance.

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CHAPTER 1
INTRODUCTIONS

1.1 Background and significance of research

In 2019, the World Health Organization (WHO) indicated that the number of people having visual impairment or blindness was about 2.2 billion and the people with visual impairment around 1 billion could have been prevented. The major causes of visual impairment are the cataracts, uncorrected refractive errors, age-related macular degeneration (AMD), glaucoma, and diabetic retinopathy. In addition, the people with the age over 50 years are the most of visual impairment (; World Health Organization, 2019a). In 2050, the estimated population of people with visual impairment could be due to population growth and ageing, there would be 588 million of who have moderate or severe vision impaired (Bourne et al., 2017). The visual impairment was categorized into 2 groups by the International Classification of Diseases 11th revision, as a distance and a near visual impairment. The distance visual impairment was divided into 4 categories: mild with the visual acuity (VA) less than 6/12 (0.5), moderate (VA<6/18 (0.33)), severe (VA<6/60 (0.1)) and blindness (VA<3/60 (0.05)) (World Health Organization, 2019b). The moderate and severe visual impairment can be termed as "low vision" see Figure 1-1. The specifying of people with low vision from WHO are visual acuity less than 6/18 (0.33) or better than 3/60 (0.05) in the better eye with the best correction (World Health Organization, 2020).

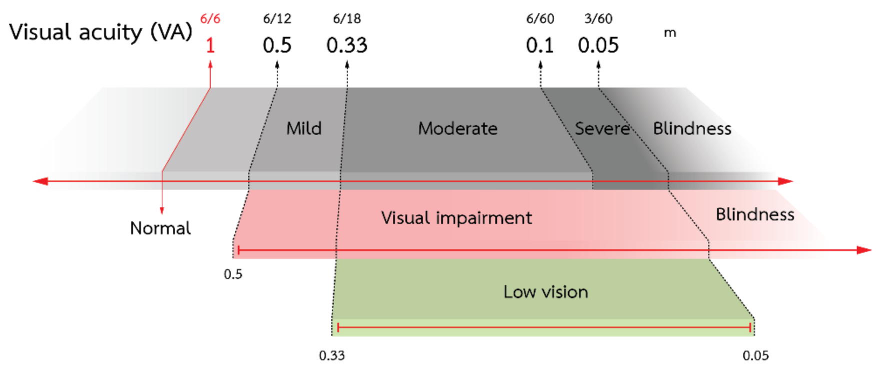

Figure 1-1 Visual acuity of visual impairment and low vision

Many researchers showed the relationship between the system of economic and low vision people, they presented the impact of low vision people on their job. The low vision had less chance to the new development of skill and less freedom to the adjustment of their job (S. M. Mojon-Azzi, Sousa-Poza, & Mojon, 2010). Moreover, the report indicated that the impact of the problem can be an effect in reduced employment opportunities, lower performance of education and increase of the risk of death (Eckert et al., 2015; McCarty, Nanjan, & Taylor, 2001; Ramrattan et al., 2001; Taylor, Katala, Munoz, & Turner, 1991). The estimation of the economic burden of low vision and the eyes disorders was demonstrated that the eyes disorders affected the economic burden around 27.5 billion dollars in 2012 and increased indirect or direct costs for the period of a person's life (Wittenborn et al., 2013). Many countries had an issue with high costs and economic impact of visual impairment (S. Mojon-Azzi, Sousa-Poza, & Mojon, 2008). Furthermore, the quality of life, visual acuity and functional conditions increased in the risk of depression. This also associated with the problem in the daily activity of living and with the quality of life decreasing in low vision people (Kempen, Ballemans, Ranchor, van Rens, & Zijlstra, 2012; Stelmack, 2001).

Low vision people have a loss of performance ability on daily living activities, visual field loss, reduced contrast of sensitivity and low visual acuity but cannot be corrected by contact lenses or glasses (Manavutt, 2017; Markowitz, 2006; Y. Zhao, Hu, Hashash, & Azenkot, 2017). The other researchers have developed smart glasses for people with low vision such as video see through platforms (VST) or optical see through (OST) smart glasses (Massof, Rickman, & Lalle, 1994; Peli, Luo, Bowers, & Rensing, 2009; H. Zhao, Plaisant, & Shneiderman, 2005; Y. Zhao et al., 2017). Nevertheless, smart glasses have many using limitations. For instance, there are unclear how low vision people perceive the element of the environment on the glasses and whether they could make use application of glasses (Thierfelder, Lege, & Ulrich, 1998; Y. Zhao et al., 2017; Y. Zhao, Szpiro, & Azenkot, 2015). Additional devices may not be suitable for people with low vision or may sometimes burden them, therefore, improving the environment may be beneficial to people with low vision.

Light is one of the 3 important components for visibility. The quality of lighting conditions and suitable illumination are significant factors to improve vision particularly for low vision people. The high quality of lighting conditions involves with an optimized light including sufficient illumination level, minimal glare, enhancement of a good contrast of objects and direction of illumination (Brunnström, Sörensen, Alsterstad, & Sjöstrand, 2004). Decreased quality of illumination reduces visibility for people with low vision such as carrying out of daily activities because they need high quality lighting conditions to enhance their environment visibility (Kooijman et al., 1994). The people with low vision may be able to see or discriminate better when the appropriate illuminations are provided (Cullinan, Gould, Silver, & Irvine, 1979). Poor lighting condition cannot enhance perception of people with low vision.

The high contrast color and suitable illuminations are constituents that should be used for improving color discrimination in activities and safety in daily life. Many researchers recommended that there is an effect of different elements on the visual perception of low vision people and the color can be enhanced and discriminated resulted in color and object recognition (Arditi & Cho, 2007; Y.-Z. Wang, 2001; Wurm, Legge, Isenberg, & Luebker, 1993). The color contrast refers the phenomenon that the surrounding color have an effect on the color impression. For instance, the dark handrails placed on the bright wall can be discriminated easily because of the high contrast between the handrails and the wall (Duffy, Huebner, & Wormsley, 2002; Klein & Meyrath, 2010). The chromaticity contrast describes the occurrence on the different of saturated color or hue in the visual or scene perception (Witzel & Gegenfurtner, 2014). Some activities in daily life related to visual perception are found to be difficult for low vision people. Illumination level, luminance and chromaticity contrast seems to be the main factors for enhancing visual performance for the people with low vision. The chromaticity contrast partly depends on its color of illumination, which is directly related to its spectral power distribution (SPD). Therefore, optimizing the SPD could improve the quality of lighting condition by enhancing the contrast of colored objects. People with low vision is a group of visual impairment having some usable vision and our research focuses on modifying illumination to enhance their residual vision.

Note: The cloudy and blurred visions caused by uncorrected refractive errors, cataract that clouding of the crystalline lens of the eye, and vascular occlusions (Biousse, Newman, & Sternberg Jr, 1997; Corn & Erin, 2010; Qureshi, Ahmed, & Ahmed, 2014; World Health Organization, 2017). The people with uncorrected refractive errors and cataract about 78 % of people with low vision (World Health Organization, 2017).

1.2 Objectives

1.2.1 To investigate the influence of illuminance levels and correlated color temperature (CCT) on the mobility of subjects with low vision or wearing simulated low vision glasses.

1.2.2 To examine the deviation of the scale in the activity on participants with low vision and wearing simulated low vision glasses.

1.2.3 To determine the luminance contrast and color difference thresholds of 6-hue pairs under 14 LED channels through the simulated low vision glasses.

1.2.4 To obtain optimized spectral power distributions (SPD) of 3 supplement light sources for 2 types of people with low vision.

1.2.5 To verify the performance of 3 supplement light sources.

1.3 Hypothesis

1.3.1 The people with low vision are able to improve the mobility according to the environment when changing illuminance levels and correlated color temperature.

1.3.2 The ability to discriminate color can be enhanced by using optimized spectral power distribution.

1.4 Research scope

1.5.1 Investigating the mobility and activities of low vision people under changing illuminance levels and correlated color temperature of the light source.

1.5.2 Determining the luminance, chromaticity contrasts and color difference thresholds of colored pairs while participants wearing 2 types of simulated low vision glasses.

1.5.3 Optimizing the combinations of spectral power distributions and verifying 200 physical colored pairs under lighting while participants wearing 2 types of simulated low vision glasses.

1.5.4 Testing the color discrimination under the optimized lighting combinations with different spectral power distributions in the patients with low vision from Metta-Pracharak hospital.

1.5 Research procedure

1.5.1 Investigation of the effects of illuminance and CCT on the mobility of the low vision.

1.5.1.1 Set up experimental room and lighting conditions to investigate the effects of illuminance and CCT on the mobility of people with low vision.

1.5.1.2 The first experiment is to 1) investigate whether the illuminance levels and CCT affect walking speed of 3 groups of participant involving low vision people, healthy elderly with simulated low vision glasses and the elderly without the simulated low vision glasses. 2) investigate whether the response time and the number of mistakes for doing an intricate task by the 3 groups of observers are significantly different.

1.5.2 Optimization of sets of SPD that contrast of a set of colored pairs

1.5.2.1 The second experiment involves obtaining the spectral reflectance of 4 Munsell matt color samples (5R5/8, 5Y5/6, 5G5/8, and 5B5/8) under the Telelumen light replicator with 14 LED channels.

1.5.2.2 The color samples under 14 LED channels are arranged in pairs: red-yellow, red-green, red-blue, yellow-green, yellow-blue, and green blue.

1.5.2.3 The third experiment involves determining the luminance and chromaticity contrast threshold of 6-hue pairs from the second experiment. The luminance of individual color of the main colored pairs is generated from 5% to 95%

with 5% interval. Then, they are paired and 1596 colored pairs (6 main hue x 14 LED channels x 19 luminance levels) are obtained.

1.5.2.4 The colored pairs with high color difference will be examined and excluded from the samples in the first step by using the method of limits.

1.5.2.5 Fifty-six observers determined the luminance contrasts of 6-hue pairs under 14 SPDs to optimize combinations of LED with different SPDs form 768 color sample pairs for 2 distances (70 and 35 cm) and 2 types of low vision: cloudy and blurred vision.

1.5.2.6 The combinations of SPD producing the fastest response of color discrimination (FR-L), optimized set of SPDs giving the contrast threshold of minimum color difference perceived through the simulated cloudy vision and blurred vision (CV-L and BV-L) are determined.

1.5.2.7 The performance of 3 sets of SPD obtained from 1.5.2.6 is compared with white LED (W-L) in terms of color discrimination. One hundred sixty observers with 2 types of simulated low vision glasses discriminate 200 colored pairs.

1.5.2.8 The performance of 3 combinations of SPD is tested by 30 patient participants from Metta-Pracharak hospital using 200 colored pairs.

1.6 Expected beneficial outcomes from the research

1.6.1 Obtain optimized spectral power distributions of 3 supplement light sources for 2 types of people with low vision.

1.6.2 Obtain 3 prototypes of the supplement light source for color discrimination for 2 types of the low vision.

CHAPTER 2
THEORETICAL CONSIDERATION AND LITERATURE REVIEWS

2.1 Theories

According to a physical quantity, light is described in the relative efficiency with the electromagnetic spectrum between 380 and 780 nm. One of the previous theories explained light related to the concept that light was emitted from both eyes. However, one questioning by Aristotle was why we could not be perceived in the dark. Thus, this theory was rejected. Nowadays, many alternatives theories have been advanced described. General theories explained light as an energy transfer from one point to another point (Richtmyer, F. K., Kennard, E. H., & Cooper, J. N., 1955, cited in Illuminating Engineering Society of North America, 2000).

2.1.1 Corpuscular theory

Corpuscular theory of light, contributed by Sir Isaac Newton (1642-1727), was based on assumptions as follows:

1. A source of light emitted a number of small, rigid and massless particles.
2. The particles were sporadically ejected in a straight line.
3. The particles were responded on the retina and produced a visual sensation.

2.1.2 Wave Theory

The wave can transfer energy although the medium does not travel. This theory, supported by Christiaan Huygens (1629-1695), was based on assumptions as follows:

1. A source of light emitted light in the form of waves.
2. These light waves moved with constant speed in a homogeneous medium and the speed was slow down at entering denser medium.

3. The light waves stimulated a response on the retina and produced a visual sensation.

2.1.3 Electromagnetic theory

The theory was advanced by James Clerk Maxwell (1831-1879) and based on 3 points.

1. The form of radiant energy produced luminous emitting.

2. The form of electromagnetic originated from radiant energy.

3. The electromagnetic waves responsed upon the retina in the eyes and stimulated a visual sensation.

2.1.4 Quantum theory

The theory was established by Max Planck (1858-1947) (Planck, 2014). It is a modern form of the corpuscular theory.

1. The photons were the energy, which emitted and absorbed in discontinuous quanta.

2. The dimension of each quantum (Q) is described by the product of v and h, which v is a frequency of the vibration of a photon in Hz, Q is energy in Joules, and h is 6.626×10^{-34} J·s (Planck's constant).

The electromagnetic wave and quantum physic theories give an instruction of radiant energy characteristics in illuminating engineer. The light is considered as a photon or a wave, but it is radiation that is conducted by the process of electronic. It is generated in a body of incandescent, a gas discharge lamp, or a solid-state device by exciting electrons having returned to a more stable stage in their atoms and releasing energy (Illuminating Engineering Society of North America, 2000).

2.2 Visible spectrum

The wave theory authorizes a reasonable graphical presentation of radiant energy in a straight positioning according to its frequency or wavelength. This regulation is called the spectrum. It is advantageous in indicating the relationship between wavelength regions and various radiant energy (Illuminating Engineering Society of North America, 2000). The electromagnetic spectrum covers a wide range of wavelengths (λ), values as 1 fm (1 fm = 10-15 m) for radiation of cosmic around 10 km for waves of radio. Thus, the range of magnitude approximated 19 orders as shown in Figure 2-1. The Angstrom unit (Å), the nanometer unit (nm), and the micrometer unit (μm) which represent 10^{-10}, 10^{-9} and 10^{-6} are used for units of invisible spectrum. However, the only small part of the electromagnetic wave spectrum is a visible range of humans.

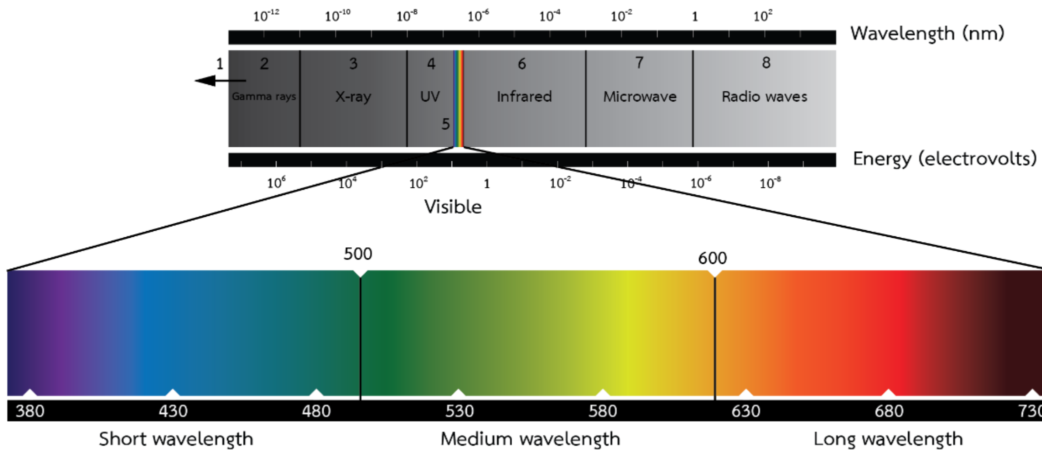

Figure 2-1 Electromagnetic spectrum: 1) cosmic radiation, 2) gamma radiation, 3) X-ray radiation, 4) ultraviolet radiation (UV), 5) near-ultraviolet radiation, 6) infrared radiation (IR), 7) microwave (VHF waves), 8) radio waves

The wavelength is a very small part between 380 to 780 nm, perceived by humans as visible light. The visible light was divided into 3 regions. The short wavelength at the left end of the range between 380 and 500 nm are perceived as violet or blue. The medium wavelength around 500 to 600 nm, the color impression changes between green and yellow. Red is perceived at the long wavelength more than 600 nm (Klein & Meyrath, 2010). The importance of the electromagnetic spectrum for illuminating engineering are 3 regions as UV, visible light, and IR. However, the eyes should be protected from UV or IR radiation; eventhough the radiation of wavelength near-visible light cannot be exactly perceived by humans (Illuminating Engineering Society of North America, 2000).

2.3 Light sources

The light source can be divided into 2 groups; temperature and luminescence radiator, based on the mechanism of light generation (Table 2-1). In the future, lasers and semiconductor diodes are expected to substitute the light source that used to date. A general characterization of an optical radiation source distribution output is correlated with the temperature of blackbody or spectral power distribution. At lower temperature, the alloy emits energy of heat in the form of IR, with increasing temperature, the dark red glows. The color changes to yellow and orange, lastly to bluish-white, when the temperature increases (Klein & Meyrath, 2010).

Table 2-1 Kinds of optical light sources (Illuminating Engineering Society of North America, 2000).

Temperature radiation		Luminescence radiator
Natural	Artificial	Artificial
Sunlight Scattered light of the earth atmosphere, Start, Galaxies	Blackbody radiator Incandescent lamp Arc lamp	Gas discharge tube, Fluorescent lamp, Light emitting diode (LED) Source of coherent light (laser)

2.3.1 Blackbody Radiation

The spectral properties of a blackbody and intensity depends on the temperature. The radiant power emitted from an aperture in an enclosure may be close to a blackbody radiator. The incandescent lamp is often explained by comparison with that from a blackbody radiator. In theory, most of the energy emitted by the wall of the blackbody is a return after being absorbed by the wall. Therefore, a blackbody radiates power and give it wavelength as any other light source having the same temperature (Illuminating Engineering Society of North America, 2000). The Planck law of radiation provided the spectral radiance $B_v(v,T)$ frequency density v radiation per unit frequency at the equilibrium of thermal at temperature as shown in Equation (1) (Klein & Meyrath, 2010; Rybicki & Lightman, 2008).

$$B_v(v,T) = (2hv^3/c^2)(1/e^{hv/kT}-1) \tag{1}$$

where h = Planck's constant,

c = speed of light in a vacuum,

k = Boltzmann constant,

v = frequency,

T = temperature (K, Kelvin)

2.3.2 Color temperature

The color temperature of a selective radiator is a temperature which a blackbody is given to produce the same color as that of the selective radiator. Color temperature can be calculated from the chromaticity coordinates. The difference between chromaticity's of blackbody and incandescent lamp is not important for practical because the intersection in surfaces of the helix formed in tungsten are similar to a blackbody radiator. Consequently, the spectral power distribution from filaments in an incandescent lamp and a blackbody have the same temperature (Illuminating Engineering Society of North America, 2000). The different spectrum colors are emitted by a blackbody radiator with temperature changing, thus, it is useful to describe them in terms of color temperature. The color temperature of a light source harmonizes to the temperature of the blackbody radiator which produces the light with similar color as an actual light source. A temperature radiator can be determined as a color temperature. The different optical radiator such as a luminescence radiator, are characterized by a so-called correlated color temperature

(CCT). The sun is the most famous temperature radiator, the temperature inside the sun is greater than 10^7 K. Figure 2-2 presents the spectral power distribution in wavelength provides by Planck's. At a temperature of 500 K, the spectral power is in the IR region. Increasing higher temperatures more than 10^4 K, this peak shifts beyond the range of visible in the UV region. However, the temperature between 7,600 to 3,700 K, the spectrum lies as the respective edges of the visible range (Klein & Meyrath, 2010). The color temperature describes the color appearance of the light. For example, Table 2-2 shows the color temperature of interior lighting (Staff, 2004).

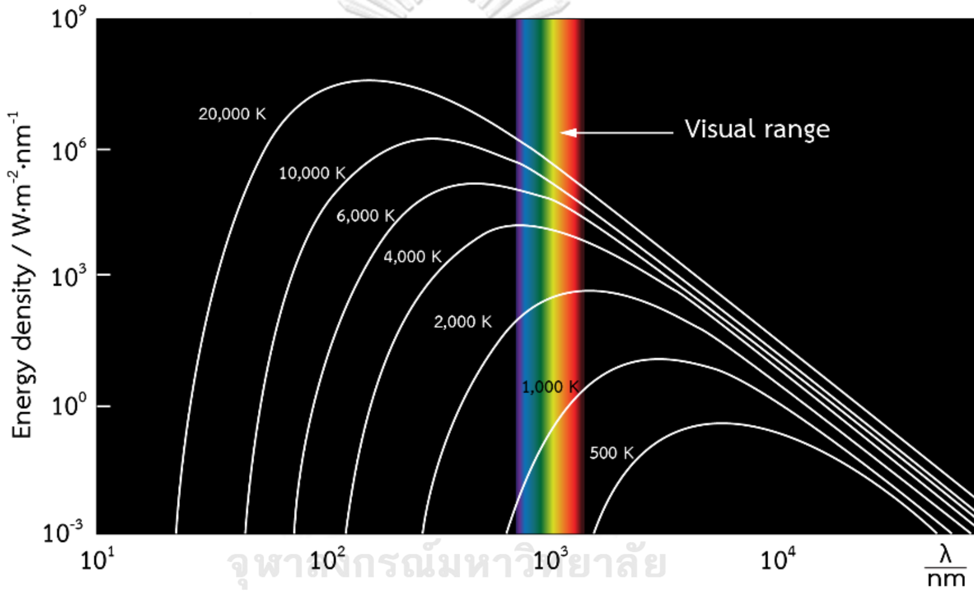

Figure 2-2 Spectral power distribution of blackbody radiator of different temperatures (Klein & Meyrath, 2010).

Table 2-2 Color temperature of interior lighting and appearance (Staff, 2004)

	Color temperature	Appearance	Association
Warm white	Up to 3300 K	Reddish	Warm
Intermediate white	3300 – 5300 K	White	Neutral
Cool white	From 5300 K	Bluish	Cool

2.3.3 Illuminants

The wide range of light sources complicates the visual assessment of color objects. They are exposed to change when put under natural or artificial illuminations such as daylight or fluorescence light. The change of illumination can change the impression of visual color.

The International Commision on Illumination (CIE) defined the standard illuminants and provided the relative spectral power distribution in tabular values (CIE illuminant). The light source the corresponds to a technically comprehended CIE illuminant is called CIE source. Using the same CIE source for visual assesment is reliable (Klein & Meyrath, 2010).

2.3.4 Light-Emitting Diodes

Light-emitting diodes (LEDs) create light by electroluminescence method which low-voltage direct current is applied to a suitably doped crystal containing junction. Aluminum indium gallium phosphide (AlInGaP) and indium gallium nitride (InGaN) were most commonly used for light-emitting diode technologies.

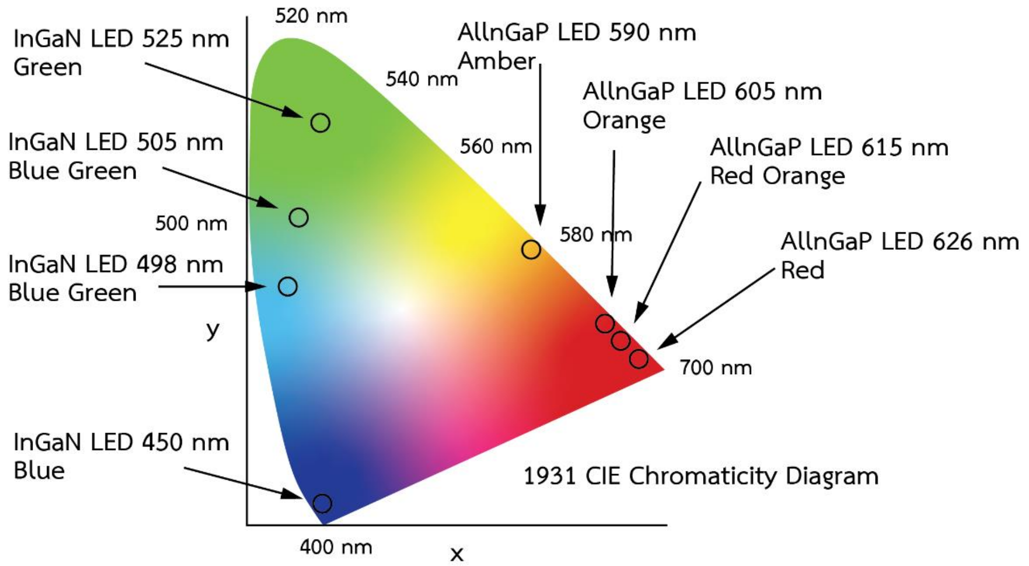

Figure 2-3 Dominant wavelength (nm) of LEDs devices plotted on the 1931 chromaticity diagram (Illuminating Engineering Society of North America, 2000).

The dominant wavelength emitted were specified in terms of the color of an LED device. Dominant wavelengths for the colors created by AlInGaP and InGaN LED devices were plotted on the 1931 CIE chromaticity diagram, shown in Figure 2-3. AlInGaP LEDs produce red (626 to 630 nm), red orange (615 to 621 nm), orange (605 nm), and amber (590 to 592 nm). InGaN LEDs produce green (525 nm), blue green (498 to 505 nm), and blue (470 nm). Moreover, the LED may be dimmed to 10% of maximum of current and still have intensity of luminous across an LED matrix (Illuminating Engineering Society of North America, 2000).

2.3.5 Units of measurement

A branch of radiometry, the photometry is the measurement of radiation in terms of the visual response of a human. The very narrow band of the electromagnetic spectrum approximately from 380 to 780 nm was responded by the human visual system, depending on the individual observer. Vision can be grouped according to the rod and cone of the adaptive state; photopic, mesopic and scotopic vision. The luminance approximately 0.01 cd/m^2 provides scotopic vision, the light is insufficient to perform the cone photoreceptor. However, it is adequate to stimulate the rod photoreceptor system.

The CIE has provided a standard observer response curve as a photopic luminous efficiency function, suggested by $V(\lambda)$ and a scotopic luminous efficiency function, $V'(\lambda)$ (Figure 2-4). The standard observer response curve with a peak at around 555 nm, is used for a weighting function standard, which applied to a spectral power distribution of the light being measured. Thus, It is an estimation of the perceived brightness of the light (Illuminating Engineering Society of North America, 2000).

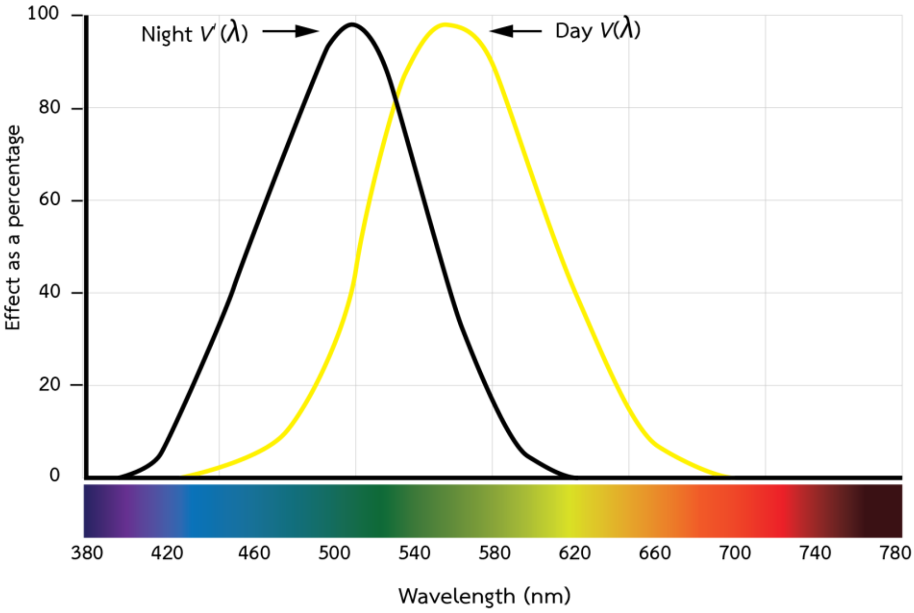

Figure 2-4 Relative spectral perception of brightness (Staff, 2004)

Lumen, lm, is unit of luminous flux. The luminous flux explains the light quantity emitted by a light source (Figure 2-5). The beam of monochromatic of luminous flux has frequency around 540 × 10^{12} hertz which radiant flux is 1/683 watt as 1 lumen. Moreover, the frequency 540 × 1012 hertz closely similar to a wavelength of approximately 555 nm for which the $V(\lambda)$. The luminous efficiency is a ratio of luminous flux to electrical power consumed (lm/W).

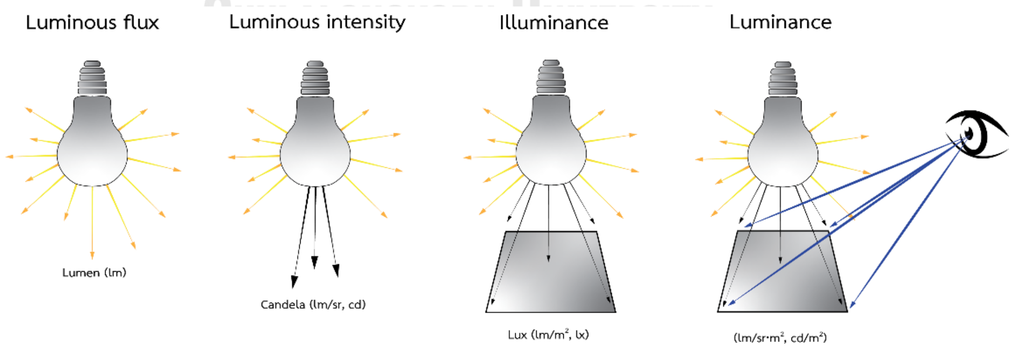

Figure 2-5 Parameters for lighting; luminous flux, luminous intensity, illuminance, luminance

Candela, cd is unit of luminous intensity. The luminous intensity in a given direction, of a point source emitting 1 lumen per steradian is 1 candela or refers to the light quantity which is radiated in a particular direction.

Lux, lx is unit of illuminance (luminous flux per unit area incident on a surface). Illuminance explains the quantity of luminous flux falling on a surface per unit area or luminous flux of 1 uniformly of lumen distributed over a surface of area 1 square meter is 1 lux.

Candela per square meter, cd/m^2 is unit of luminance. Luminance is a basic lighting parameter was perceived by the eye. The brightness of the light source's impression on a surface depends on a degree of reflection or luminous intensity of 1 uniformly of candela distributed over a surface area of 1 square meter is 1 candela per square meter (Hunt & Pointer, 2011; Staff, 2004).

2.4 Visual system structure

The eye and brain are parts of the image processing system, They are working together to explain the visual environment. Inside the eye, photons of light are absorbed by the photoreceptors which transformed to electrical signals. These signals were transmitted by the optic nerve to the visual cortex for processing (Illuminating Engineering Society of North America, 2000).

2.4.1 The eye

The eye is one of the most complicated particularize organs in the body. It is accountable for up to 80% of the consciousness information. The eye can differentiate image, define the distance and depth of an image, and the shape of the target as well as tone and color (Sardegna, 2002). The eye structures are divided into 3 parts: 1) the ocularmotor components as eye muscles; 2) the optical components including the cornea, crystalline lens, pupil, and intraocular humors and 3) the neurological components involved retina and optic nerve (Illuminating Engineering Society of North America, 2000).

2.4.1.1 Ocularmotor components

The ocularmotor components of the eye including 3 pairs of muscles: 1) superior rectus muscle and superior oblique muscle; 2) medial rectus muscle and lateral rectus muscle and 3) inferior rectus muscle and interior oblique muscle as shown in Figure 2-6. The position of muscles are lines of sight of the two eyes which both pointed towards the similar object of gaze. The line of the eye passes through the retina which for discriminating the detail as the fovea. If the detail of the image does not fall on the fovea, the detail of the image will decrease (Illuminating Engineering Society of North America, 2000).

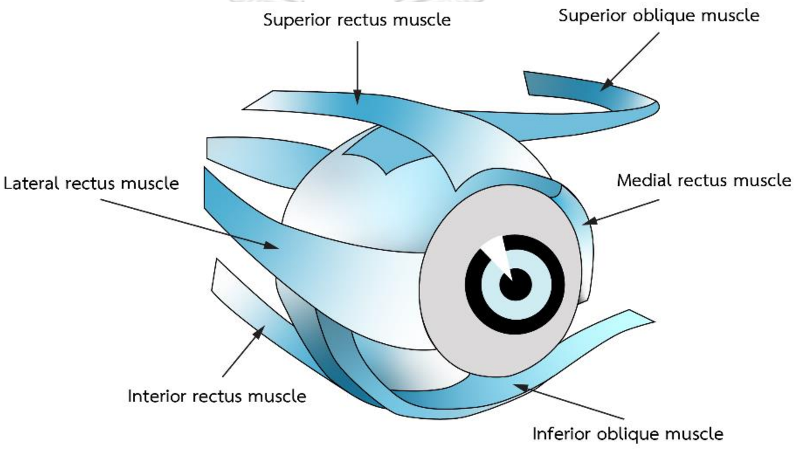

Figure 2-6 The extraocular muscles and the eye used to move it (Illuminating Engineering Society of North America, 2000).

2.4.1.2 Optical components

The cornea bends and focuses on entering light. Neighboring the cornea is called the sclera. The conjunctiva is a thin layer of membrane and covers the sclera. The cornea and sclera operate together to shield the eye. Behind the cornea is the clear liquid which conducts nutrients to the cornea and lens, and also takes away waste. The iris is a thin circle of membrane hanged behind the chamber of anterior and in a straightway line to the cornea. The iris provides the color of the eye. The hues depend on the pigment on the iris. The middle of the iris is called the pupil, a tiny hole through which light proceeds into the eye. The pupil can change the size by the different amount of light. The iris and pupil are located in anterior of the posterior chamber. The crystalline lens, located behind the posterior chamber, focuses the light that accesses the eye through the pupil. The lens is fixed by thousands of fibers called zonules. The fibers are fixed to the ciliary muscle and work with the muscle to allow the lens for shape change. The change of the lens' shape is to precisely focused the light of target at varying distances. The large area behind the lens is contained with a clear gel, called the vitreous which provides the eye form and substance (Sardegna, 2002).

The function of the optical components is to form the target of an image on the retina. The light has to be transmitted through the eye without scattering and absorption, and the target of the image has to be focused on the retina. The transmittance of the crystalline lens permutes with age and wavelength. In adults and young eyes, the most of incident radiation shorter than 300 nm is absorbed by the cornea. However, the crystalline lens of human slowly develops a pigmentation of yellow. These results attenuate the transmission of light to the retina, particularly in the short-wavelength region of the visible light. The range of radiation between 380 to 950 nm with limited attenuation is received by the retina (Illuminating Engineering Society of North America, 2000).

2.4.1.3 Neurological and supportive components

Approximately 80% posterior of the eye is enclosed by 3 layers, it moistens and protect the eye, transform light into electrical signals. The sclera protects the contents of the eye and defines its shape. The choroid, a very high vascular contains the blood supply to the eye. The retina is an innermost layer, it converts light radiation into electrical signals and sent to the brain (Illuminating Engineering Society of North America, 2000).

2.4.1.4 Photoreceptors

The light-sensitive receptors are rods and cones, there were contained on the retina. Rods and cones have different morphology and spectral sensitivity of photopigments which they contain. Rods are not still in the fovea, but the number of rods is increased to a maximum at around 20° of eccentricity and then decrease towards the edges of the retina. All the rod cells were contained the similar photopigment as rhodopsin which has a peak spectral sensitivity around 507 nm. Cones were divided into 3 classes which characterized by the photopigment that it contains: erythrolabe (L-type, long-type), chlorolabe (M-type, medium-type), or cyanolabe (S-type, short-type). Cones are concentrated on the fovea while there are cones in all of the retina. Three types of cone acting at the same time with a peak spectral sensitivity at around 555 nm. In addition, the photopigment differences in the cones make color discrimination possible (Illuminating Engineering Society of North America, 2000).

2.4.1.5 Receptive fields

Photoreceptors are not transferring their information directly to the brain but send to other cells in the retina which through ganglion cells with terminal axons become the optic nerve. "Pooled" is a light received by a number of receptors, which provide a signal to stimulate a ganglion cell. The receptive field is the area of the retina that stimulates a ganglion cell, and it begins the image processing which authorizes the visual system to explain the visual environment (Illuminating Engineering Society of North America, 2000).

2.4.1.6 Neural pathways

The electrical signals from the receptive fields on the retina were transmitted through the optic nerve. About 20% of the optic nerve fibers reach the superior colliculus and around 80% to the lateral geniculate nucleus and on to the visual cortex. The signal information by the lateral geniculate nucleus was taken to the visual cortex. The visual cortex was assigned to analyze and interpret from the visual field (Illuminating Engineering Society of North America, 2000).

2.4.2 Visual acuity

The visual acuity that means to describe the performance to resolve fine the details. The resolution acuity is the ability to perceive that there are 2 stimuli rather than one on the visual field. The measurement was used in terms of the smallest angular separation between 2 stimuli which resolution acuity is of the order of 1 min of arc. The recognition acuity is performance to correctly identify a visual target which in differentiating between letter a G and C, show in Figure 2-7. The letters were used to perform the visual and recognition acuity testing in clinical. Generally, recognition acuity is of the order of minutes of arc. Which many other threshold tasks, visual acuity deviate with retinal illuminance, the magnitude of background field, duration of exposure, and target motion. Visual acuity wherewith increases which the duration of exposure increases, up to around 500 ms, after as no further improvement occurs. The movement of the target can restrict the exposure duration and the ability to get the retinal image on the fovea. Increasing the target speed tends to visual acuity decreases. Scotopic was the only condition under as the fovea fails to have the best visual acuity. In this case, the fovea is inactive (Illuminating Engineering Society of North America, 2000).

The visual acuity is an assessment of detail a person sees in relevance to the quality of detail someone with normal vision sees. It is started as an equation with 20 as the first number in feet or 6 in meters, a slash mark and the second number of either 15, 20, 25, 30, 40, 50, 70, 100 or 200, such as 20/20 (6/6). The first number shows the distance at which the assessment is taken. The second number presents the distance at which a generally sighted person can notice specific detail. Normal of perfect vision is to note a 20/20 or 6/6. Another person with 20/20 (6/6) vision sees the detail at 20 feet (6 meters) that a generally sighted person sees at 20 feet. Someone with 20/160 vision sees detail at 20 feet that people with normal vision could see at 160 feet (Sardegna, 2002). The standard projection charts such as the Snellen chart, that are used by most eye care specialists are ineffectual for evaluating the distance visual acuity of visually impaired people because these charts have lower contrast may not be effortlessly clear by many low vision people. These charts are presented at the standard distance of 6 meters or 20 feet, it is too far for many low vision people to maintain fixation. Most general eye care do not ask their low vision people to move near or view at a low vision chart if they cannot notice the largest letters on the eye chart. In this case, counting fingers is often renowned as visual acuity assessment for people with visual acuity less than 20/400

(6/120), which is generally the greatest acuity number on standard visual acuity charts (Corn & Erin, 2010).

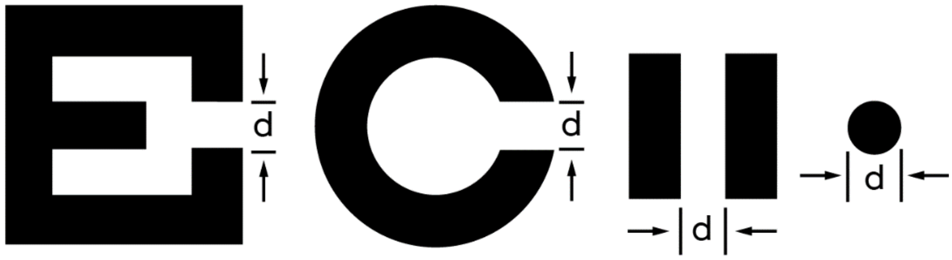

Figure 2-7 General used test objects for determining resolution limits and visual acuity. Gratings, letters, and Landolt rings have all been used as acuity test objects. The critical size is demonstrated by dimension d (Illuminating Engineering Society of North America, 2000).

2.4.3 Contrast threshold

The visual system provides virtually no useful information when the retina is uniformly illuminated. However, highly specialized to compile information related luminous edges and gradients in the visual field. The performance to detect a target with a background can be quantified by its threshold contrast. In addition, threshold contrast is the luminance contrast of the target that can be ascertained on around 50% of the occasions it is shown. Various factors affect threshold contrast. The target size and retinal illuminance are more important (Illuminating Engineering Society of North America, 2000).

2.4.4 Color Discrimination

The visual system varies in its performance to discriminate wavelength. There are areas of maximum wavelength discrimination in the middle of the visible spectrum, but discrimination falls off at the spectral extremes. Moreover, the performance to discriminate hue from white is a wavelength dependent. Monochromatic colors from the edges of the visible spectrum are simply discriminated from white because they are more saturated than colors in the middle of the spectrum. The non-spectral colors discrimination ability is also related to their chromaticities. Normally, color discrimination is best on the fovea and decreases in the direction of the periphery. Nevertheless, color discrimination for very small fields shown to the fovea is poor because there are few s-cones in the center of the fovea. This effect is known as small filed tritanopia. The ability to discriminate colors were estimated in terms of distances in chromaticity space. A series of ellipses on the chromaticity coordinates of different colors were produced by MacAdam. Each ellipse explains the boundary at which a provide the percentage of people are able to define the two different colors, one with chromaticity coordinates on the ellipse and one with chromaticity coordinate at the center of the ellipse, are just perceptibly different.

The retinal illuminances are important because they determine the managed state of the visual system. If the retinal illuminances are in the range of scotopic, no colors can be seen and not possible to discrimination. For the range of mesopic, colors can be seen but colors discrimination is poor, especially for low reflectance colors. The retinal illuminance increases when the color discrimination threshold reduced. The method continues until a retinal illuminance of approximately 30 trolands is obtained, after which there is little change in the color discrimination performance. Thus, the light spectrum is important because it changes the stimulus to the visual system (Illuminating Engineering Society of North America, 2000).

2.4.5 Improving visual performance

The main purpose of several lighting installations is to enable people to operate their work quickly, simply, safely, and comfortably. To achieve this point, it is necessary to give lighting that guarantees people are operating on the plateau of visual ability and not on or close to the escarpment (Illuminating Engineering Society of North America, 2000).

2.4.5.1 Task changing

- The increasing size of detail in the task. For example, by magnification.
- The increasing the luminance contrast of the detail on the task such as by tonner adding to the printer.
- For off-axis tasks in a cluttered field, making object to be detected clearly different from the surrounding objects which many different dimensions as possible. For example, by using size, contrast, different color, and shape.
- Make sure the object shows a shape image in the retina such as by going to an optometrist (Illuminating Engineering Society of North America, 2000).

2.4.5.2 Lighting changing

- Increasing adaptation luminance. For example, set up illuminance increasing.
- Ensure good color discrimination is needed, using a lamp with a high color rendering index (CRI) more than 80.
- Using the lighting without glare and veiling reflections. For example, by eliminating any direct views of the light source or using matte materials (Illuminating Engineering Society of North America, 2000).

2.4.6 Visual comfort

The installations of lighting are rarely designed for visual ability alone. Visual comfort is almost always a consideration. The feature of lighting which causes visual discomfort including relevant to visual ability (Illuminating Engineering Society of North America, 2000).

2.4.6.1 Symptoms and causes of visual discomfort

Visual discomfort can provide a spacious list of symptoms. Generally, the more common are sore, red, itchy, and watering eyes; migraine attacks and headaches; gastrointestinal problems; and pains associated with poor posture and aches. Visual discomforts are not the only source of these symptoms. All can have other causes. This abstruseness makes it important to consider other possible causes before mentioning an occurrence of any of these symptoms to the conditions of lighting. The visual system is designed to extract information from the environment. This is importantly a "signal-to-noise" problem with the signal being the information required and the noise being all the other information in the environment. Features of the visual environment that recede the ratio of signal-to-noise, either by decreasing the signal or increasing the noise, can cause visual discomfort. There are many different predicaments where the ratio of signal-to-noise problem can emerge. Any visual task that has the qualifications that place it close to threshold has a low ratio of signal-to-noise and in consequence, has a high level of visual difficulty. To bring the task closer to increase its size of visual is one reaction to a high level of visual difficulty. Which the task is brought closer, the mechanism of the eye modulates to keep the retinal image in focus, an improvement that might make it produce close to its limits. This adjustment can conduct directly to tire of the eye muscles, and indirectly to exhaust of other muscles because of the observer adopting an uncommon posture. These results can provide symptoms of visual discomfort. However, when it is not possible to adjust closer to the task, signals close to the threshold can produce symptoms of visual discomfort. This example of this emerges when driving on the fog or in a snowstorm. These situations, the visual system is finding for information that is underhand but that may present suddenly and require a fast response. The stress while driving in these situations is ordinary experience. Several symptoms of visual discomfort may appear when there is a high noise level of visual. For example, looking at a printed page that has a large area of high contrast has been associated with the happening of headaches, reading difficulties, and migraines. Another form of this cause of visual discomfort occurs when there are two alternative views of the world such as when a lighting installation is reflected from a screen monitor of a computer. The screen shows both the generated image and a reflected image of the room (Illuminating Engineering Society of North America, 2000).

2.4.6.2 Lighting conditions that can cause discomfort

Many different characteristics of lighting that can cause visual discomfort. Lighting insufficiency for the simple performance of a task in an obvious problem that can be determined by one of the recommended in improving visual performance. Thus, attention will be provided to flicker, glare, shadows, and veiling reflections. It could be noted that the impact of these discomfort conditions depends on the environment. All can be used to confident effect in some contexts.

Flicker. A lighting installation that gives visible flicker will be universally disliked, except it is being used for party entertainment. The different dimension of individual, and the fact that electrical signals associated with flicker can be detected on the retina even which there is no visible flicker, this cases that a clear safety edge is necessary if flicker is not to be perceived by anyone. The major variables that examined flicker perception are the percentage modulation and frequency of the oscillation in light output, the ratio of the visual field over when the flicker appears, and the adaptation luminance. Temporal modulation transfer functions were used to predict whether a provided fluctuation of light output will be visible. To eliminate the flicker perception, it is essential to decrease the percentage modulation of the oscillation or increasing frequency of oscillation above the critical flicker frequency, the adaptation luminance, or the area of the visual field over when the oscillation occurs. However, the last two possibilities appear occasionally with general lighting. A common approach is to use control gear of high frequency for discharge lamps. While occurring of flicker over a large area of the visual field is practically disturbing, occurring of flicker over a very small part of the visual field is less disturbing and is a very effective way to draw intention to a specific location. This situation is widely used with emergency vehicles.

Glare. Glare appears in two conditions. First, it is possible to have too much light which produces a response of photophobic, in that the observer squints, looks away or blinks. The full sunlight is too much light. The only solution to this issue is to decrease the retinal illuminance by overcasting a bright part of the visual field such as wearing a baseball cap or sunglasses. Second, glare appears when the luminance range in an environment of visual is too large. The glare of this kind can have two effects: decreasing a visual ability until it is close to or in the escarpment of visual performance, and discomfort of feeling. A glare that decreases the visual ability is called disability glare and is due to light scattered in the eye, decreasing the luminance contrast on the retinal image. The effect of light scattered on the luminance contrast of the target can be mocked by increasing a uniform "veil" of luminance to the target.

Shadows. Shadows appear when light from a direction is intercepted by a turbid object. Large objects reduce the illuminance over a large area. This is normally the issue in industrial lighting where large pieces of machinery cast shadows in adjacent areas. The effect of shadows can outdo either by increasing the ratio of interreflected light by providing local lighting in the shadowed area or using high-reflectance surfaces. However, the object is small and close to the area of attention, the shadow can be cast over a meaningful area, which in turn can cause confusion of perceptual, especially if the shadow moves. For example, the shadow of a hand-cast on a blueprint. This issue can be decreased by providing local lighting that can be adjusted in position or increasing the interreflected light in the space. Even if shadows can cause discomfort of visual, it could be noted that in the form of shading, they are a precious element in indicative the form of three-dimensional objects.

Veiling Reflections. Veiling reflections are luminous reflections from semi-matte or specular surfaces that physically change the contrast of the visual task and thus change the stimulus shown to the system of visual. Disability glare and veiling reflections are identical in that two change the luminance contrast on the retinal image but vary in that veiling reflections change the luminance contrast of the task while disability glare changes the luminance contrast on the retinal image. The two determinants that impose the magnitude and nature of veiling reflections are the secularity of the material being viewed and the geometry. However, the object is a perfect diffuse reflector, no veiling reflections can appear if it has a specular reflection constitutive, veiling reflections can happen. The positions which veiling reflections appear are those which the incident ray corresponding to the reflected ray that achieves the eye of an observer from the target comes from high light sources. This means that the magnitude and strength of such reflections can vary dramatically within an installation of single lighting. Veiling reflections can cause discomfort of visual because they can decrease the luminance contrast and thence the difficulty of the task. In some cases, luminance contrast can rise as veiling reflections increase. This case is a combination of diffuse and specular reflecting materials are used for the background and target. Thus, a high luminance can cause the polarity of luminance contrast to recede (Illuminating Engineering Society of North America, 2000).

2.4.6.3 Comfort, performance and expectations

The lighting conditions that conciliate visual ability are close always considered uncomfortable, lighting conditions that permit a high level of visual ability can be speculated uncomfortable. There is another feature of visual comfort that differentiate it from the visual performance. Visual performance is defined merely the capabilities of the visual system. Visual comfort is connected to the expectations of people. Any installation of lighting that does not meet expectations may be examined uncomfortable even though visual performance is sufficient, and expectations can alter over time. Also recommended another potential impact of visual comfort. Conditions of lighting that are respected uncomfortable may influence task ability by changing motivation although they have no effect on the stimuli shown to the visual system and visual ability (Illuminating Engineering Society of North America, 2000).

2.4.6.4 Approaches to improving visual comfort

To guarantee visual comfort it is essential to ensure that the lighting allows a good level of visual ability and does not cause a disturbance. This can be done by the following:

1. Analyses the visual tasks to be operated and define the characteristics of the lighting required to allow a high level of visual ability of the tasks.

2. Remove flicker from the light sources by using high-frequency control gear for discharge lamps. If this is not possible, eliminate the percentage modulation of the perceived flicker by combined lighting from sources operating on phase differences of the electricity supply.

3. Eliminate disability glare by the selection, positioning, and point of luminaires to cut the luminance of the luminaires close to the common lines of sight.

4. Remove discomfort glare by the selection and design of luminaires. Selecting a high-reflectance surface in the space will help eliminate discomfort glare by improving the background luminance against which the luminaires are seen.

5. Examine the density and extent of any shadows that are probably to occur. When shadows are unpleasant and large-area shadows are likely to occur, use the surfaces of high-reflectance in the space to expand the amount of interreflected light and use more lower-wattage lamps to contribute the desired illuminance. If shadows cannot be avoided because of the extent of obstacle in the space, give supplementary lighting in the shadowed areas. If dense, small-area shadows appear in the area of work, use adjustable of lighting to moderate their impact.

6. Reduce veiling reflections by removing the specular reflectance of the surface, or by changing the viewer between geometry, the surface being viewed, and the observer, or by expanding the amount of interreflected light in the space (Illuminating Engineering Society of North America, 2000).

2.4.7 Perception of lighting

The perception of the visual world is not merely determined by the physical stimuli shown to the visual system on the retinal image. A large number of visual illusions is enough to present this. But the stimuli to the visual system give information as the visual system decipher on the simple of previous experience and simultaneous information. There are four primary attributes of an object that are stable over a wide range of lighting conditions. They are:

Lightness. Lightness is the perceptual attribute related to the physical quantity of reflectance. In most situations of lighting, it is possible to discriminate between the illuminance on a surface and its reflectance, that is, to distinguish the difference between a high-reflectance surface receiving a low illuminance and a low-reflectance surface receiving a high illuminance, even when two surfaces have the same luminance. It is the ability to perceptually segregate the luminance of the retinal image into its parts of reflectance and illuminance that guarantee that a piece of coal placed on a window is always seen as black although a white paper far from a window is always seen as white, even when the luminance of black coal is higher than the luminance of white paper.

Color. The stimulus a surface demonstrates to the visual system depends on the content of spectral illuminating the surface and spectral reflectance of the surface. Nevertheless, changing large in the content of spectral illuminant can be made without causing any changes in a realized color. This is obvious from the ease with which two similar colors can be discriminated when seen side by side and from the difficulty in discrimination when they are seen successively.

Size. Which object gets farther away; the size of its retinal image gets smaller but the object itself is not seen as getting smaller. This case indicated that using clues such as texture and masking, it is normally possible to consider the distance and then to compensate unconsciously for distance increasing.

Shape the object changes its orientation in space, its retinal image changes. However, in conditions of lighting, it is possible to separate the orientation in space so a plate of circular will always appear circular even when its oblique image in elliptical (Illuminating Engineering Society of North America, 2000).

2.4.7.1 Guidelines for acceptable lighting

Many studies investigated the acceptability of specific aspects of lighting. This section discusses what is known about the preference for three lighting elements, all of which are under the control by designer of lighting (Illuminating Engineering Society of North America, 2000).

2.4.7.1.1 Illuminance

The congeniality of different illuminances in offices and other working areas has been investigated to try to define the effect of illuminance on the preference of observer. Figure 2-8 presents the percentage of observers considering the lighting of space with systematically varied space surface luminance up to 150 cd/m^2 to be too dark, good, or too bright. Individualistic of the ceiling and wall luminances, the maximum ratio of "good" assessments appeared when the luminance of the working was 130 cd/m^2. These results were extended and verified over an extensive range of illuminance. Another experiment, the task of finding a random array of numbers for a specific number was carried out under illuminances ranging from 50 to 10,000 lx, and with differing contrast as black numbers on grey and white paper. individually subject provided an opinion of the lighting, showing whether it was "too dark", "good", or "too bright". Consideration of optimum illuminance increased with reducing task contrast and with age. The subjects preferred 1000 lx when finding the high-contrast number lists, but selected 1800 lx when searching the lower-contrast materials. The average, for two contrast levels, the younger subjects with age less than 50 years old, showing that 2000 lx was better, while the older people required 5000 lx to reach approximate satisfaction. The highest illuminances between 5000 to 10000 lx, rated acceptability reduced even though the ability of the task continued to increase. This common trend of increased preference for higher illuminances for more visually tasks of difficult, followed by a reduces in satisfaction at even higher illuminances, has been duplicated by subsequent investigators using a variety of tasks (Illuminating Engineering Society of North America, 2000).

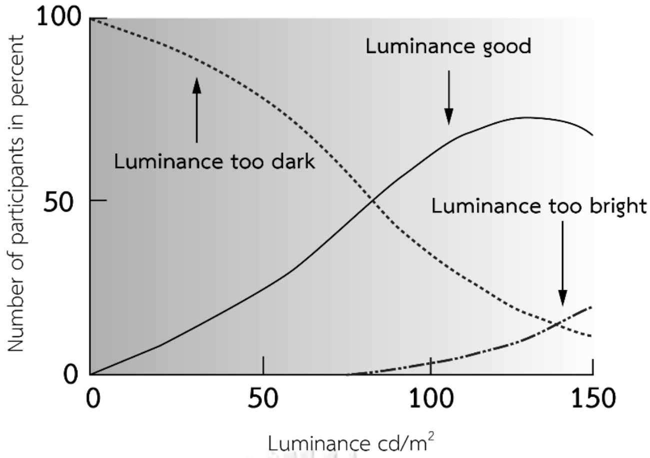

Figure 2-8 The observer's percentages rating the luminance of their desks as too dark, good, or too bright (Illuminating Engineering Society of North America, 2000).

2.4.7.1.2 Spatial Distribution

The studies that changing the spatial distribution of light affects vision have been investigated since the mid-nineteenth century. The effect of spatial distributions differences of light on visual ability and preference have been examined extensively. The spatial distribution of illuminance arcoss the working area is also significant. Studies of acceptable illuminance uniformity across a desk of office have presented that acceptability starts to decline as the ratio of the minimum-to maximum illuminance over the area of working falls below around 0.7. It could be noted that this nonuniformity consisted of a steady change in illuminance crossways the desk such as would be created by a large spacing in a regular array of luminaires. When the variation in illuminance had associated with a sharp edge, such as would be made by the shadow of a shelf, acceptability would start to decline at a ratio of higher minimum-to-maximum illuminance. Another feature of localized distributions of illuminance is the preferred proportion of task to desktop luminances under levels differences of ambient illuminance. Subjects were asked to sit at each of six desks with the unspecified reflectance difference of each desktop under four illuminances levels as 50, 100, 500, and 1000 lx, and copy figures from one white sheet of paper onto another. They then questioned to specify at which desk they preferred to perform this task under the illuminance differences. When increasing the illuminance, the subjects preferred lower-reflectance desktops. For higher illuminance, approximately 500 lx the preferred proportion between the paper and the desk was 3:1, but for lower illuminances 2:1 was preferred. As a guide for design decides, the ratio limits of the luminance have been suggested for various applications. For example, offices, institutions, facility of education, area of industrial, and residences. For supplementary guidance, proposed limits on reflectances of large surfaces are provided for the same applications. Using these reflectance limits, along with a selection of color appropriate, could help to control luminance and keep within the proportion limits without generating a bland and unexciting environment (Illuminating Engineering Society of North America, 2000).

2.4.7.1.3 Color of illumination

The color of illumination was described by two independent properties: correlated color temperature (CCT), or chromaticity, and color rendering. There is oftentimes confusion between color rendering and chromaticity. In this case, chromaticity represents the color appearance of the light source, "cool light" for high CCT values, in contrast, "warm light" for low CCT values. Color rendering points out to the performance of a light source, with its specifics CCT, to render the colors of objects the similar as a reference light source of the similar CCT. This is generally measured in terms of the CIE General Color Rendering Index. Another experiment investigating the psychological effects of varying CCT and illuminance has recommended that using lamps with CCT values at a low level of illuminance will make space appear dim and cold. In contrast, using lamps with low CCT values at high level of illuminance will make space become artificial and wildly colorful. However, these results have been approximately replicated, other examined have failed to find the same tradeoff of illuminance and CCT. By preference, they found that when the people spent time in the room or space for color adaptation to appear, the perception of rooms or spaces lighted with lamps of color temperature differences was dominated by illuminance. This means that where color adaptation occurs with no chance to compare lamps with different CCTs the CCT of the light source is comparatively unimportant to perception. Where comparisons can be made or do not for color adaptation appear, CCT is more probable to be important. At the very slightest this confusion means that the general belief about the tradeoff of illuminance and CCT could be treated with some skepticism (Illuminating Engineering Society of North America, 2000).

2.5 Color

The radiation energy of electromagnetic provides a physical stimulus that enters the eye and causes the color sensation. The characteristics of the spectral stimulus were integrated by the visual system and cannot be distinguished without the use of an instrument. Because the color rendering of light sources and color progressively important in the design of an environment of illuminance, lighting designers want a good working information of the vocabulary and practices of modern color science. The esthetic use of color to make pleasing interiors needs coordination between the person designing the lighting and the interior designer. Each needs to know how to use color to help offer the desired distribution and brightness levels (Illuminating Engineering Society of North America, 2000). When we see a scene, the visual system produces a perceptual of the surrounding from the energy of radiating that reaches our eyes from the targets or objects within that scene. One of the elements for perception is color. There are chromatic stimuli differences in any scene that observe, and visual system is able to capture that detail or information, relating to the wavelength of visible light. Thus, color is something internal and perception. The chromatic stimulus is radiating of electromagnetic from sources and objects through the optic system and stimulus the visual process. Therefore, color perception is a sensation made by the chromatic stimulus that creates it possible to make different that stimulus from others with a similar area, duration, shape and texture (Gulrajani, 2010). There are 3 basic components of color: light sources, objects, and observers (Hunt & Pointer, 2011).

2.5.1 Basic perceptual attributes of colors

There are 3 basic perceptual attributes of color, in the context of signals of visual. The definition. Brightness: the attributes of a visual perception according to which an area occurs to exhibit more (bright) or less light (dim). Hue: the attributes of a visual perception according to which an area occurs to be similar to one, or to proportions of two, of the realized colors red, green, and blue. Colorfulness: the attributes of a visual perception according to which an area occurs to exhibit more or less of its hue (Hunt & Pointer, 2011).

2.5.2 Relative perceptual attributes of colors

When considering a grey and white patch is seen side by side on a paper. While observing both patches under the bright sunlight, it will look very bright, if both patches were placed into the shade or indoors, it will look less bright. However, the white patch will still look white and a grey patch will still look grey. This important phenomenon that relative perceptual attributes of color are provided separate names.

The lightness is used to expand the brightness of targets or objects relative to that of a similarly white illuminant. Therefore, the brightness could depend on the dimension of a signal of achromatic. Lightness would prepossess to remain constant for a provided color. White and grey could then be recognized as such by their lightness, independent of their brightnesses. Thus, lightness was defined as the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting.

Brightness relative to that of a white, it is possible to judge colorfulness in ratio to the brightness of a white, and the relative colorfulness then given is called chroma. When the level of illumination falls, the colorfulness of objects reduces. Consequently, in daylight, it may look high colorful or look less under the clouds. The level of illumination falls in the evening the colorfulness slowly decreases to zero while scotopic levels are achieved. The colorfulness judged in ratio to the brightness of the white is then looked to be unchanged, and this relative colorfulness is the chroma. Thus, chroma was defined as the colorfulness of an area judged in proportion to the brightness of a similarly illuminated area that appears to be white or highly transmitting. For saturation are described as a colorfulness of an area judged in proportion to its brightness. This saturation case, because the judgement of saturation does not need the concept of a similarly illuminated white, it is appropriate to both related and unrelated colors (Hunt & Pointer, 2011).

2.5.3 The CIE standard light sources

The generally light sources give a variety of spectral power distributions differences. This result provided adaptation processes of the visual system; an object of color undergoes considerable changes in color appearance when changing light source. Moreover, colored pairs that match under one light source will not as a consequence match under another. For decrease the difficult problem with this case, and maintain some make a simple representation of it, the CIE has indicated some standardization. The CIE separates between illuminants, which are explained in spectral power distributions, and sources which are explained as physically achievable manufacturers of radiant power.

Standard illuminant A; An illuminant with the same relative spectral power distribution as a Planckian radiator having a temperature around 2856 K.

CIE illuminant B; An illuminant having the relative spectral power distribution with a correlated color temperature around 4874 K and was deliberated to represent sunlight.

CIE illuminant C; An illuminant with the relative spectral power distribution having correlated color temperature approximately 6774 K and was deliberated to represent average daylight.

Standard Illuminant D65 having a correlated color temperature of about 6504 K with representing average daylight all over the visible spectrum and into the ultraviolet region as far as around 300 nm (Hunt & Pointer, 2011).

2.5.4 The CIE 176

2.5.4.1 CIE 1976 Lightness L*

A scale of greys can be constructed in which the values of the ratios $100L/L_n$ are in uniform increments, such as 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100, where L suggests the luminances of the greys and L_n that of the suitable reference white. A scale of greys can be constructed in which the values of the ratios $100L/L_n$ are in uniform increments, such as 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100, where L suggests the luminances of the greys and Ln that of the suitable reference white. It is described in terms of the proportion of the Y tristimulus value the color examined to that of the reference white, that is Y/Y_n which is equal to L/L_n, as equation (2) (Hunt & Pointer, 2011):

$$L^* = 116f(Y/Y_n) - 16 \qquad (2)$$

where $f(Y/Y_n) = (Y/Y_n)^{1/3}$ for $Y/Y_n > (6/29)^3$

$f(Y/Y_n) = (841/108)(Y/Y_n) + 4/29$ for $Y/Y_n \leq (6/29)^3$

2.5.4.2 CIE 1976 (L*a*b*) color space

L*: lightness or black to white contribution equation (3);

a*: red to green contribution equation (4);

b*: yellow to blue contribution equation (5) (Klein & Meyrath, 2010).

$$L^* = 116f(Y/Y_n) - 16 \qquad (3)$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \qquad (4)$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \qquad (5)$$

where $f(X/X_n) = (X/X_n)^{1/3}$ for $X/X_n > (6/29)^3$

$$f(X/X_n) = (841/108)(X/X_n) + 4/29 \qquad \text{for} X/X_n \leq (6/29)^3$$
and $$f(Y/Y_n) = (Y/Y_n)^{1/3} \qquad \text{for} Y/Y_n > (6/29)^3$$
$$f(Y/Y_n) = (841/108)(Y/Y_n) + 4/29 \qquad \text{for} Y/Y_n \leq (6/29)^3$$
and $$f(Z/Z_n) = (Z/Z_n)^{1/3} \qquad \text{for} Z/Z_n > (6/29)^3$$
$$f(Z/Z_n) = (841/108)(Z/Z_n) + 4/29 \qquad \text{for} Z/Z_n \leq (6/29)^3$$

These corresponding to color opponent theory of Hering. This is taken into account that experience exhibits that there contain no hues of absorption colors such as greenish-red, reddish-green, or bluish-yellow. The expression CIELAB is an alternate for CIE and the color values L*, a*, b* (Klein & Meyrath, 2010).

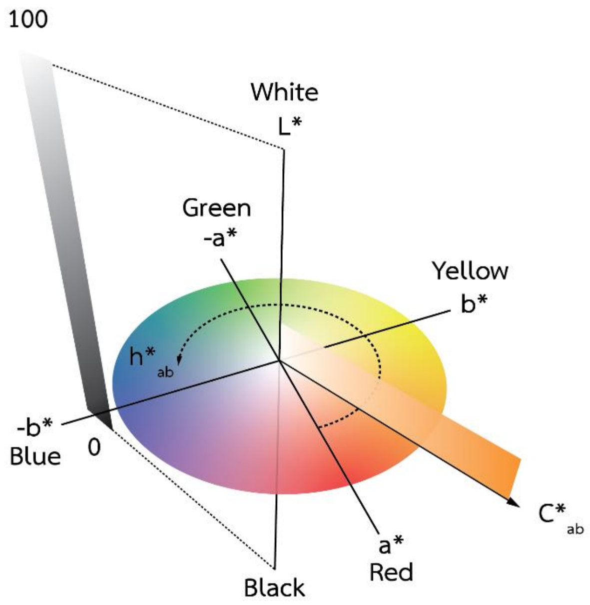

Figure 2-9 CIE L*, a*, b* axes of CIELAB color space and chroma C^*_{ab}, hue angle h^*_{ab}

2.5.4.3 The CIE 1976 chroma, C^*_{ab}

Properties of colors were characterized by attributes such as lightness, chroma, hue, or hue angle. The CIELAB system approaches now the benefit that these properties can also be quantified and visualized. These quantities follow alternatively – instead of Cartesian coordinates L*, a*, b* – from cylindrical with chroma C^*_{ab} like the radius in Figure 2-9 and equation (6) (Klein & Meyrath, 2010).

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$$ (6)

2.5.4.4 The CIE 1976 hue-angle, h_{ab}

Hue-angle h^*_{ab} like the azimuth angle in Figure 2-9 and shown the equation (7).

$$h^*_{ab} = \arctan(b^*/a^*)$$ (7)

2.5.4.5 The CIE 1976 color difference

The numerical of entire color difference ΔE^*_{ab} from the three-dimensional Pythagorean theorem as a Figure 2-10 and shown the equation (8) and (9).

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$ (8)

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta H^*_{ab})^2 + (\Delta C^*_{ab})^2]^{1/2}$$ (9)

This equation of color difference enables to specify quantitatively the estimated value of the realized color difference between two perceived colors. Other points must unquestionably take the following aspects into account:

1. The sign of the single-color contributions is lost on account of the squares; from the numerical value of ΔE^*_{ab} alone, it is not practicable to draw any reasons with regard to the three independent color differences.

2. As experience indicates normally non-uniform color space, solely for infinitesimal color differences in the range of around $\Delta E^*_{ab} \leq 5$. The values of color change almost uniformly only in small regions of the nonlinearly transformed color space.

3. The same size and shape of non-self-luminous colors should be applied to the CIELAB color space. However, for visual assessment, the sample and reference color have to be collected in the same environment of color of middle grey (Klein & Meyrath, 2010).

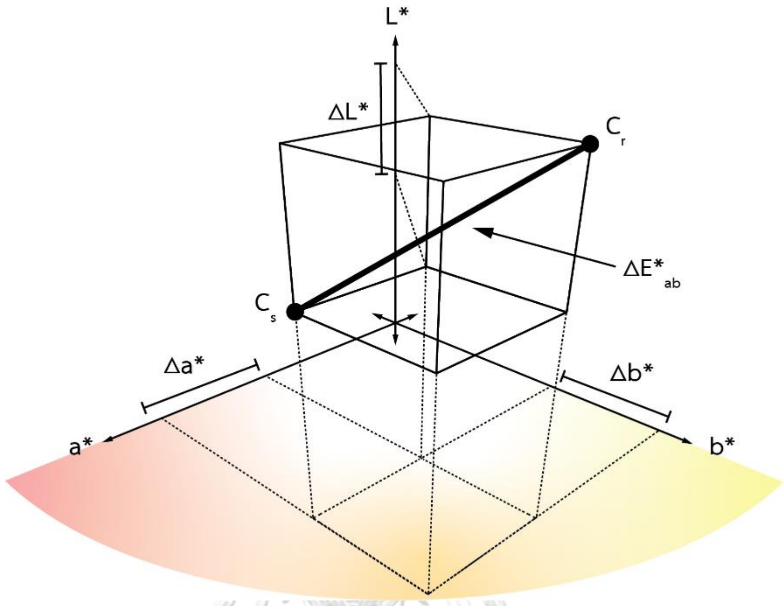

Figure 2-10 Color difference ΔE^*_{ab} between color sample C_S and reference color C_R in CIELAB color space

2.5.5 The CIE94 color difference formulae

The CIE recommended matching further absorbent colors in order to perceive an improved equation of color difference. Consequently, in 1994, the equation (10) of color difference was shown. It was described as the CIE94 color difference formula (Klein & Meyrath, 2010).

$$\Delta E^*_{94} = [(\Delta L^*/k_L s_L)^2 + (\Delta L^*/k_C s_C)^2 + (\Delta L^*/k_H s_H)^2]^{1/2} \quad (10)$$

where $\Delta C^*_{ab} = C_1 - C_2$

$C_1 = (a_1^{\,2} + b_1^{\,2})^{1/2}$

$C_2 = (a_2^{\,2} + b_2^{\,2})^{1/2}$

$S_L = 1$

$S_C = 1 + K_1(C_1)$

$S_H = 1 + K_2(C_2)$

k_L = 1 for default, 2 for textiles

k_C = 1 for default

k_H = 1 for default

K_1 = 0.045 for graphic arts, 0.048 for textiles

K_2 = 0.015 for graphic arts, 0.014 for textiles (Lindbloom, 2017a)

2.5.6 Derivation of RGB from XYZ tristimulus value

Provided the chromaticity coordinates of an RGB system (X_r,$Y_{,r}$), (X_g,Y_g), and (X_b,Y_b) and they reference white (X_w,Y_w,Z_w). This is the converting XYZ to RGB method to compute the 3 × 3 matrix and shown the equation (11).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M] \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (11)$$

where

$$[M] = \begin{bmatrix} S_rX_r & S_gX_g & S_bX_b \\ S_rY_r & S_gY_g & S_bY_b \\ S_rZ_r & S_gZ_g & S_bZ_b \end{bmatrix}$$

$X_r = X_r/Y_r$

$Y_r = 1$

$Z_r = (1 - X_r - Y_r)/ Y_r$

$X_g = X_g/Y_g$

$Y_g = 1$

$Z_g = (1 − X_g − Y_g)/ Y_g$

$X_b = X_b/Y_b$

$Y_b = 1$

$Z_b = (1 − X_b − Y_b)/ Y_b$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix}^{-1} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix}$$

XYZ to Adobe RGB $[M]^{-1}$ for the D65 reference white (Lindbloom, 2017b).

$$\begin{bmatrix} 2.0413690 & -0.5349464 & -0.3446944 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0134474 & -0.1183897 & 1.0154096 \end{bmatrix}$$

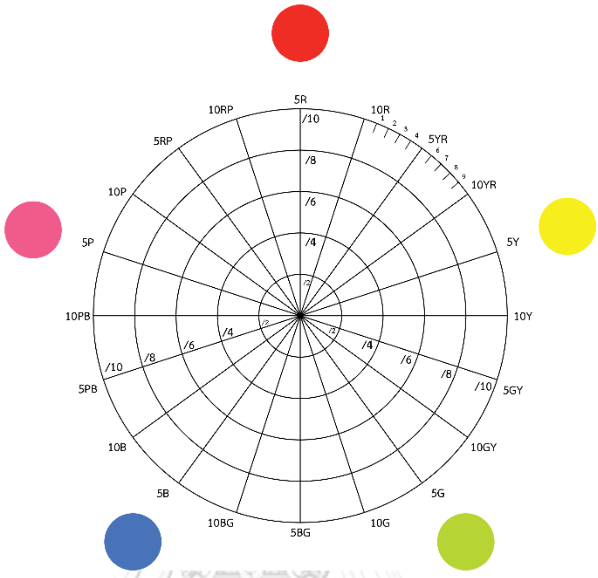

Figure 2-11 Hue circle arrangement in the Munsell color order system

(Hunt & Pointer, 2011)

2.5.7 Munsell color order system

The Munsell color order system is one of the most widely used. Munsell color was originated by the artist A.H. Munsell in 1905. There are ten main steps of grey scale, with 10 for white designated, and black zero, the grey scale with values between 1 to 9 as becoming lighter. The lightness differences between pair sample as 3 and 4, is then intended to be perceptual as any other pair like 7 and 8. The correlation between the luminance factor and number on this scale was used for all color samples as well as for the greys and was referred to as Munsell Value. The Munsell Value, V, of a sample, can be midway between the whole numbers of the eleven basic neutral samples, and it was designated by using decimals. For instance, a sample having a value of 8.5 would be intended to be perceptually intermediate in lightness between samples with values of 8 and 9. The position of the hues around the axis of grey scale is intended to represent different uniform in perceived hue between adjacent hue pages. There are five main hues as, Red (5R), Yellow (5Y), Green (5G), Blue (5B), and Purple (P). The middle hues are determined: 5YR, 5GY, 5BG, 5PB, and 5RP. Exceptional divisions between 5R and 5YR are defined: 6R, 7R, 8R, 9R, 10R, 1YR, 2YR, 3YR, and 4YR, with similar appointments between other hues, as present in Figure 2-11. Color sample with Munsell hue of 2.5YR is intended to be perceptually intermediate between samples with Munsell Hues of 2YR and 3YR. The spaces of the samples from the axis of grey scale were intended to represent uniform differences in perceived chroma and are provided numbers that are regularly as small as 4 or less for weak colors. Munsell chroma was demonstrated by an oblique line preceding the value of numerical, for instance, /7. Once again decimals were used to indicate middle way samples between integers as /7.5 presents that the sample is intended to be perceptually intermediate in chroma between samples with Munsell chromas of /7 and /8. In Figure 2-11 the dots appear for samples with Munsell chromas of /2, /4, /6, /8, and /10, for Munsell Hues at the 5 and 10 positions. The full Munsell identification is always provided in the order hue, value, chroma (HVC), show in Figure 2-12, for instance, 2.5Y6/8 represent that the hue is middle between 10YR and 5Y, that the lightness is modelled lighter than a medium grey, and that it has a considerably strong Chroma (Hunt & Pointer, 2011).

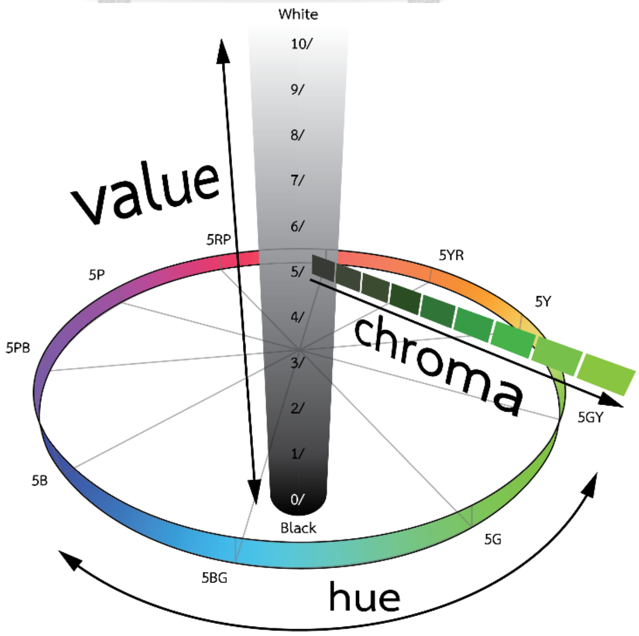

Figure 2-12 Munsell color order system (Gulrajani, 2010)

2.6 Low vision

Many of the definitions used to explain low vision have developed as organizations responsible for healthcare management and the carriage of services in the progressed world have attempted to classify disability in such a way as to control, or alternately enhance, access to services or benefits (Jackson & Wolffsohn, 2007). People with low vision often needs to make such an adaptation in seeing objects. For them, a discrepancy exists what those with typical vision are able to do and what they need to do with vision. Nevertheless, people with low vision can use techniques such as low vision devices or modify their environments to improve the visual information they are given and to absolute tasks more efficiently. Moreover, they may become an expert at reading environmental cues that become more notable for them than for those with representative vision. The definition of low vision is used: "a person who has a measurable vision but has difficulty accomplishing or cannot accomplish visual tasks, even with prescribed corrective lenses, but who can enhance his or her ability to accomplish these tasks with the use of compensatory visual strategies, low vision devices, and environment modifications" from Foundation of Low Vision Clinical and Functional Perspectives (Corn & Erin, 2010). According to the low vision manual, they pointed the low vision, the problem of visual impairment from an optical or optometric background recommend the term "low vision", which to a large extent has to evolve from the term "subnormal vision". This term is synonymous with visual impairment, with the added providing that the residual vision is usable. The blind persons, having a visual acuity of no sensing of light in both eyes, approximately less than 6% of the visually impaired population, and those with a visual acuity of perception of light only, a further 5%. Around 11% of visually impaired persons not including in the category of low vision. Moreover, the low vision was defined as "vision that, when corrected by optimal refractive correction, is not adequate for the patient’s needs". Low vision is a functional explanation that can be practiced easily to any patient with a disorder or disease affecting the visual system (Jackson & Wolffsohn, 2007). People with low vision may be caused by injury, defect of birth, disease or ageing. The most general vision diseases or disorders are glaucoma, age-related macular degeneration (AMD), cataract, optic nerve atrophy, and diabetic retinopathy. Some conditions limit the vision such as blurring or clouding the common or central vision. Low vision people may require low vision services. The specialists in eye care who examine the people with low vision or patient of the eye, they assess how the patient uses vision and how it affects activities, by giving the specific recommended and training low vision aids (Sardegna, 2002).

2.6.1 Abnormal color vision

Around 8% of males and 0.2% of females have an abnormal color vision. Abnormal color vision appears because of abnormal photoreceptor photopigments. This cause for the preponderance of males is that abnormal color vision due to a different genetic on the X-chromosome. Males have only one X-chromosome. In contrast, females have two, and for a female to have abnormal color vision, two X-chromosomes must have the same abnormal gene. For about activities, abnormal color vision causes small problems, because the demand identification of color is unnecessary or because there are other cues by which the essential information can be achieved such as relative location in traffic signals. Abnormal color vision does become an issue when color is single or notable means used to identify objects such as in some forms of electrical wiring. Abnormal people have difficulty with such activities (Illuminating Engineering Society of North America, 2000).

2.6.2 Aging

The visual system ages, a number of changes in its capabilities and structure. Normally, the first evident change is the loss of accommodation. Accommodative function reduces quickly with age approximately 45 years, most of the people can no longer focus at a near target around 50 cm and might need the assistance of optical. This is known as presbyopia. When the age 60, there is very small accommodative performance remaining is most of the population, this result effects on a fixed-focus optical system. This insufficiency of focusing performance is remunerated somewhat by the physiologically smaller pupils in the people with elderly because these increase the depth of field of the eye. Nevertheless, the smaller pupils expand the requirement for task luminance to keep the similar retinal illuminances as when the pupils were larger. The increasing inflexibility of the lens with many other forms of focusing difficulty can be remunerated by adapting the optical power of the optical system with contact lens and spectacles, the other changes that appear in the eye cannot. The visual system ages, the quantity of light achieving the retina is decreased, the light reaching the retina is change by preferential absorption of short wavelengths. The rate changes accelerate occur when ageing after 60 years. Moreover, these changes in the optical characteristics of the eye, depreciation in the neurological components of the visual system also appear in later life. The results of these changes with age are decreased visual acuity, reduced contrast sensitivity, lower color discrimination, increased more time to adapt to large and unexpected changes in luminance, and increased glare sensitivity. Lighting can be selected to partially recompense for these changes. Particularly, the quality of life in elderly people has been presented to be improved by increasing the quality of lighting. Simply giving more light might not be sufficient. The lighting must be provided in an appropriate such as avoided discomfort glare and veiling reflections. When the elderly people are likely to be moving from a brighter area to a dark area. For example, a supermarket to a parking lot, this case has a transition zone with a reducing illuminance is desirable. This transition zone permits their visual system more time to take the changes in adaptation (Illuminating Engineering Society of North America, 2000).

2.6.3 Visibility of age

The visibility is determined to represent details that we can still explain in detail, which can be found from the inverse of the lowest angle that can differentiate. The angle is determined by the arc of minutes. If we can distinguish the line spacing up to an angle 1 arc of minute, the visibility will be 1.0, which is quite good. In general, the visibility can be as high as 1.2 or 1.5. For a driver's license in Japan must have better visibility than 0.6 for both eyes. For Thailand, the color blindness test is performed by the Ishihara test and also tests deep and wide sight.

Our vision system continuously increases in the field of visual detail, the sharpness of our eyes increases to a maximum of about 1.2 at 20 years old, which the sharpness of the eyes begins to decrease about 50 to 60 years old. Many researchers investigated the relationship between the sharpness of eyesight and age, they founded that the average visual sharpness decreases and occurs rapidly after 40 years of age. Changes in eye sharpness for life span showed that sharpness of eyesight increased sharply in infancy and reached a peak at 20 years old. Good eye sharpness is still in its infancy but begins to decline at age 50 and sharply decreases at age 60. The sharpness of the eyesight decreases rapidly caused by cataracts. Recently, cataract surgery has progressed considerably and the elderly can have normal vision after surgery (Katemake & Ikeda, 2012).

2.6.4 Conditions that cause visual impairment

Partial sight is a state of vision that drops between blindness and normal vision. Although several people are born with partial sight, the more than haft of people with partial sight are people with elderly. Approximately the partially sighted, 20% became partially sighted between birth and 40 years old, 21% between 41 and 60 years and 59% after 60 years old. Surveys in the United Kingdom and the United States introduced that the ratio of the total population who are categorized as partially sighted is in the range 0.5 to 1%. Three common cause of partial sight are cataract, macular degeneration, and glaucoma. These causes including different parts of the eye and have implications differences for how lighting might be used to improve or help people with partial sight (Illuminating Engineering Society of North America, 2000). The general conditions and diseases that bring about visual impairment in adults and children are below. The perspective of which diseases are usually congenital or adventitious, which tend to be progressive, and how various vision troubles are connected to the eye anatomy (Corn & Erin, 2010).

2.6.4.1 Cataract

The cataract is a clouding or opacity of the crystalline lens in the eye. Cataracts range in scale and density from small, visually unimportant opacities to an opacity of the lens. Cataracts can expand over the life span and its causes and direction are different on adults and children. For childhood cataracts, approximately 5-15% of preventable childhood blindness all over the world. Congenital cataracts are those present from birth, and childish cataracts are those appearing in the early 2 years of life. The most general causes of childhood cataracts are from inherited metabolic disease or genetic. Cataracts can appear in one or both side of the eyes. Some involve the entire lens, while other specific cloud layers on the lens. The biggest and opacity of denser, the greater the probability that it will vision impaired. The most important visual issue is caused by a decreasing of visual acuity, although reduction of contrast-sensitivity and problems with glare also occur. Small cataracts probably cured by the pupil magnification to allow an obvious view around the edge of the cataract. However, the surgery is the central component of treatment for visually impairing cataracts. The first surgery is very critical for young children because of the jeopardize of expanding amblyopia from the retinal blurred image caused by the cataract. Surgery delay in young children with dense bilateral cataracts can cause in the evolution of nystagmus from decrease visual input to the anterior visual pathway and permanent visual loss from amblyopia. The unsticking the cataract is not enough to guarantee good vision. Good acquiescence with all treatments, including the use of postoperative medications, spectacle wear or consistent contact lens, and modifying to treat amblyopia, is critical for effective reinstatement of vision. With previous diagnosis and treatment with surgery, consistent amblyopia treatment and refractive correctio, most young children with bilateral congenital cataracts have good visual acuity outcomes. For the adult, the population more than 75 years old have a cataract changing in the crystalline lens. In point of fact, cataract is the most important cause of blindness of adult in the world, affecting approximately more than 50 million people. Age-related cataracts expand slowly and are common because they are a general part of the process of ageing. As the ages of the eye, changing in the makeup of the lens cause to confine water, yellow, become denser and shape changing. These results cause the lens becomes more nontransparent, changing the refractive error and diminishes of vision. As with childhood cataract, to any extent part of the lens can be affected (Corn & Erin, 2010).

2.6.4.2 Glaucoma

A glaucoma is a group of conditions that result in harm to the optic nerve and are almost ever related with high intraocular pressure or the eye pressure. While high intraocular pressure is one endanger factor for the evolution of glaucoma, other factors such as blood flow to the optic nerve impairment may be just as important. For the elderly, glaucoma is one of the more general causes of visually impaired, as well as age-related macular degeneration, cataracts, and diabetic retinopathy. Two main types of glaucoma in adults as an open-angle and closed-angle. Open-angle glaucoma, the eye pressure increasing is slow and symptoms are rare. The pressure is not probably high at all and progressive visually loss usually goes unnoticed till late in the disease. However, the loss of vision involved both eyes is often asymmetric. For closed-angle glaucoma appears when the drainage process of the eye is blocked. This result is a sudden eye pressure increases, causing vomiting, nausea, and painful of red-eye painful. Vision reduces from swelling of the cornea. The glaucoma causes in young children are often different in glaucoma adults. General causes of children glaucoma are trauma, surgery particularly from congenital cataract surgery, uveitis, anterior segment dysgenesis, and systemic diseases. The most general type of glaucoma in children is primary infantile glaucoma or primary congenital glaucoma. This result is an issue with the outflow of fluid from the eye. Both side of the eyes or one eye may be affected. The cornea swelling caused by glaucoma, it can occur a cloudy appearance to the front of the eye (Corn & Erin, 2010).

2.6.4.3 Optic atrophy

Optic atrophy is the general causes of visually impaired in among children. That means the atrophy mention any condition causing the optic nerve degeneration. Investigation of the eye will disclose a pale optic disc. The optic nerve was made up by retinal ganglion cell axons. Anything that causes the ganglion cells degeneration may damage to the optic nerve or optic tract can result in atrophy of optic nerve. In young children, general causes involve tumor, infection, inflammation, and head trauma. Moreover, it can also be related to premature birth, lack of oxygen, intrauterine infection. For adults, normally causes including trauma, tumor, multiple sclerosis, and thyroid eye disease. Loss of vision is a slowly progressive beginning and often goes unrecognized until the loss is relatively severe. Vision loss is slowly progressive beginning between four and eight years of age and often goes unrecognized until the visual loss. Other vision problems relate the loss of color vision particularly color discrimination between yellow and blue (Corn & Erin, 2010).

2.6.4.4 Macular degeneration

Macular degeneration is a term group of generally untreatable diseases that affect the macular area of the retina and have some genetic component. Some types are bilateral, familial, and progressive. For instance, best vitelliform degeneration or best disease, and achromatopsia and often relate the system of central nervous. In dry macular degeneration, may a more general condition, cone cells in the macula atrophy, this cause is no medical or treatment of surgical. For wet macular degeneration, a rather rare disorder, new blood vessels increase under the macula, this condition was treated by laser therapy. Age-related macular degeneration (AMD) is a disease caused by the retinal photoreceptors and pigment epithelium degeneration. This result causes of vision loss in adults approximately 50 years old and its increasing prevalence around after the age of 65. It is often related with diseases of vascular such as stroke and arteriosclerosis. Age-related macular degeneration probably causes loss of central visual acuity, sometimes caused by a combination of genetic and surrounding factors such as smoking of cigarette and ultraviolet light exposure. The most general issue is central visual acuity loss, ranging from 20/30 (6/9) to light perception only (Corn & Erin, 2010).

2.6.4.5 Diabetic retinopathy

The diabetes mellitus is a disease caused the failure to create or use insulin, this result in high levels of blood sugar in the bloodstream. There are two types of diabetes, type 1; insulin-conditional on diabetes mellitus, and type 2; non-insulin-conditional on diabetes mellitus. The two types are causes in relative insulin insufficiency. Moreover, both types of result in the body is disabled to process sugar. Destruction of blood vessels over the body and the development of new abnormal blood vessels were caused by high blood sugar. These new blood vessels puncture fluid and protein, scar, and bleed. This causes in complications. For example, a heart attack, poor circulation, kidney failure, stroke, and blindness. The risk of expanding complications, particularly related eye disease like diabetic retinopathy. The diabetic eye is damages to the small blood vessels in a retina and is shows in all people with diabetes around the age of 20 years old or more than (Corn & Erin, 2010).

2.6.5 Environmental manipulations

Modifying the surroundings in which someone lives, or works can have a considerable influence on how expeditiously he or she can use vision. Certified vision rehabilitation therapists, teachers of students with visual impairment and certified positioning and mobility specialists may help the individual with this task by observing them during normal daily activities in order to assess factors in each environment in which tasks are performed that may be interfering with efficient use of vision. Based on the assessment, the professional can then recommend the individual in experimenting with various environmental qualification to define which are helpful. Options associated with environmental manipulation are usually based on one or more of the following factors: lighting, contrast, color distance, and size (Corn & Erin, 2010).

2.6.5.1 Lighting

Several persons with low vision can decide the optimal lighting for their personal eye condition and levels of vision. For instance, one person may look for that a 200 watts lighting bulb gives just the right quantity of light for reading, another person may notice that 200 watts make far too much glare, and still, another may realize that the level of lighting is not important for them visual functioning. Some individuals may want a different type of light sources such as incandescent, fluorescent, halogen, xenon, or a combination of light sources, is obliging or preferred. For some people with visually impaired, low vision devices work best when the light sources are behind them, shining over the shoulder onto the work surface, several people prefer a device of low vision with built-in lighting. A person with low vision needs to experiment to realize the best lighting conditions for comfortable viewing and needs to expand strategies for using vision situations where it is not practicable to command lighting conditions. For instance, in a dim restaurant, one person may use a spotlight to the read menu more easily, another person may wear absorptive lenses to decrease glare from directed lighting, and still, another may take a seat near a window to use the natural light or daylight. At houses, people with low vision may look for ways to provide more, less, or lighting differences for comfort in performing tasks, for example, the use of a solar tube or additional lamps or the installation of skylights can increase the overall illumination levels of light in rooms or spaces. Command of illumination through the use of dimmer switches allow a person with low vision to modify the levels of illumination according to low vision people needs in a particular setting, at a particular time of day, and according to variations in the functioning of visual. A variance of inexpensive dimmer switches is obtainable at a retail store that carries lighting supplies such as standard switches and lightbulbs. These devices can be installed as renewals for standard light in most residential or commercial settings. There is also a diversity of types of lighting accessible such as xenon, fluorescent, and halogen. People with low vision may have a preference for one over another, and valuation should include observation of functional tasks using different types of lighting to impose preferences and efficiency (Corn & Erin, 2010).

2.6.5.2 Contrast

The use of contrast can be advantageous to many people with low vision. For example, in the kitchen a people with low vision may select to have a board of cutting with a dark side and a brighter side; the dark side is used for cutting bright-colored foods such as onions, and the brighter side is for cutting dark-colored food, such as green peppers. In the living room, a people with low vision may set a dark table on a brighter-colored floor surface. For the dining room, it is obliging to use white of pastel plates on a dark tablecloth. Stairs are easier to see with a strip of contrasting tape at the border of each step. Likewise, in needlework, such as knitting, is greatly easier to complete when the conflict with cotton color and needles are used. It is general to use color to heighten contrast by placing colored acetate sheets over printed materials. For instance, the use of a yellow acetate sheet as an overlay enhances the visible performance of blueprints by enhancing contrast. Strongly colored toys may be located in white containers or on shelves with white. Activity areas, wheelchair or highchair trays, and cribs should be selected with contrast in mind: use solid, light color rather than busy, background patterns with colorful to extension contrast in order that maximizes visual efficiency in low vision children (Corn & Erin, 2010).

2.6.5.3 Color

Some low vision people who have color insufficiency do not find techniques for operating colors to be useful, but others find the use of color exceedingly helpful. Moreover, reliable colors maybe move visible and hence more useful under specific lighting conditions. Colors and combinations of color that persons who are generally sighted often think are highly visible, such as red on a black display of electronic, may not be distinguished as such by people with low vision. Because there are so many variables included in visual perception, a low vision people must investigation best uses of color to maximize their functioning of visual. General use of color is to organize or code identical items with different colors. For example, equipment for daily living and communication or toys may be color code to help young children to find and locate such as towel, wash-cloth, toothbrush, cup, and comb in the bathroom; dishes, silverware, and napkins in the kitchen; and musical toys, puzzles, and games in the activities room. The items themselves may be of easily distinguishable colors according to the classification or related items may be stored in a bucket of different colors. For school-age children with low vision may color-coding books. Likewise, adults with low vision may use color-code for filing paperwork. Natural colors in the surrounding can also supply important cues to low vision people. For instance, in a convenient store, people may need only look for many shelves of red and white cans to know that soup is in a specific passageway. While travelling, a person may pinpoint marks on a route by color, so they know, for example, left just after the yellow accommodate and right between the white and brown barrier. Young children in the first stages of orientation and mobility instruction may advantage from color cues in early childhood or special needs environment of the classroom, where different areas of the room or space may have scopes of a certain color, and pathway to different rooms, such as the bathroom or rest room, office, cafeteria, gym, and library, are marked with different colors of tape on the floor. This is specifically helpful for children navigating in wheelchairs who are dealing with the complex tasks of using visual cues for adjustment while remembering ways (Corn & Erin, 2010).

2.6.6 Illumination for low vision

Improving illumination is one of the critical methods of increasing an individual vision without using optical devices. There are some normally suggested lighting levels for specific conditions and environments or tasks that have been defined by groups of professionals whose specialty is illumination such as the Illuminating Engineering Society of North America (IESNA). For a low vision people, the quantity of illumination for comfortable viewing may be associated with many individual factors. For instance, the extent and location of visual impairment, the time of day, and preference. Because suitable lighting conditions are a necessity for low vision people, practitioners must circumspectly examine not only the amount of light but also position and type of lighting when estimating how to adjust the surrounding to maximize an individual's use of vision (Corn & Erin, 2010).

2.6.6.1 Types of light

Illumination also relates to the lighting type that is immediate. The natural source, the light of full spectrum is the sun. For some low vision people, the light of nature, or sunlight, maybe the optimum viewing surrounding or environment; other individuals may behave with most sensitivity in sunlight. Differences in types of indoor lighting are obtainable, some of which replicate the natural light of the sun. People with low vision may have a liking for one type of light over another. When taking into account the lighting of supplemental, different types and wattages of bulbs can be evaluated with the individual to find preferences. Incandescent light is normally correlated with indoor household lighting. It comes in a diversity of wattages, depending on the brightness of light that is necessary. Standard incandescent bulbs cannot provide blue of the light spectrum well, offering the light a yellowish hue. Even although incandescent lighting attends to operate the least annoying lighting surrounding for most viewing tasks, it may not allow the high levels of contrast that some low vision people requirement. Full-spectrum and halogen incandescent bulbs also are obtainable. Full-spectrum bulbs reproduce sunlight and are declared by some companies to get better visual acuity as well as crease fatigue. Halogen bulbs comprise better blue and green of the visual spectrum than standard incandescent bulbs, establishing a whiter and brighter light. Fluorescent light is a cooler source of light that yields higher illumination levels, but it can provide visual fatigue because of its probable strobe like effect. This type of lighting is general in office buildings and school classrooms. Full-spectrum fluorescent lights also are obtainable. Fluorescent and Incandescent light bulbs are existence replaced more and more by newer technology, more energy-efficient light sources. For example, light-emitting diodes (LEDs), high-intensity discharge (HID) lamps, and Laser Light. There are full-spectrum options. LEDs are an electronic light source which is obtainable at different brightness levels and normally have a longer life span than conventional incandescent bulbs. HID lamps, which are like the headlight in some brand-new car, give off a better quantity of light per watt and are sometimes used in large areas or buildings in place of fluorescent lighting. Moreover, people with low vision may also require discussing newer natural lighting options for their home surrounding. Solar tubes, a newer option to standard skylights, trap sunlight on the rooftop of home and manage the light through reflective tubes to different rooms or space in the home. They can be used to light regularly dark areas (Corn & Erin, 2010).

2.6.6.2 Position of light sources

There is no expression for conclusive the position of a light source for a provided person, so when the problem of positioning is regarded, persons should be evaluated according to his or her eye condition, the type of task to be operated, the setting, the obtainable light sources, the ratio the time of day, and the preference of personal. In common, supplemental light sources are located so that the light comes over the shoulder opposite the hand of preferred to avoid the body from casting shadows in the workspace to be observed. If the people with monocularly, the lighting may be installed so that it comes over the shoulder adjacent the eye. Those who use supplemental light sources could location the light as near to the task or object to be investigated as is comfortable because the better distance the object to be viewed is from the light source. As elderly people, changes tend to appear in their optical systems; for instance, the quality of light transmitted to the retina area may be decreased. In these cases, the elderly people may adjust near to the object being viewed or may turn on more lighting, both of which are common modifications to increase contrast. With increasing illumination levels, not only do the people perceive better comfort, but the viewed image is brighter and easier to discern. Several cases, a reading stand was selected for using to supply increased lighting without shadows and to assist the reader put the tasks in a location that is comfortable for observing.

2.6.6.3 Adaptation of light and dark

Mobility from bright illumination settings into dark settings need around 8 to 25 minutes for the light receptor cells of the retina, the rod cells, to adjust totally to lower light levels. As explain the cone cells, which are used in perceiving color and searching detail, quickly adaptation, in a common, adjust from low illumination levels to high illumination surrounding in around 7 minutes. Thus, it is important for professionals who are giving people with low vision services of rehabilitation to monitor the performance to adjust different lighting conditions and to examine the use of adaptations, to encourage smoother transitions between environments differences (Corn & Erin, 2010).

2.6.6.4 Glare

The one of an important factor that must be examined in a discussion of illumination is glare, they were divided into two main types: discomfort glare and disability glare. Discomfort glare is caused by an outside source within the surroundings of personal and may intervene with the person performance to view the information of data being observed. In common, discomfort glare is caused by light-reflective of surfaces are too bright. Moreover, it can be due to widely varying illumination levels in the surrounding. For example, the discomfort glare is the reflection of light off of snow or a desk that reflects the light of the ceiling, this causing visual fatigue. When light sources of glare in the environment interfere with the intension of images being observed, the glare is referred to as environmental glare. For instance, the tiny particles in the air reflecting light on high gloss in a book or magazine.

Disability glare is related to the visual system and can be occurred by cloudiness in the media of ocular, scarring of corneal, and cataracts. For example, scarring of corneal causes lights passing over the eye to emit of scattering throughout the eye, creating an image of distort, and uncomfortable glare. Moreover, people with retinal diseases or dysfunctional irises may experience glare on account of abnormal sensitivity to ambient light and difficulty adjustment of illumination. Improvements can be made in the surrounding and to materials and surfaces of work to give absorbing of light, as well as reflecting of light, surrounding to reduces the glare interference in visual activities. A decreasing in objects or materials suspended from a ceiling such as the carpets were placed under workstation, using a desktop blotter, or wearing of a cap with a brim are all samples of such adaptations. A person can also be educated to reposition the body to decrease the situation of glare. The different types of glare are affecting the person can determinant into the resolving made about how to decrease the glare effects. It is essential to evaluate the sensitivity of the person to glare under a wide range of surrounding conditions.

2.6.6.5 Illumination control

For people with difficulty adjusting to different level of illuminations or who have a problem with surfaces create too much glare, an illumination control may be advantageous. Moreover, modifying type of lightbulb and control of illumination can be reached wattage, over the use of rheostat switches to operate supplemental lighting and lighting condition of rooms. Rheostat switches are types of equipment mounted on a lamp and over other sources of light to operate the level of lighting. It can be installed on both overhead and tabletop sources of supplemental light to permit a people with low vision, particularly photophobia people, to operate lighting condition for various near and distance observing tasks. Another person can use rheostats to produce suitable illumination levels to execute different tasks, to recompense for light changing in a room or space at different times of the day to escape visual fatigue, or to facilitate lighting to dissimilar types of materials. Other pieces of equipment that are used to the illumination control and reflective glares are dark-glasses and light-absorptive lenses (Corn & Erin, 2010).

Literature review

The relationship between lighting and quality of life is important for elderly people. The researcher indicated that when the improvement of the lighting standard was applied, the elderly prefer this condition, and they did not want to replace it with the previous lighting conditions (Sörensen & Brunnström, 1995). Also, the research studied the impact of lighting on the daily activities of people with low vision's house. The results showed that the impact on the daily activities of the basic lighting adaptation was significant for tasks operated on the surface of the working area such as in the kitchen, and it is possible to improve the quality of life by increasing the quality of lighting conditions (Brunnström et al., 2004). A similar experiment examined the influence of lighting on activities of a daily living performance in elderly, cataract, and AMD people. The finding indicated that the participants tend to take action with activities better under brighter lighting conditions (Evans, Sawyerr, Jessa, Brodrick, & Slater, 2010). For glaucoma patients, the experiment took a survey in the participant with glaucoma using 62 questions covering 10 broad aspects of daily life activities. The result showed that the AMD people had a decreasing quality of life and they had a low ability for adapting to glare and different lighting levels, especially in activities requiring functional peripheral vision (Nelson, Aspinall, & O'Brien, 1999). Moreover, the other study examined vision measured between the clinic and home such as lighting conditions. The information indicated that the vision measured in the clinics was better than vision measured at home because of differences in lighting conditions and poor home lighting. This indicates that it is important to optimize lighting at home and improve the vision of elderly and people with low vision (Bhorade et al., 2013).

Increasing levels of illumination have a significant effect on reading performance in AMD patients. The experiment designed to examined illumination levels for reading speed. This result showed that increasing illumination improved their performance of reading. This information recommended that higher level of illumination than previously suggested would enhance reading speed in people with low vision (Eldred, 1992). This result is similar to the experiment examined reading performance on participants with AMD. They suggested that the illuminance for improving reading performance for AMD people is at least 2000 lx and should be a concern the optimal illumination for each patient (Bowers, Meek, & Stewart, 2001). Improving suitable lighting with compensating illumination may enhance visual perception and may decrease the prevalent disability in people with low vision (Cullinan et al., 1979). Other experiments compared chromaticity and luminance contrast with normal vision and people with low vision. The psychophysical method was selected to measure the reading speed. The researchers founded that normal people have a similar reading speed with high color and luminance contrasts, for the low vision people, their reading speed better with luminance contrast than with color contrast (Legge, Parish, Luebker, & Wurm, 1990). Wolffsohn et al. studied the effect of correlated color temperature (CCT) on the performance of reading for the low vision people. The results demonstrated that correlated color temperature did not relate to the reading ability (Wolffsohn, Palmer, Rubinstein, & Eperjesi, 2012).

The effects of the spectral power distribution (SPD) and illuminance of task lighting on visual function in AMD people were investigated. The researcher demonstrated that increasing the illuminance of the task had an effect on visual function, especially for AMD people. They found that there were no significant effects of SPD of the standard peart coat incandescent, day light blue in candescent, warm white fluorescent and cool white fluorescent on the other viusal functions except for improvement in contrast sesitivity with day light blue incandescent (Haymes & Lee, 2006). Another experiment examined the effect of spectral power distribution on the contrast sensitivity in AMD people. The different light sources were halogen incandescent and fluorescent. This finding recommended that the full spectral radiance light sources for the illumination better than interrupted spectral radiance in the fluorescent light source (Holton, Christiansen, Albeck, & Johnsen, 2011).

Several researchers have also investigated the performance of walking and visual perception of people with visual impairment. They studied and evaluated the ability of a dynamic visual assessment of a person with low vision to detect danger environmental. The result indicated that the assessment of distance vision recognition (DVRA) may visually increase their performance to identify curbs, obstacles, or overhangs. DVRA was a useful visual evaluation tool that complements the information, given by existing clinical vision assessments (Ludt & Goodrich, 2002). Also, the other researchers examined the relationship between visual performance in people with low vision and their mobility, walking speed with obstacles. This information showed that participants' field of view has a relation with walking speed and good predictors for some aspects of mobility performance (Leat & Lovie-Kitchin, 2008). Another experiment investigated the relationship between the measurement of clinical vision and walking ability under different levels of illumination for people with low vision. They presented that people with low vision have worse mobility than people with normal vision when decreased illumination levels and visual field extent was the strongest predictor of walking performance (Black et al., 1997). The poor lighting conditions caused reduce foot placement accuracy, especially in older people and AMD. The improper foot placement can lead to injury and high fall risk (Alexander et al., 2014). Moreover, the risk of falls and movement occurred in most patients. Thus, the researcher suggested that good lighting for the elderly or people with low vision should be provided, particularly in a hospital environment (Källstrand-Ericson & Hildingh, 2009).

Light-emitting diodes (LEDs) involved the narrow spectrum in the visible range and the researcher found that the purplish to red, greenish to blue and yellow shades were poor color discrimination under the LEDs (Mahler, Ezrati, & Viénot, 2009; Royer, Houser, & Wilkerson, 2012; Szabó, Schanda, Bodrogi, & Radkov, 2007; Viénot et al., 2005). The LEDs with narrow and gaps of spectrum were very poorly CRI and color fidelity, in contrast, the smooth spectrum was provided flexible color fidelity (David, 2014; Ohno, 2004, 2005). The CIE CRI was incompletely precise to evaluate some light sources with narrow spectral and was no correlation to color preference of participants and color quality. The researcher indicated that the IES R_f (IES's fidelity index) was suitable to measure color fidelity than CIE R_a (color redering index) (Dangol et al., 2013; Jost-Boissard, Fontoynont, & Blanc-Gonnet, 2009; Lee & Yoon, 2020; Narendran & Deng, 2002; Smet, David, & Whitehead, 2016). Another research studied a new color discrimination measurement for LEDs and they described that the larger color gamut area or Gamut Area Index (GAI) was not related to better color discrimination. They suggested the R_d which a new color discrimination measurement based on quantifies of cap transpositions number in the Farnsworth-Munsell 100 Hue (Esposito & Houser, 2019). In addition, although the CRIs of commercial LED light sources were high for the general lighting conditions, they were not used for indicating the performance of whiteness assessment (Zwinkels & Noel, 2011). Wang et al., examined influence of 20 CCT levels on comfort and preference for LED lignting, the results indicated that the CRIs of CCTs did not show the significant effect on preference and perceptual comfort (Q. Wang, Xu, Zhang, & Wang, 2017). This results were supported by Islam et al., they presented that the CRI was not a good indicator participants's preference for lighting and suggested that the Color Quality Scale (CQS) and Gamut Area Scale (Qg), CQS and Color Preference Scale (Qp) were better indicators than CRI (Islam et al., 2013).

Moreover, the researcher studied the ability to render color of LEDs with the different spectral in the short wavelength, the results indicated that the LED with 415 nm was better color fidelity than the LED with 450 nm (Wei, Houser, David, & Krames, 2015). The color discrimination of the elderly was better performance under higher illuminance of LED lighting (Smet et al., 2016). Another experiment demonstrated the appropriate correlated color temperature of LED light source for better color discrimination was around 5000 K compared to the conventional halogen lighting (Königs, Mayr, & Buchner, 2019; Pardo, Suero, Pérez, & Martínez-Borreguero, 2014). Huang et al. also demonstrated that the CCT of 5500 K was suitable for color discrimination (Huang et al., 2019). Janosik and Marczak compared fluorescent lighting with CCT of 6500 K and 2700 K on visual performance of the elderly people and they presented that the cool white lighting was much better discriminated hues (Janosik & Marczak, 2016). For the road lighting, the researcher suggested that the LED lighting with CCT of 3000 K provided better color discrimination and decent for the human eye adaptation than lighting with lower CCT (Jin, Jin, Chen, Cen, & Yuan, 2015). Zhai et al. investigated the impact of illuminance levels and CCT of LED lighting on visual perceptions when viewing the art painting, the results concluded that the illuminance levels had a major impact than CCT (Zhai, Luo, & Liu, 2015).

The color samples were enhanced more highlight and improve visual impression by RGB LED lighting (Feng, Xu, Han, & Zhang, 2017). Tamura et al. studied the performance of LEDs lighting for improving the color discrimination in Ishihara test and Farnsworth Panel D-15 test, they found that the LEDs in long wavelength at 630 and 660 nm were better color dicrimination (Tamura et al., 2017). The RGB LED with 465 nm, 525 nm and 640 nm provided a slightly better color discrimination than the D65 (Flinkman, Laamanen, Silfsten, Hauta-Kasari, & Vahimaa, 2014).

CHAPTER 3

METHODS

3.1 Materials and equipment

3.1.1 Effects of illuminance levels and correlated color temperature on mobility and activities of people with low vision

- Two types of stimulated low vision glasses, Lustiner, France
    - Narrow visual field (left eye)/blind (right eye), visual field 15°.
    - Blurred (left eye)/blind (right eye), Finger count 1 feet (FC1).
- The walking path (13.5 m)
    - White wallpaper
    - Forty gray cylindrical shape of corrugated board floor obstacles (height=25.5 cm, diameter=6 cm)
    - Fifteen gray spheres hanging obstacles (r=10.5 cm)
    - Kinect Xbox 360 camera, Microsoft, USA
- Konica Minolta CS1000A spectroradiometer, Japan
- Konica Minolta White tile calibration plate CS-A5, 15376001, Japan
- Konica Minolta CL500A illuminance spectrophotometer, Japan
- Konica Minolta T-10A illuminance meter, Japan
- Bogdan LED strip, Model: C-A 5050-RGB-MPUAU, Thailand
- Bogdan LED strip, Model: B12441RGB60-TOP, Thailand
- K white LED strip, Model: KS-LL, Thailand
- Arduino Uno SMD R3, Italy

3.1.2 Obtaining spectral reflectance of Munsell color under LED with different spectral power distributions

- Telelumen light replicator™, USA
- Light booth for Telelumen light replicator
- Konica Minolta white tile calibration plate CS-A5, 15376001, Japan
- Program light replicator dashboard software, USA

- Four physical matt Munsell colors (5R5/8, 5Y5/6, 5G5/8 and 5B5/8), USA
- Konica Minolta CS2000A spectroradiometer, Japan
- Data measurement program CS-S10w software, Japan
- Konica Minolta CL500A illuminance spectrophotometer, USA

3.1.3 Determination of the luminance and chromaticity contrast thresholds of colored pairs by participants wearing 2 types of simulated low vision glasses: cloudy and blurred visions.

- Two types of stimulated low vision glasses, M.Takata Optical Company Limited, Japan
    - Cloudy vision (VA=0.08)
    - Blurred vision (VA=0.06)
- Konica Minolta CS2000 spectroradiometer, Japan
- Konica Minolta CL500A illuminance spectrophotometer, Japan
- X-Rite I1 Eye-One Pro spectrophotometer, USA
- EIZO monitor display model ColorEdge CS2420, Japan
- Number Snellen chart, Thailand
- Farnworth-Munsell 100-hue test, USA
- Light booth
- Program MATLAB, USA

3.1.4 Optimization of 3 mix-regions of SPD for contrast enhancement using 200 physical colors by participants wearing 2 types of simulated low vision glasses and patients with low vision.

- LEDCube any SPD simulator, THOUSLITE, China
- Light booth
- Two types of stimulated low vision glasses, M.Takata Optical Company Limited, Japan
    - Cloudy vision (VA=0.08)
    - Blurred vision (VA=0.06)

- Forty physical matt Munsell color order system (10BG5/8, 7.5BG5/8, 5BG5/8, 2.5BG5/8, 10G5/8, 7.5G5/8, 5G5/8, 2.5G5/8, 10GY5/8, 7.5GY5/8, 5GY5/8, 2.5GY5/6, 10Y5/6, 7.5Y5/6, 5Y5/6, 2.5Y5/6, 10YR5/8, 7.5YR5/8, 5YR5/8, 2.5YR5/8, 10R5/8, 7.5R5/8, 5R5/8, 2.5R5/8, 10RP5/8, 7.5RP5/8, 5PR5/8, 2.5RP5/8, 10P5/8, 7.5P5/8, 5P5/8, 2.5P5/8, 10PB5/8, 7.5PB5/8, 5PB5/8, 2.5PB5/8, 10B5/8, 7.5B5/8, 5B5/8, 2.5B5/8), USA
- Konica Minolta CS2000 spectroradiometer, Japan
- Konica Minolta White tile Calibration plate CS-A5, 15376001, Japan
- Konica Minolta CL500A illuminance spectrophotometer, Japan
- Konica Minolta portable spectrophotometer CM-700d, Japan

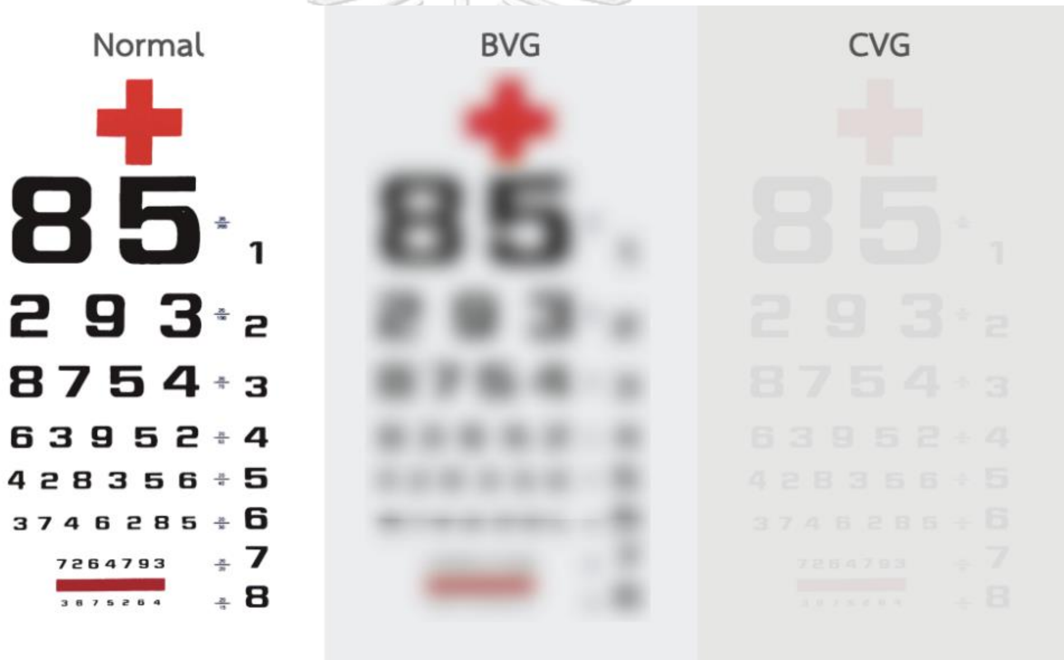

Figure 3-1 Appearance of the Snellen chart through CVG and BVG

3.2 Experimental procedure

3.2.1 Effects of illuminance levels and correlated color temperature on mobility of people with low vision

This first part of the experiment, we examined walking or mobility courses under different illuminance levels and correlated color temperatures performed by a group of people with low vision and healthy elderly. The second part of the experiment, we tested the accuracy of activities performed by both groups. The experimental room was at the 6th floor in the department of imaging and printing technology, faculty of science, Chulalongkorn university, Thailand.

3.2.1.1 Participants

Fifty volunteers with low vision, the age average of 31.36 (SD=11.78), from the Low Vision Association Thailand and 13 healthy elderly, the age average of 66.08 (SD=3.73), were recruited in order to examine their performance and to compare the performance between them. The people with low vision were divided into 2 main groups based on conditions of their eyes: 1) blurred vision in both eyes (blurred/blurred) (24 participants, n=24, #1); and 2) blurred on one side of the eyes and another one blind (blurred/blind) (17 participants, n=17 #2). The rest of the volunteer with low vision (n=9) were not large enough to be categorized. The healthy elderly wearing 2 types of simulated low vision glasses from Lustiner France included 1) a narrow visual field on one side and another one blind (n=7, #3) and 2) blurred on one side and another one blind (n=6, #4). The last two groups were the same healthy elderly (#3 and #4) but they did not wear simulated low vision glasses (n=7, #5 and n=6, #6). The summary of participants is shown in Table 3-1 and Table A-2 in Appendix A.

Table 3-1 Summary of participants with low vision and elderly in the experiment

Groups	#1	#2	#3	#4	#5	#6
Number of participants	24	17	7	6	7	6
	9*					
Average of age	31.36 (SD=11.78)		66.08 (SD=3.73)			

* The low vision peoples whose left and right eyes were different from the majority and were not large enough to be grouped (depending on their visibility). It could be defined as follows: narrow visual field/blind (n=3), narrow visual field/blurred (n=1), blurred/narrow visual field (n=1), narrow visual filed/narrow visual filed (n=1), central blind/central blind (n=1), blurred/central blind (n=2).

3.2.1.2 Light sources and experimental set up

In the first part, the RGB flexible LED strips were installed on the panel of the ceiling of the walking path. The Arduino Uno microcontroller with pulse-width modulation (PWM) dimming techniques with N-channel MOSFETs (STP16NF06 model) was used to control the illumination of LEDs strips. In the second part of the experiment, white LEDs strips with the correlated color temperature (CCT) of 6000 K were installed on the ceiling at the simulated kitchen space. The illuminances on the surface of kitchen counter and the island table were around 520 lx and 400 lx respectively. The experimental room with the walking path was set up with the lighting on the ceiling as shown in Figure 3-2. The walls of the experimental room were attached with white paper having the average lightness (CIE L*) of 86. The height of walking path from the floor to ceiling was 2.5 m. The straight distance from the start to the end was 13.5 m and the average of the distance when taking into account the extra steps after avoiding the obstacles in the walking path was 15 m. The floor obstacles were made of corrugated board and the hanging obstacles were made of foam and they were hung from the ceiling using transparent strings. The range of lightness of the obstacle was between 35 to 40. A Kinect camera was used to record the movements and the number of touching obstacles by participants. The camera was equipped with a wide lens which could capture all the experimental room. The average illuminance of the natural light from outside was around 5 lx because the clear glass windows of the experimental room located at the corner of the building was facing the north and the east. The vertical blinds were closed at all times during the experiment.

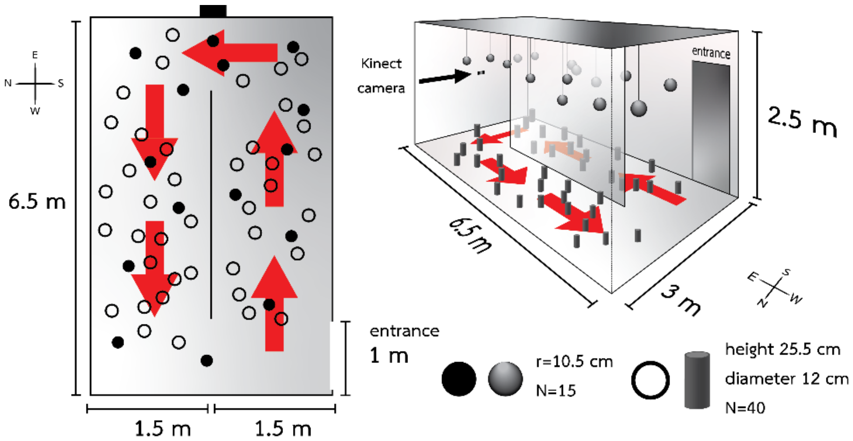

Figure 3-2 2D (left) and 3D (right) diagram of the experimental room including walk way. The black circles represent the hanging obstacles and white circles represent floor obstacles.

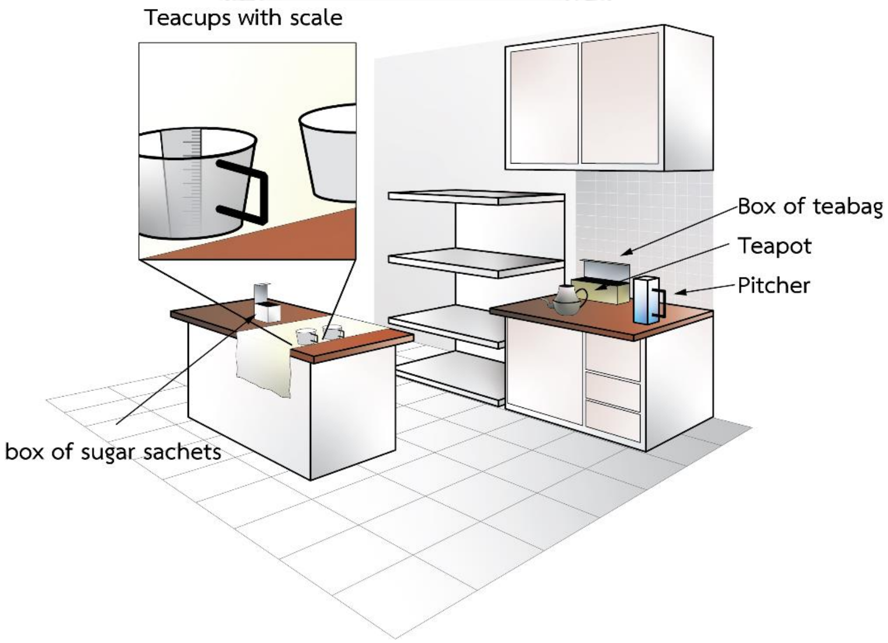

Figure 3-3 Diagram of simulated kitchen space for testing correctness of activities.

The simulated kitchen space was use for testing the correctness of activities carried out by participants. The space included a kitchen counter, a hanging cabinet attached to the wall and an island table placed about 1 meter away from the counter. A teapot, 2 of teacups with measured scale, a pitcher filled with water, a box of teabags and a box of sugar sachets were provided as shown in Figure 3-3.

3.2.1.3 Lighting conditions

There were 7 sessions in the mobility walk course including 1000 lx/3000 K, 1000 lx/6500 K, 100 lx/3000 K, 100 lx/6500 K, 10 lx/3000 K, 10 lx/6500 K, and LEDs switched off. The uniformities of illuminance for 6 conditions are shown in Table A-1 of appendix A. The SPD of lighting conditions were measured using the Konica Minolta CS1000A spectroradiometer and the average of 36 measurements of 2 conditions 100 lx/3000K and 100 lx/6500K are shown in Figure 3-4.

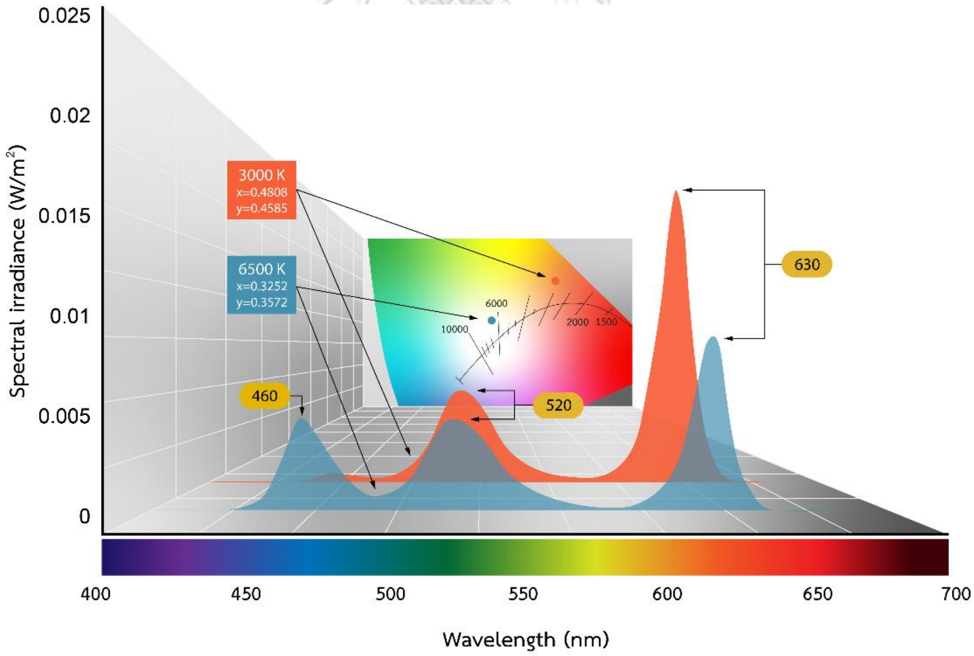

Figure 3-4 SPD of lighting conditions (100 lx/3000 K and 100 lx/6500 K) from RGB LED strips and their chromaticity coordinateds showed along with the scale of CCT.

3.2.1.4 Procedure

Participants with low vision were interviewed before categorizing them based on visual perception. The experimenter described the instructions as follows: “walk naturally from one end of the way to another end, avoid any obstacles located on the way and try not to come into contact with them.” The participants were adapted to the lighting environment around 5 minutes before each session. When they finished any 2 sessions, 1 set of the mobility walk course, such as 1000 lx/6500 K and 1000 lx/3000 K, the participants were led to the kitchen space for carrying out 1 session of activity. After that, the participant began the next walking course, new session and alternate with the testing of accuracy activities. The procedure was shown in Figure 3-5.

The testing of correctness of activities involved making 2 cups of tea with a specific amount of water. The procedure was as follows: the participants poured water from the pitcher to the teapot and put the teabag into a teapot. After that, they placed the tea pot on the island table. On the island table, the 2 teacups and the box of sugar sachets were already placed beforehand. The participants filled sugar and then poured the tea from the teapot into 2 teacups until it reached the specified scale. The participants carried out the mobility testing 7 times and the accuracy testing 3 times. The elderly with normal vision did the mobility test 2 only under 2 lighting conditions (1000 lx/6500 K and LED off) and did the accuracy testing twice.

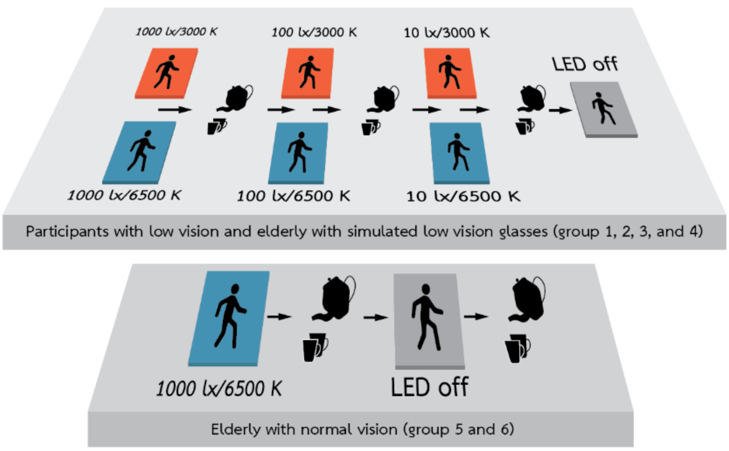

Figure 3-5 Diagram the experiment process

3.2.1.5 Lighting measurement

The illuminance levels and correlated color temperature were measured using the Konica Minolta T-10A illuminance meter with 3 heads connections. The luminance of obstacles and the wall of the walking path were measured using Konica Minolta CS1000A spectroradiometer. The luminances of the obstacles under 7 conditions are shown in Table 3-2.

Table 3-2 Luminance of floor obstacles, hanging obstacles, walls under different lighting conditions were measured by the Konica Minolta CS1000A spectroradiometer.

Luminance (cd/m^2)							
Illuminance (lx)	1000		100		10		LED off
CCT (K)	6500	3000	6500	3000	6500	3000	
Floor obstacles	24.63	25.46	3.07	3.01	0.68	0.61	0.38
Hanging obstacles	41.64	42.23	5.23	5.58	0.91	0.78	0.18
Wall	160.05	161.86	20.73	19.52	3.57	3.42	0.49

3.2.1.6 Analysis

The walking speed and the number of odstacle contacts were used for assessing the mobility under each lighting condition. A score of contact then was calculated by using the number of contacts based on equation (13) (Hassan, Lovie-Kitchin, & Woods, 2002; Marron & Bailey, 1982):

$$\text{Contact score} = \log_{10}(100/1 + \text{number of contacts}) \quad (13)$$

The 1-way ANOVA of data was used to see if the illuminance levels and CCT affect the mobility in terms of the walking speed and the contact scores. Consequently, the comparison between groups of participants would be made to investigate if the different functional visibilities performs differently under different lighting conditions. The *t*-test statistic would be used for testing the mean difference of the amount of deviation from specified scale in the accuracy activity and of the response time on mobility performance.

3.2.2 Obtaining spectral reflectance of Munsell colors under LED with different spectral power distributions

This experiment was to obtain the spectral reflectance of 4 Munsell color samples under 14 LED channels. The experiment was carried out at the intelligent lighting laboratory in the school of engineering, Monash university Malaysia.

3.2.2.1 Munsell color samples

Four matte physical Musell color samples: 5R, 5Y, 5G and 5B having value (V) of 5 and chroma (C) of 8 except for 5Y for 5/6 were used in the experiment. The sample size was 8 x 10 inch and the color appearance shown in Figure 3-6.

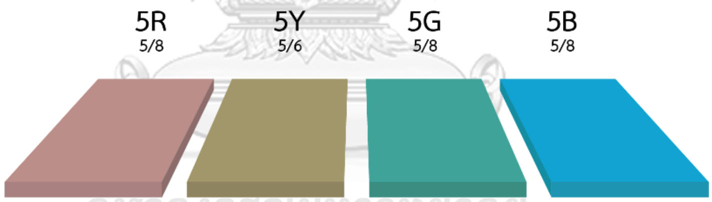

Figure 3-6 Four matte Munsell samples: 5R5/8, 5Y5/6, 5G5/8 and 5B5/8.

3.2.2.2 Light sources and experimental set up

The Telelumen light replicator light source having 16 channels of independent LEDs, as shown in Figure 3-7, was used. The wavelength range was between 395 to 735 nm and the tunable CCT was approximately 1,000 K to 100,000 K with the color rendering index (CRI) greater than 90. The intensity of illumination levels was controlled using the light replicator dashboard software. The 14 LEDs channels out of 16 were selected because the 1st channel, 395 nm, was near the ultraviolet light (UV) and the last channel, 735 nm, was near an infrared (IR). Both of them were out of the scope of study. These 14 LEDs channels that covered the visible region of electromagnetic spectrum included 410 nm, 420 nm, 435 nm, 455 nm, 475 nm, 495 nm, 535 nm, 540 nm, 555 nm, 595 nm, 615 nm, 630 nm, 660 nm and 700 nm. We classified them into 3 groups as shown in Figure 3-7. The 1st group was the short wavelength: 410 nm, 420 nm, 435 nm, 455 nm, 475 nm and 495 nm. The 2nd group was the medium wavelength: 535 nm, 540 nm, 555 nm and 595 nm and the 3rd group was the long wavelength: 615 nm, 630 nm, 660 nm and 700 nm. The Telelumen light replicator was installed on the top of the light booth, the distance between the Telelumen light source and the bottom of the light booth was 70 cm. The middle gray paper board of about N5 Musell was attached at the walls of the light booth. The experiment was carried out in the dark room.

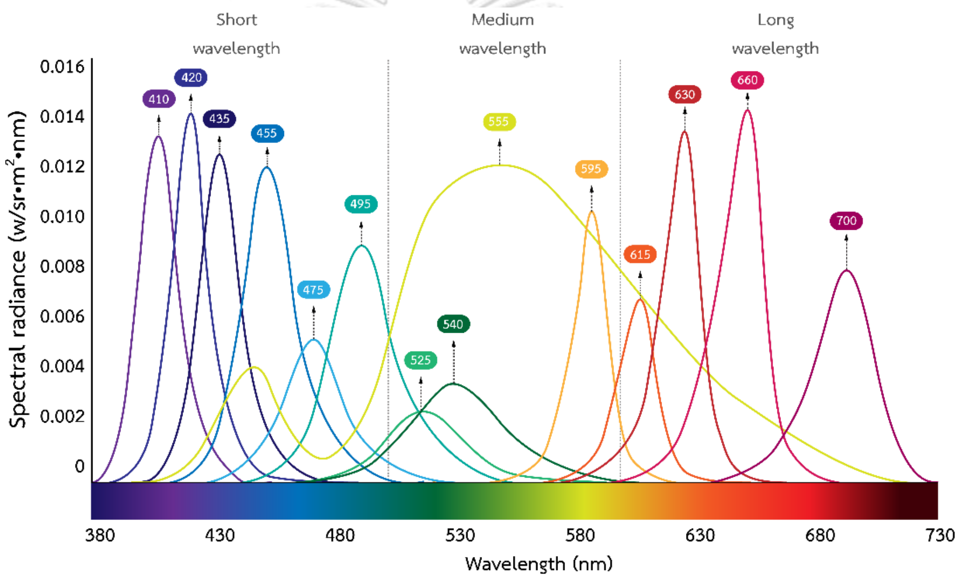

Figure 3-7 Spectral power distributions of the LEDs in the Telelumen light replicator.

3.2.2.3 Color and light measurement

The SPD and the luminance of 14 LEDs channels were measured using the Konica Minolta CS2000A spectroradiometer with CS-S10w software. The spectral reflectance of 4 Munsell samples under 14 LEDs channels were measured by the same device at the angle of 45° and the distance of 35 cm away from the samples. The individual reflectance was the average of 5 positions and 5 replications. Consequently, there were 56 data sets (4 color x 14 LEDs channels) of colored samples for paring and leveling the luminance into 19 steps (next experiment).

3.2.3 Determination of the luminance and chromaticity contrast thresholds of colored pairs by participants wearing 2 types of simulated low vision glasses: cloudy and blurred visions.

In this part of the experiment, we investigated the LED channels that enhanced the contrast of colored pairs for people wearing simulated low vision glasses. The data sets from the previous section were used to generate luminance pairs for determining the luminance and chromaticity contrast thresholds. The overview of the experiment shown in Figure 3-8. The experimental room was at the 6th floor in the department of imaging and printing technology, Faculty of science, Chulalongkorn university Thailand.

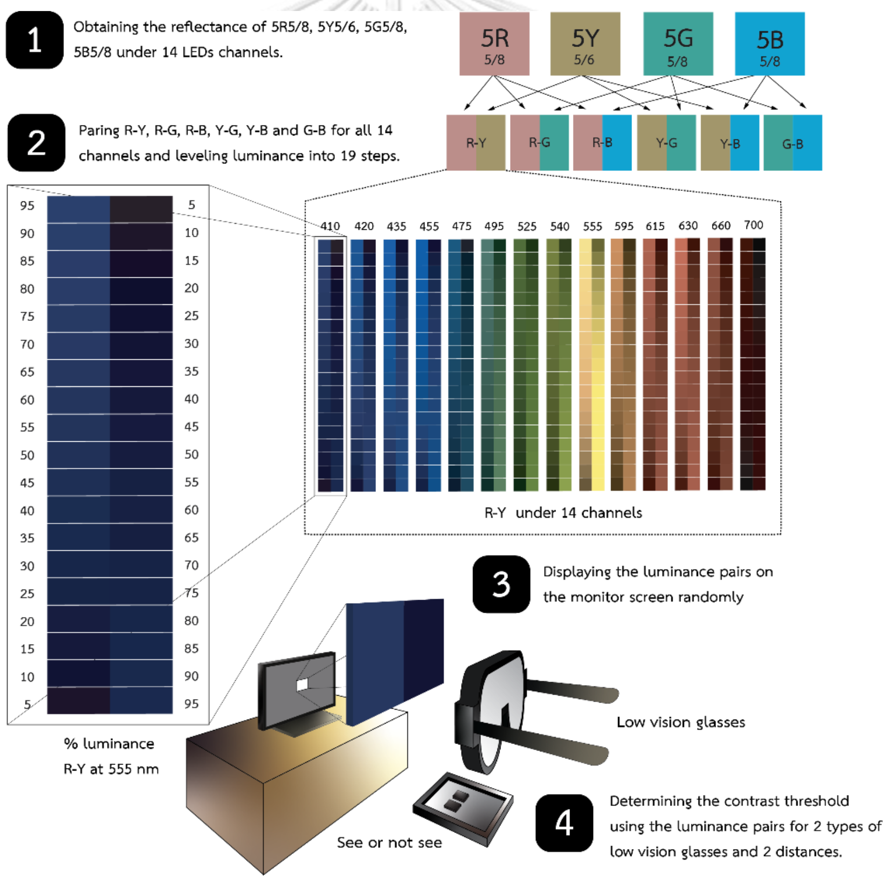

Figure 3-8 Overview of obtaining spectral reflectance of Munsell color under different spectral power distributions (1 and 2) and the determination of LED channels enhancing the contrast of selected hues for simulated low vision subjects (3 and 4)

3.2.3.1 Participants

Fifty-two participants with normal vision including undergraduate and master's degree students from Chulalongkorn university Thailand participated in the experiment. There were 26 males and 26 females with the average age of 21 years old (SD=2). All participants passed color discrimination test using Farnsworth-Munsell 100 Hue test under D65 and were evaluated visual acuity using Snellen chart. The total error scores (TES) of the Farnsworth-Munsell 100 Hue test were less than 68 and classified in a normal range of competence for color discrimination. For the visual acuity, all participants must be a normal vision with the 20/20 (6/6) of visual acuity. They randomly wore either cloudy vision (CVG) or blurry vision simulated glasses (BVG) with visual acuity of 0.08 and 0.06 respectively.

3.2.3.2 Experimental set up

The experimental room was set up with kitchen environment. On the kitchen counter, the EIZO monitor display model ColorEdge CS2420 was installed (Figure 3-8 #3) and blended into the environment. The teacups, pots, and the kitchen utensils were placed on the surface of kitchen counter under the having cabinets. The screen display was calibrated using X-Rite i1 Eye-One Pro spectrophotometer with Adobe RGB color space and white point of 6500 K. The monitor was masked with mid gray cardboard and only the colored pairs area of 5 x 5 cm^2 were presented at the center of the monitor. The participants sat at 35 cm and 70 cm away from the monitor and responded when the colored pairs sample appeared. The chair was adjusted to fit the height of the participants. The Konica Minolta CL500A illuminance spectrophotometer was used to measure illuminance, for 5 areas with 3 replications, at the kitchen counter near the monitor. The level of illuminance of the kitchen was fixed at around 600 lux to ensure that the participants perceive all the color pair samples on the screen display as an object color, not a light source color.

3.2.3.3 Generating luminance pairs

The XYZ tristimulus value of 4 color samples (5R5/8, 5Y5/6, 5G5/8, and 5B5/8) under different color LEDs channels calculated from the spectral reflectance of Munsell colors, under different spectral power distributions, and transformed to Adobe RBG using MATLAB program, were arranged in pairs (Figure 3-8 #2): red-green, red-blue, yellow-green, yellow-blue, and green-blue (There were 6 main colored pairs for each of 14 color LEDs channels). Next step, the luminance of individual of color in the pair was generated from 5% to 95% with 5% interval (19 steps of luminance). For instance, red under LED channel of 555 nm pairing with yellow under 555 nm, consisted of 19 sub luminance pairs, the levels of luminance from 5% of minimum to 95% of maximum luminances. The first pair was the red under 555 nm with 95% luminance pairing with the yellow under 555 nm with 5% luminance. The last pair of red paired with yellow under 555 nm was the red of 5% luminance pairing with yellow of 95% luminance as shown in Figure 3-8. The total of sub luminance pairs was 1596 pairs (6 main colored pairs x 14 color LEDs channels x 19 luminance levels). These 1596 pairs plus 84 pairs (6 main colored pairs x 14 color LEDs channels). These samples were initially used for color discrimination testing. The method of limits was performed to eliminate the redundant colored pairs with high color difference and this was done by the experimenter waering simulated low vision glasses. This method could decrease the number of total colored pairs to 768.

3.2.3.4 Procedure

After the participants did the visual acuity and the Farnsworth-Munsell 100 Hue test, the experimenter explained the instruction and provided the simulated low vision glasses. The colored pair was observed at a time by the participant at 2 distances: 35 cm and 70 cm, subtended the visual angle of about 2° and 10° respectively. All participants with the simulated low vision glasses adapted to the environment in the simulated kitchen area for 2 minutes before starting the experiment. On the monitor, before the colored pair was presented randomly a mid gray image appeared for 3 seconds to allow adaptation. The participants observed the difference of each colored pair and judged “see the difference” or “not see the difference” by pressing the button of numeric keypad as shown in Figure 3-8 #4. The decision time, starting from showing the colored pari until pressing the bottom, was recorded using MATLAB. The participants were allowed to break at any time as they needed. The program could stop and start recording time again. The average time of testing was approximately 1 hour and 40 minutes for 2 distances for 1 type of simulated low vision glasses. Compensation of 600 bath/person was given to participants after they completed the test.

3.2.3.5 Measuring color on the screen

The Konica Minolta CS2000 spectroradiometer was used to measure colored pairsv3 time at 1 area on the display at the distance of 35 cm and 70 cm with and without 2 types of simulated low vision glasses at the front of the measuring lens. The CIE 1976 color difference (ΔE^*_{ab}) between colors in the pair was calculated for both distances and 3 conditions: without glasses, cloudy vision glasses (CVG), and blurred vision glasses (BVG).

3.2.3.6 Analysis

The judgements on colored pairs: “see the difference”, “not see the difference” and the time when the samples appeared until the participants made decision, for 2 types of simulated low vision glasses and 2 distances, were examined. These results would be used to determine the LED channels that enhance color discrimination of tested pairs. Twenty-six participants wore individual type of glasses. For the analysis, each colored pairs was counted if more than 13 participants perceived the difference of the colored pair. Then, the CIE 1976 color difference (ΔE^*_{ab}) between colors in the pairs would be calculated. The minimum of color difference or the threshold obtained from colored pairs for 768 main colored pairs determined the least difference of the pair that the observers could perceive. The analyses were carried out for 2 type of glasses and 2 distances. The thresholds under different channels were plotted and determined for selecting LED channels that enhanced the performance of color discrimination in short, medium and long wavelength regions.

3.2.4 Testing the performance of optimized lighting obtained from a combination of LED channels by subjects wearing simulated low vision glasses.

The selected LED channels from section 3.2.3 were combined to obtain 3 sets of white light for cloudy vision, for blurry vision and for fast response. These 3 sets of white light were tested the performance. The testing room was at the 6^{th} floor in imaging and printing technology building, Chulalongkorn university Thailand and laboratories Hubert Curien in manufacture campus, Université Jean Monnet, France. Followings are the test descriptions.

3.2.4.1 Participants

One hundred sixty undergraduate and graduate students from Chulalongkorn university and Université Jean Monnet with normal vision, 80 males and 80 females, who have experience and study in the field of color, with the average age of 23 years old (SD=3.59), participated in the experiment. The participants were equally randomized into a group of wearing simulated cloudy low vision glasses (CVG) with VA 0.08 and blurred vision glasses (BVG) with VA 0.06.

3.2.4.2 Light source and experimental set up

The LED Cube Any SPD simulator, 14 LED channels, with the correlated color temperature (CCT) was approximately 2,000 to 20,000 K was used in the experiment. The 14 LED channels were 405 nm, 425 nm, 450 nm, 475 nm, 505 nm, 525 nm, 540 nm, 595 nm, 635 nm, 660 nm, 670 nm, 700 nm, cool and warm channels. In the experiment, the LED channels were distributed in 3 regions: short wavelength (405 nm, 435 nm, 450 nm and 475 nm), medium wavelength (505 nm, 525 nm, 540 nm, and 595 nm) and long wavelength (635 nm, 660 nm, 670 nm, and 700 nm). The light intensity and the color channels were controlled using MATLAB. The LED Cube Any SPD simulator was installed on the top of the light booth. The dimension of the light booth was 43L x 43W x 43H cm with the mid gray walls and floor. The experiment was set up in the darkroom.

3.2.4.3 Lighting conditions

There were 4 lighting conditions including 3 conditions from section 3.2.4.2 and commercial white light. The 1^{st} condition was the lighting giving fastest response time (FR-L) for color discrimination of colored pairs. It was the combination of 425 nm, 540 nm, and 635 nm with CCT of 6000 K. The 2^{nd} condition was the optimized light source in color discrimination, perceived by the participants wearing simulated cloudy vision glasses (CV-L). It was the combination of 475 nm, 595 nm and 700 nm. The 3^{rd} condition was the optimized light source with the combination of 425 nm, 535 nm and 660 nm in color discrimination perceived by simulated blurry vision glasses (BV-L). The commercial white light (W-L) was LED with CCT of 6000 K. Konica Minolta CS2000 spectroradiometer and the standard white tile were used for measuring the luminance and SPD of 4 lighting conditions. The measuring distance was at 50 cm from the standard white tile, at the ground of light booth. The average luminance of 4 lighting conditions, from 5 replications, were approximately 187.32 cd/cm^2 (SD=0.62). Figure 3-9 shows the SPD and CIExy chromaticity coordinate of lighting conditions.

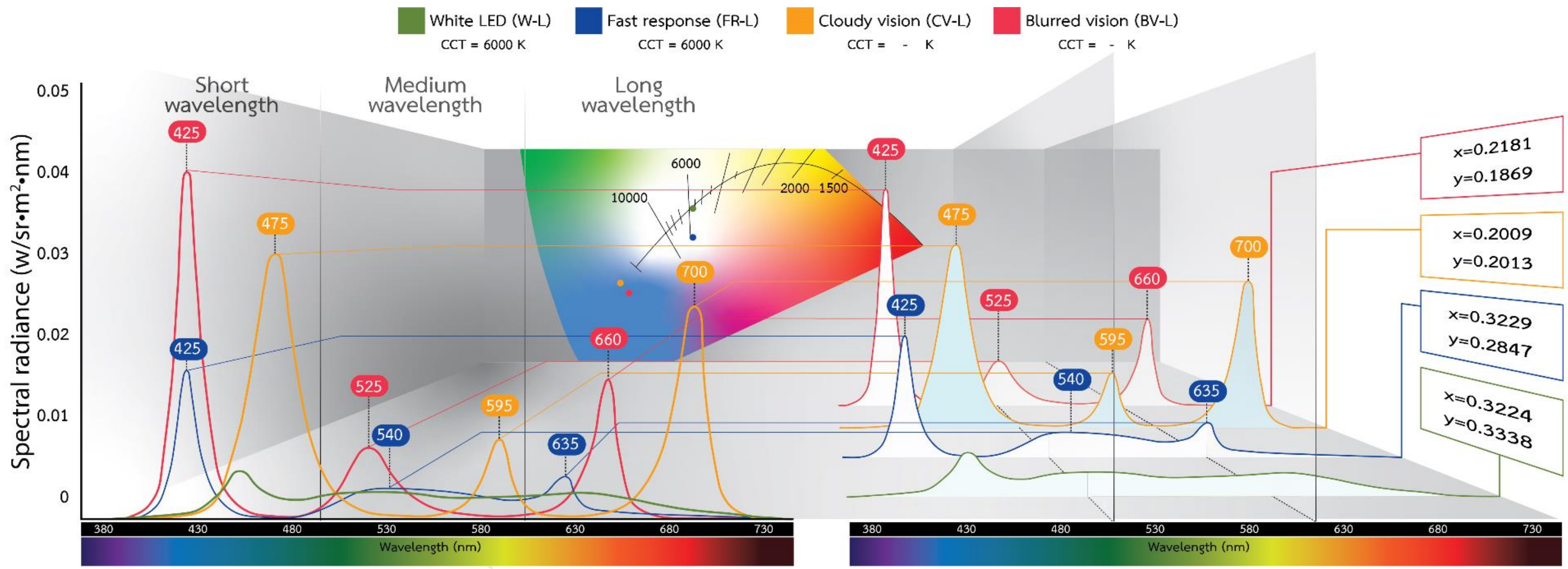

Figure 3-9 SPDs of 4 lighting conditions, divided into 3 groups based on the wavelengths CCT and the CIExy chromaticity coordinates.

3.2.4.4 Colored pairs

Forty matte Munsell samples (10BG5/8, 7.5BG5/8, 5BG5/8, 2.5BG5/8, 10G5/8, 7.5G5/8, 5G5/8, 2.5G5/8, 10GY5/8, 7.5GY5/8, 5GY5/8, 2.5GY5/6, 10Y5/6, 7.5Y5/6, 5Y5/6, 2.5Y5/6, 10YR5/8, 7.5YR5/8, 5YR5/8, 2.5YR5/8, 10R5/8, 7.5R5/8, 5R5/8, 2.5R5/8, 10RP5/8, 7.5RP5/8, 5PR5/8, 2.5RP5/8, 10P5/8, 7.5P5/8, 5P5/8, 2.5P5/8, 10PB5/8, 7.5PB5/8, 5PB5/8, 2.5PB5/8, 10B5/8, 7.5B5/8, 5B5/8, and 2.5B5/8) were systematically paired, as shown in Figure 3-10, to obtain 200 colored pairs. The systematically colored pairs started from 5YR paired with 2.5YR (5YR-2.5YR 1st), 10R (5YR-10R 2nd), 7.5R (5YR-7.5R 3rd), 5R (5YR-5R 4th) and 2.5R (5YR-2.5R 5th). Next colored pairs were 2.5YR paired with 10R (2.5YR-10R 6th), 7.5R (2.5YR-7.5R 7th), 5R (2.5YR-5R 8th), 2.5R (2.5YR-2.5R 9th) and 10RP (2.5YR-10RP 10th) until the 200th pair. The size of each color was 5 cm x 2.5 cm, thus, the size of colored pair was 5 cm x 5 cm.

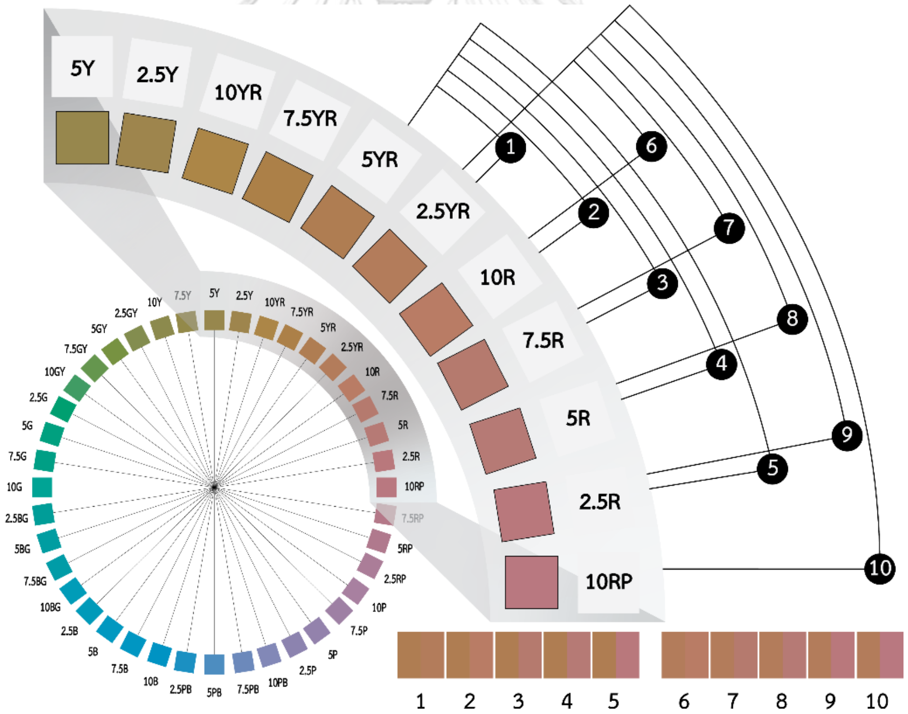

Figure 3-10 Systematic pairing of matte Munsell used in the experiment, an example shown 10 color pair samples (5YR-2.5YR 1st, 5YR-10R 2nd, 5YR-7.5R 3rd, 5YR-5R 4th, 5YR-2.5R 5th, 2.5YR-10R 6th, 2.5YR-7.5R 7th, 2.5YR-5R 8th, 2.5YR-7.5R 9th, and 2.5YR-10RP 10th).

3.2.4.5 Procedure

Participants were randomly provided the simulated low vision glasses and given the following instructions before starting the experiment. “There are 2 types of simulated low vision glasses. You will wear 1 type of them. While you are wearing them, your visibility will be similar to people with low vision. There are 200 colored pairs in front of you. They are equally divided into 10 groups based on hues. You will observe and judge colored pairs one at a time into 3 categories depending on what you perceive it. The 1st category is when you cannot see the color difference of colored pairs. You then pick that pair and put it into the 1st compartment of the storage in front of you. The 2nd category is when you just see the color difference but not very clear. Then you put this pair into the middle compartment. The 3rd category is when you see the contrast of the pair clearly. You put this pair into the last compartment.” The overview of the experiment is shown in Figure 3-11. When the participants wore the simulated low vision glasses, they were allowed to adapt to the environment, the lighting condition and the types of glasses, for 2 minutes before starting the experiment. The response time for judging of color difference of the sample pairs were recorded.

3.2.4.6 Color measuring

The colored pairs were measured under 4 lighting conditions mentioned in the section 3.2.4.3 at the distance of observing the colored pairs using Konica Minolta CS2000 spectroradiometer with and without simulated low vision lens: cloudy (CVG) and blurred vision (BVG) in front of lens. The average of 5 measurements for each color were recorded. The Konica Minolta portable spectrophotometer CM-700d was also used for measuring the colored pairs in specularl included mode (SPIN) for 5 areas. The CIELAB values at illuminant/observer: D65/2° were obtained. There are 520 CIELAB values (40 main hues x 4 lighting conditions (W-L, FR-L, CV-L, and BV-L) x 3 types of glasses (without glasses, CVG and BVG) + 40 CIEL*a*b* values from Konica Minolta portable spectrophotometer CM-700d). The color difference CIE 1994 (ΔE^*_{94}) between 2 colors in the pair for 200 pairs in all lighting conditions and different type of glasses were calculated.

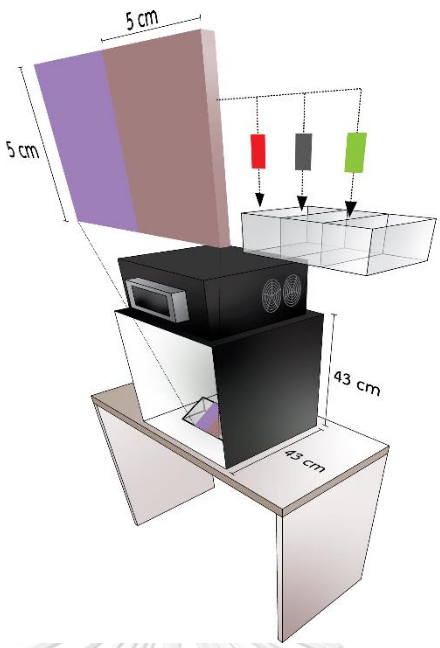

Figure 3-11 Experimental set up with the LED Cube-Any SPD simulator, light booth, colored pairs and a compartment storage.

3.2.4.7 Analysis

The number of colored pairs judged into 3 categories and the response time by the participants were analyzed for 4 lighting conditions. There were 160 participants in total: 80 of them waering CVG equally participanted in CV-L, BV-L, FR-L and W-L and another half waering BVG equally participanted in CV-L, BV-L, FR-L and W-L. The frequency of the selection of colored pairs for individual category that was greater than 10 would be counted. These colored pairs then were calculated for color difference CIE1994 (ΔE^*_{94}) in the pair. The range of minimum and maximum of color difference then were plotted in 3 categories for all lighting conditions and for 2 types of simulated low vision glasses.

3.2.5 Testing the performance of optimized lighting obtained from a combination of LED channels by the patients with low vision from Metta-Pracharak hospital.

This experiment was similar to section 3.2.4. The only difference was replacing participants from normal vision people wearing simulated low vision glasses to the patients with low vision from Mettapracharak hospital. The experiment was set up in the darkroom at Mettapracharak (Wat Raikhing) hospital.

3.2.5.1 Participants

Thirty patients with low vision participants from Mettapracharak hospital with the average age of 61.79 years old (SD=7.94) were included in the experiment by the hospital researcher. The criteria for including patients were:

- No gender restriction
- Over 18 years old since the date of the experiment
- The visual acuity (VA) of both eyes between is 0.05 (20/400) to 0.33 (20/60)
- No color blindness
- No blindness of both eyes
- Cloudy vision or blurred vision
- No restriction of disease type

Before starting the experiment, the consent document was provided to all participants and the procedure of the experiment were explained. The protocols of research were approved and reviewed by the research ethics review committee for the research involving human research participants, health sciences group, Chulalongkorn university (No.224.2/62) and Mettapracharak (Wat Raikhing) hospital research ethics committee (No.007/2563).

3.2.5.2 Lighting conditions

This part of the experiment, 3 lighting conditions including: fast response lighting condition (FR-L), cloudy vision lighting condition (CV-L) and blurred vision lighting condition (BV-L) similar to the previous part were examined for testing performance for people with low vision. The SPD and CCT of 3 lighting conditions are shown in Figure 3-9.

3.2.5.3 Procedure

The participants were patients who have an appointment with a doctor to follow up the symptom on the day we set up the survey. The experiment was carried out after screening the participants and during they were waiting for a doctor. The hospital researcher explained the overview of the experiment to the participants and if they feel uncomfortable such as dizziness or eyes fatigue, they must let the experimenter know. They could stop at any time if they feel discomfort. All the participants who involved the experiment would not lose the opportunity to receive treatment on that day. The instructions were explained to all participants before starting the experiment: "This is a data sheet for research participants and research consent letters. This experiment is a test performance of lighting conditions. The final results can be useful for adjusting environments or surrounding to facilitate low vision people. In front of you, there are 200 colored pairs. They divided into 10 groups based on the hues, these are 20 colored pairs in each group. You will observe the colored pairs one by one and judge it into 3 categories depending on what you perceive it. The 1st category is when you cannot see the color difference of colored pair. You then pick that pair and put it into the 1st compartment of the storage in front of you. The 2nd category is when you just see the color difference but not very clear. Then you put this pair into the middle compartment. The 3rd category is when you see the contrast of the pair clearly. You put this pair into the last compartment."

After the explanation, the participants were allowed to adapt to the environment for 2 minutes before starting the test. The average time for testing approximately 17 minutes for judging 200 colored pairs under 1 lighting condition. The 3 lighting conditions were randomly selected for testing each participant. The information related to participants were kept confidentially and any information that can identify patient or participant did not appear in the report. Participants were paid for 400 baht/person after the test was completed. In the case that the participants were unable to stay till the end of the test or did not want to continue the test, they received the compensation based on response time for the test.

3.2.5.4 Analysis

The analysis of experiment was similar to section 3.2.4. The number of colored pairs selected for each category and the response time by the participants analyzed. There were 30 participants with low vision in the experiment. This was the difference from the previous part. In a lighting condition, 10 patients with low vision participated. The frequency of the selection of colored pairs for individual category that was greater than 5 would be counted. These colored pairs then were calculated for color difference (ΔE^*_{94}). The range of minimum and maximum of color difference then were plotted in 3 categories in all lighting conditions.

CHAPTER 4
RESULTS AND DISCUSTIONS

4.1 Mobility and activities

4.1.1 Mobility course

The statistics and F-statistics obtained from the 1-way ANOVA for illuminance and CCT effects on walking speed and contact score for #1 to #4 are shown in the following tables: Table 4-1, Table 4-2 and Table 4-3 (effect and their interaction on walking speed), Table 4-4, Table 4-5 and Table 4-6 (effects and their interaction on contact score). There was no statistically significant effect of illuminance and CCT on walking speed for #1 blurred/blurred and #2 blind/blurred & blurred/blind visions under 6 lighting conditions. There was no interaction effect of illuminance and CCT on walking speed. For #3 and #4, elderly subjects wearing narrow visual field (NV)/blind and blurred/blind simulation glasses respectively, showed that the illuminance did not affect the walking speed of #3 but significantly affected #4. The paired *t*-test showed that the walking speed of #4 under 1000 lx (M=0.21, SD=0.05) was significantly lower than that under 100 lx (M=0.31, SD=0.11) and 10 lx (M=0.35 SD=0.07). Under the similar illuminance of 1000 lx, the #4 elderly wearing the blurred/blind glasses walked slower than the low vision subject #2 blurred/blind who did not show a significant difference under the illuminance 10 lx to 1000 lx. The results clearly shows that the low vision #1 and #2 exhibited better mobility under all 7 lighting conditions compared to the elderly wearing low vision glasses #4. The elderly #3 NV/blind walked faster than the elderly #4 blurred/blind.

In terms of unintentional contact, there was no significant differenct effects of illuminance and CCT on contact score for #1 - #4. There was also no interaction effect of illuminance and CCT on contact scores. The elderly #3 NV/blind demonstrated less collisions with obstacles than #4 blurred/blind. The same elderly participants of #3 and #4 when they did not wear the low vision glasses, they were classified as #5 and #6 respectively. They did not collide with any obstacles while walking under 1000 lx/6500 K and with LEDs turne off.

The session of LEDs switched off shows that there were no significant differences, in walking speed, obtained from LEDs turned off and between the other 6 lighting conditions performed by #1 and #2. Among 6 lighting conditions, the averages of walking speed of the 2 similar types of low vision: #1 blurred/blurred and #2 blurred/blind for the lighting conditions of 10 lx/6500 K ($p<.05$) and 10 lx/3000 K ($p<.05$). The #2 blurred/blind walked slower than #1 under low illuminance of 10 lx at CCT of 6500 K and 3000 K. In addition, #2 did not show the difference in walking speed under different lighting conditions compared to #4 elderly wearing blurred/blind simulation glasses ($p>.05$). The latter walked slower at higher illuminance levels. Besides, #2 showed less unintentional contact compared to #4. The elderly wearing narrow visual field/blind glasses (n=7, M=0.25, SD=0.14) showed sumilar walking speed, in all 7 sessions, compared to the low vision participants with narrow visual field/blind (n=3, M=0.21, SD=0.09). Although the luminances of the gray obstacles at the floor and the hanging obstacles measured under 1000 lx were 36 and 47 times higher than the corresponding luminance under 10 lx, it did not improve the walking speed. It might be explained by the fact that the luminance contrast is reletively maintained. Both #5 and #6, the elderly with naked eyes participanted in 2 sessions of the mobility walking course: 1000 lx/6500 K and LEDs turned off. The mean of walking speed of the elderly under 1000 lx/6500 K (M=0.79, SD=0.25) was not significntly different ($p>.05$) from under the LEDs off, about 5 lx from natural daylight (M=0.73, SD=0.20). Under these 2 conditions, the elderly with naked eyes showed significant higher speed than the low vision of #1 and #2

Table 4-1 Statistics of walking speed (m/s) for 4 groups of participants under 7 lighting conditions.

Illuminance (lx)		1000		100		10		Led off
CCT (K)		6500	3000	6500	3000	6500	3000	
	Min	0.20	0.16	0.18	0.18	0.19	0.17	0.21
#1	Mean	0.49	0.51	0.53	0.52	0.51	0.49	0.49
(n=24)	±SD	±0.22	±0.20	±0.21	±0.18	±0.19	±0.19	±0.19
	Max	1.20	0.97	1.09	0.91	0.90	0.95	0.95
	Min	0.11	0.12	0.18	0.15	0.13	0.11	0.12
#2	Mean	0.43	0.44	0.42	0.45	0.39	0.40	0.37
(n=17)	±SD	±0.19	±0.20	±0.20	±0.20	±0.22	±0.21	±0.20
	Max	0.90	1.01	0.92	0.92	0.84	0.84	0.79
	Min	0.07	0.09	0.08	0.11	0.09	0.08	0.08
#3	Mean	0.19	0.22	0.26	0.28	0.28	0.28	0.26
(n=7)	±SD	±0.14	±0.13	±0.14	±0.12	±0.15	±0.18	±0.16
	Max	0.48	0.48	0.46	0.43	0.47	0.50	0.50
	Min	0.13	0.19	0.20	0.22	0.30	0.29	0.24
#4	Mean	0.18	0.25	0.30	0.34	0.35	0.35	0.33
(n=6)	±SD	±0.04	±0.05	±0.11	±0.10	±0.07	±0.03	±0.06
	Max	0.22	0.30	0.50	0.49	0.48	0.38	0.39

#1 low vision – blurred/blurred (Left eye/Right eye)

#2 low vision – bilnd/blurred, blurred/blind

#3, #4, #5, #6 elderly subjects.

Table 4-2 One-way ANOVA of the effect of lighting conditions on walking speed (m/s) performed by 4 groups of participant.

Groups	Speed (m/s)	Df	Sum Sq	Mean Sq	F value	Pr (>F)
#1	Lighting conditions	6	0.025	0.004	0.106	0.996
	Residuals	161	6.331	0.039		
#2	Lighting conditions	6	0.090	0.014	0.358	0.904
	Residuals	112	4.695	0.041		
#3	Lighting conditions	6	0.046	0.007	0.364	0.898
	Residuals	42	0.888	0.021		
#4	Lighting conditions	6	0.134	0.022	4.303	0.002 ***
	Residuals	35	0.182	0.005		

Table 4-3 Two-way ANOVA of the effect of illuminance levels (L) and CCTs on walking speed (m/s) of 4 groups of participant.

Groups	Speed (m/s)	Df	Sum Sq	Mean Sq	F value	Pr (>F)
#1	Illuminance (L)	2	0.015	0.007	0.188	0.828
	CCT	1	0.000	0.000	0.004	0.950
	L:CCT	2	0.006	0.003	0.076	0.927
	Residuals	138	5.533	0.040		
#2	Illuminance (L)	2	0.035	0.017	0.416	0.661
	CCT	1	0.006	0.006	0.153	0.696
	L:CCT	2	0.002	0.001	0.025	0.976
	Residuals	96	4.035	0.042		
#3	Illuminance (L)	2	0.042	0.021	1.047	0.362
	CCT	1	0.003	0.003	0.172	0.681
	L:CCT	2	0.001	0.000	0.024	0.977
	Residuals	36	0.7366	0.020		
#4	Illuminance (L)	2	0.109	0.054	10.030	0.0 ***
	CCT	1	0.010	0.010	1.952	0.172
	L:CCT	2	0.008	0.004	0.732	0.489
	Residuals	30	0.164	0.005		

Table 4-4 Statistics of contact scores of 4 groups of participants under 7 lighting conditions

Illuminance (lx)		1000		100		10		LED
CCT (K)		6500	3000	6500	3000	6500	3000	off
#1	Min	0.8	0.7	0.9	0.9	0.8	0.7	0.8
	Median	1.8	2.0	2.0	2.0	2.0	2.0	2.0
	Max	2.0	2.0	2.0	2.0	2.0	2.0	2.0
#2	Min	0.9	1.3	1.0	1.2	0.9	1.2	1.0
	Median	2.0	2.0	2.0	2.0	2.0	1.7	2.0
	Max	2.0	2.0	2.0	2.0	2.0	2.0	2.0
#3	Min	0.7	0.9	0.7	0.7	0.9	0.8	0.9
	Median	1.2	1.4	1.2	1.2	1.2	1.2	1.2
	Max	1.7	2.0	1.7	2.0	2.0	2.0	2.0
#4	Min	1.1	1.2	1.2	1.2	1.2	1.2	1.2
	Median	1.3	1.6	1.7	1.7	1.6	1.6	1.7
	Max	1.7	2.0	1.7	2.0	2.0	2.0	2.0

Table 4-5 One-way ANOVA of the effect of lighting conditions on contact scores of 4 groups of participant.

Groups	Contact score	Df	Sum Sq	Mean Sq	F value	Pr (>F)
#1	Lighting conditions	6	0.326	0.054	0.528	0.787
	Residuals	161	16.571	0.102		
#2	Lighting conditions	6	0.432	0.0719	0.661	0.681
	Residuals	112	12.19	0.1088		
#3	Lighting conditions	6	0.224	0.037	0.213	0.971
	Residuals	42	7.373	0.175		
#4	Lighting conditions	6	0.592	0.098	1.236	0.312
	Residuals	35	2.794	0.079		

Table 4-6 Two-way ANOVA of the effects of illuminance levels (L) and CCTs on contact scores of 4 groups of participant.

Groups	Contact score	Df	Sum Sq	Mean Sq	F value	Pr (>F)
#1	Illuminance (L)	2	0.068	0.034	0.33	0.719
	CCT	1	0.160	0.159	1.542	0.216
	L:CCT	2	0.095	0.047	0.457	0.634
	Residuals	138	14.282	0.103		
#2	Illuminance (L)	2	0.196	0.098	0.985	0.377
	CCT	1	0.000	0.000	0.002	0.969
	L:CCT	2	0.149	0.074	0.748	0.476
	Residuals	96	9.565	0.099		
#3	Illuminance (L)	2	0.024	0.012	0.071	0.931
	CCT	1	0.004	0.003	0.022	0.882
	L:CCT	2	0.182	0.091	0.531	0.592
	Residuals	36	6.178	0.171		
#4	Illuminance (L)	2	0.2323	0.116	1.459	0.248
	CCT	1	0.1219	0.121	1.532	0.225
	L:CCT	2	0.1003	0.050	0.630	0.539
	Residuals	30	2.3879	0.079		

Table 4-7 Statistics of walking speed (m/s) for 2 group of participants with normal vision under 2 lighting conditions

	#5		#6	
	1000 lx/6500 K	LED off	1000 lx/6500 K	LED off
Min	0.46	0.51	0.59	0.47
Mean±SD	0.69±0.26	0.67±0.16	0.85±0.20	0.77±0.22
Max	1.24	0.96	1.13	1.10

4.1.2 Activities course

The statistics of discrepancy from scale of 4 is shown in Table 4-8. The average discrepancy scale of participants with low vision, #1 and #2, was smaller than the elderly with simulated low vision glasses, #4 and #5. However, groups of participants without glasses were lower score than low vision people and both groups of participants wore glasses. The paired *t*-test showed that the discrepancy scale between group 3 (M=5.7, SD=6.6) and group 5 (M=3.1, SD=3.2) was significantly difference [t(27)=3.891, p=0.000]. Also, the result was founded a similar significantly difference between group 4 (M=8.3, SD=7.8) and group 6 (M=3.0, SD=2.6) [t(23)=3.298, p=0.003] (Table 4-9). This indicates that the 2 types of simulated low vision glasses effect on the visibility although the participants are the same person on both groups.

Table 4-8 Statistics of discrepancy scale for groups of participants under 7 lighting conditions

(mm)	#1	#2	#3	#4	#5	#6
Min	0	0	0	0	0	0
Mean±SD	4.7±4.6	4.3±5.0	5.7±6.6	8.3±7.8	3.1±3.2	3.0±2.6
Max	19	25	31	27	11	9

Table 4-9 The *t*-test results comparing between groups of participants on discrepancy scale

Groups		t	Df	P-value
#1	#2	0.4568	102.7	0.6488
#3	#4	-1.568	69.17	0.1214
#5	#6	0.1855	49.969	0.8536
#3	#5	3.891	27	0.000 ***
#4	#6	3.298	23	0.003 ***
#1 #2	#3 #4	-0.438	17.96	0.6664
#3 #4	#5 #6	2.382	13	0.0331*

4.2 Obtaining spectral reflectance of Munsell colors under LED with different spectral power distributions

Table 4-10 shows the CIELAB values of 4 Munsell colored samples, measured by using Konica Minolta CM-700d spectrophotometer, illuminant/observer: D65/2°, specular component included. The spectral reflectance of these 4 samples are shown in Figure 3-9. The Konica Minolta CS2000A spectroradiometer with the white tile was used to measure luminance of 4 color samples under different LED channels. The spectral power distributions of 14 LED channels, measured using Konica Minolta CS2000A spectroradiometer, are shown in Figure 3-7. The luminance and CIExy chromaticity coordinates of 4 color sample under 14 channels are demonstrated in Table 4-11.

Table 4-10 CLEL*a*b* of 4 color samples (illuminant/observer: D65/2°, SPIN)

Color samples	L*	a*	b*
5R5/8	50.78	33.56	14.97
5Y5/6	50.86	5.07	40.55
5G5/8	52.35	-41.34	14.59
5B5/8	53.35	-30.33	-21.19

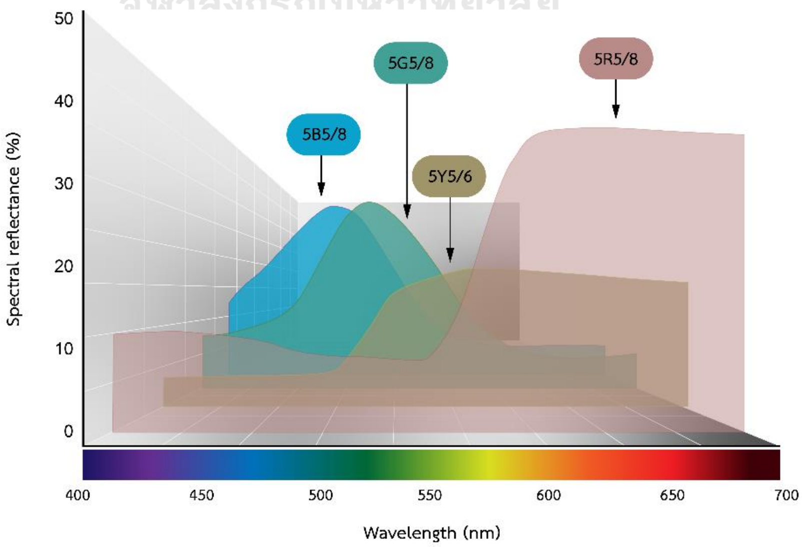

Figure 4-1 Spectral reflectance of 4 color sample: 5R5/8, 5Y5/6, 5G5/8 and 5B5/8

Table 4-11 Luminance, CIEx, and CIEy of 4 color samples under different LED channels (CH) measured by the Konica Minolta CS2000 spectroradiometer.

Color-CH	Luminance	x	y	Color-CH	Luminance	x	y
5R-410	0.12	0.1736	0.0106	5G-410	0.13	0.1702	0.015
5R-420	0.28	0.1697	0.0098	5G-420	0.31	0.1678	0.0121
5R-435	0.64	0.1646	0.0134	5G-435	0.74	0.1625	0.0162
5R-455	2.00	0.1472	0.0371	5G-455	3.57	0.1400	0.0529
5R-475	2.10	0.1200	0.1109	5G-475	5.58	0.1045	0.1622
5R-495	8.48	0.0952	0.4259	5G-495	29.35	0.0718	0.4996
5R-525	6.70	0.2309	0.6671	5G-525	21.11	0.1616	0.7259
5R-540	14.40	0.3555	0.5960	5G-540	35.04	0.2366	0.6959
5R-555	131.62	0.5134	0.4163	5G-555	150.56	0.3194	0.5643
5R-595	37.57	0.5976	0.4017	5G-595	12.38	0.5747	0.4242
5R-615	20.35	0.6651	0.3343	5G-615	3.99	0.6513	0.3479
5R-630	23.57	0.6986	0.3008	5G-630	3.64	0.6911	0.3080
5R-660	9.09	0.7185	0.2802	5G-660	1.23	0.7159	0.2832
5R-700	0.74	0.7225	0.2699	5G-700	0.11	0.7196	0.2743
5Y-410	0.05	0.1721	0.0117	5B-410	0.42	0.1672	0.0166
5Y-420	0.13	0.1693	0.0113	5B-420	0.81	0.1671	0.0113
5Y-435	0.29	0.1641	0.0148	5B-435	1.90	0.1624	0.0146
5Y-455	1.08	0.1453	0.0465	5B-455	7.74	0.1429	0.0422
5Y-475	1.54	0.1161	0.1613	5B-475	9.38	0.1119	0.1215
5Y-495	10.64	0.1145	0.5722	5B-495	36.70	0.0698	0.4214
5Y-525	12.89	0.2209	0.7205	5B-525	20.98	0.1381	0.7063
5Y-540	26.60	0.3040	0.6660	5B-540	30.87	0.2094	0.6825
5Y-555	154.65	0.4492	0.5130	5B-555	130.17	0.2791	0.4620
5Y-595	26.70	0.5901	0.4089	5B-595	10.36	0.5830	0.4157
5Y-615	12.61	0.6627	0.3366	5B-615	4.48	0.6592	0.3398
5Y-630	14.72	0.6976	0.3018	5B-630	4.72	0.6960	0.3030
5Y-660	5.36	0.7183	0.2810	5B-660	1.82	0.7181	0.2805
5Y-700	0.43	0.7234	0.2709	5B-700	0.15	0.7195	0.2706

4.3 Determination of LED channels enhancing the contrast of selected hues for simulated low vision subjects

4.3.1 Response time

The results in this part includes 1) paring R-Y, R-G, R-B, Y-G, Y-B and G-B for 14 LED channels and leveling luminance into 19 steps; 2) displaying luminance pairs on the monitor and 3) determining the luminance contrast thresholds using luminance pairs for 2 types of low vision glasses and distances. Seven hundred sixty-eight luminance pairs, after being eliminated by the method of limit, are presented in Table 4-12 for individual LED channels.

Table 4-12 Seven hundred sixty-eight pairs remained for examination in each channel.

Channels (nm)	410	420	435	455	475	495	525
Number of pairs	62	60	67	62	60	53	55
Channels (nm)	540	555	595	615	630	660	700
Number of pairs	50	48	55	56	51	53	36

Table 4-13 shows the average and the standard deviation of time responded by participants wearing 2 types of simulated low vision glasses at 2 distances. The fastest response time found at 420 nm, 555 nm and 615 nm for short, medium and long wavelengths, in both distances and both types of glasses. In addition, the response times at short wavelengths of 410 nm and 430 nm are not significantly differenct from 420 nm. Also, at long wavelength, the response times at 630 nm amd 660 nm are not significantly different from 615 nm. The results of the 2-way ANOVA of the effects of types of glasses, distances and LED channels on response time is shown in Table 4-14. There was a significant effect from these 3 variables om response time ($p<0.00$). Similar results were found that the combined effect of types of glasses and distances, types of glasses and channels, as well as distances and channels significantly affected the response time, $p\leq0.00$. The participants with BVG gave the shorter response time than with CVG. The shorter observing distance showed the shorter response time for both types of glasses.

Table 4-13 Average and standard deviation of response time by participants wearing CVG and BVG at 70 and 35 cm.

Mean of time (s)					
Types of glasses		CVG		BVG	
Distances (cm)		70	35	70	35
Short wavelength (nm)	410	3.18±0.61	2.23±0.37	2.45±0.48	1.99±0.38
	420	***3.00±0.62***	***2.22±0.48***	***2.40±0.60***	***1.98±0.52***
	435	3.10±0.83	2.26±0.87	2.54±1.03	2.21±0.85
	455	3.14±0.55	2.47±0.46*	2.59±0.58	2.40±0.52*
	475	3.24±0.41*	2.73±0.37*	2.54±0.46	2.54±0.39*
	495	3.17±0.48	2.65±0.42*	2.56±0.39	2.56±0.43*
Medium wavelength (nm)	525	3.28±0.56*	2.70±0.56*	2.63±0.60*	2.65±0.62*
	540	3.06±0.36*	2.39±0.36	2.33±0.42*	2.17±0.35*
	555	***2.74±0.41***	***2.23±0.46***	***2.07±0.37***	***2.01±0.29***
	595	3.30±0.84*	2.51±0.78*	2.40±0.84*	2.25±0.70*
Long wavelength (nm)	615	***3.30±0.45***	***2.61±0.41***	***2.47±0.53***	***2.25±0.46***
	630	3.34±0.38	2.92±0.45*	2.63±0.36	2.39±0.36
	660	3.37±0.38	2.97±0.34*	2.66±0.49*	2.41±0.35
	700	3.54±0.32*	3.20±0.37*	2.60±0.41	2.40±0.35

*= significantly different, p<.05

We divided 14 LED channels into 3 regions based on size of wavelength, short, medium and long and we investigated if the shortest response time in the same regions was significantly different from others. We found that the shortest response time of 3.00 seconds for CVG, 70 m, was not significantly different from another wavelength in the short wavelength region except for 475 nm. The asterisk is marked in the Table 4-13 for the response time that differ significantly (p<.05) from the shortest time the same regions. In general, for the short wavelength region, the LED channels that gave the optimized response time for both 2 types of glasses and 2 distances, were 410 nm, 420 nm and 435 nm. For the middle wavelength region, the optimized LED channel was 555 nm for both 2 glasses and distances. For the long wavelength region, the optimized LED channels were 615 nm, for both types of glasses and for 2 distances. The LED channel of 700 nm was optimized for BVG vision in both distances.

Table 4-14 Two-way ANOVA of the effect of types of glasses (TG), distances (D), and channels (CH) on time response for response time.

Time (s)	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Types of glasses (TG)	1	174.4	174.44	528	0.00 ***
Distances (D)	1	133.4	133.36	403.7	0.00 ***
Channels (CH)	13	98.8	7.60	26.042	0.00 ***
TG:D	1	37	37.03	126.823	0.00 ***
TG:CH	13	13.8	1.06	3.637	0.00 ***
D:CH	13	15.1	1.16	3.988	0.00 ***
TG:D:CH	13	5.1	0.39	1.339	0.182
Residuals	3016	880.6	0.29		

4.3.2 Contrast thresholds analysis

Addition to the response time, we recorded the psychophysics response of "see/not see difference" and the color differences of 768 pairs. Table 4-15 shows the number of colored pairs that the majority of participants (>13 for individual session from 26 participants) observed the difference. The participants wearing BVG could discriminate the difference of the generated luminance pairs greater than the ones wearing CVG in both distances. The shorter distance promoted ability to discriminate color among participants.

Table 4-15 The number of colored pairs that were perceived the differences by more than 13 participants.

Types of glasses	CVG		BVG	
Distances (cm)	70	35	70	35
Number of pairs	536	619	699	741
% from total (768)	69.8	80.6	91.0	96.5

Table 4-16 and Table 4-17 present the minimum color difference (ΔE^*_{ab}) between colors in the pair calculated from the CIELAB measured through CVG and BVG lenses respectively. These minimum ΔE^*_{ab} values were taken, for example, from 536 pairs (see Table 4-15, 3rd row, 2nd column) in the case of CVG, 70 m. These 536 pairs included the generated luminance pairs of 6 main colored pairs (R-Y, R-G, R-B, Y-G, Y-B and G-B). We calculated ΔE^*_{ab} of the pairs and showed here only the least color difference which could be used for determination of the threshold. We also calculated the luminance and chromaticity contrasts which they could be used as thresholds shown in Table 4-18, for CVG, andTable 4-19, for BVG.

The appearance of the Snellen chart through CVG and BVG are shown in Figure 3-1. We could see that the sharpness of edge could be observed through CVG not through BVG. The contrast of 2 colored areas could obviously be observed through BVG, not through CVG. The minimum ΔE^*_{ab} and the minimum luminance contrast (%) in the pairs that the participants with CVG could discriminate at 70 cm was lower than that with BVG. That means lesser color difference and luminance contrast between any objects are required for visibility through CVG than BVG at 70 cm. However, the number of colored pairs that the majority of participants with CVG could discriminate was 21% less than those with BVG at 70 cm (see Table 4-15). We may infer that the results of the visual assessment and the instrumental assessment based on ΔE^*_{ab} and luminance contrasts (%) were adverse; in contrast, the visual assessment in this case gave similar trend to the instrumental assessment based on chromaticity contrast (%). Hereafter, we will call the minimum luminance contrast

(%) as luminance contrast threshold and the minimum chromaticity contrast (%) as chromaticity contrast threshold.

We could see from Table 4-18 and Table 4-19 that the chromaticity contrast threshold through CVG was higher than through BVG for both 35 and 70 cm. That means higher chromaticity contrast between any object are reguired for visibility through CVG than BVG. This was confirmed by the number of the distinguishable pairs through CVG that was lower than through BVG for both distances. The chromaticity contrast threshold at 35 cm were lower than at 70 cm, for both types of glasses; this was also confirmed by the number of the discernable pairs at 35 cm that was higher than 70 cm.

The summaries of optimized channels for both types of glasses are shown in Table 4-20 and Table 4-21. As mentioned above that if irrespective of distance, the channels were selected for the next experiment which 3 channels for mixing white light. For the cloudy vision was channel 475 nm in a short wavelength, channel 595 nm in the medium wavelength, and channel 700 nm for long wavelength because channel 660 nm was near medium wavelength, this case was difficult to mixing into white light. Besides, for blurred vision was channel 435 nm not channel 475 nm because this case tried to avoid duplicate channels in the cloudy vision that had only channel 475 nm. Also, a similar case in the medium wavelength selected channel 525 nm and channel 660 nm for long wavelength. Unfortunately, the fourth experiment selected the LEDCube any SPD simulator for a light source which slightly different channels from the Telelumen light replicator in the second experiment, caused by the limitations of the equipment resulting in the inability to use the original light source.

Table 4-16 The minimum CIE 1976 color difference (ΔE^*_{ab}) in each channel observed by participants wearing CVG at the distances of 70 and 35 cm.

ΔE^*_{ab} CVG													
	70 cm						35 cm						
CH	R-Y	R-G	R-B	Y-G	Y-B	G-B	R-Y	R-G	R-B	Y-G	Y-B	G-B	CH
410	3.8	3.6	***1.9***	3.7	3.3	4.0	7.0	4.3	4.0	5.5	4.2	3.5	410
420	3.7	4.3	3.1	5.0	3.5	4.7	6.1	6.1	5.6	4.4	4.7	4.3	420
435	3.8	5.0	5.0	4.8	4.0	7.0	3.4	6.6	5.0	6.7	4.8	5.0	435
455	3.8	6.9	4.3	3.4	3.6	7.1	5.4	7.2	6.1	4.9	6.0	7.3	455
475	***2.0***	3.4	2.4	***3.0***	2.5	***2.0***	***1.6***	2.6	2.4	***3.7***	***2.2***	***3.4***	***475***
495	2.1	***1.6***	2.4	3.4	***1.7***	2.9	3.9	***2.4***	***2.3***	6.2	3.2	5.0	495
525	2.2	***2.4***	2.6	3.4	3.0	2.6	***3.3***	4.6	4.4	***2.2***	***2.8***	2.9	525
540	***1.9***	6.8	7.0	3.1	3.2	4.1	3.4	10.9	12.1	6.1	4.6	3.6	540
555	9.6	23.1	27.6	23.4	18.5	10.3	12.0	32.0	10.7	32.8	17.3	16.9	555
595	2.7	2.6	***1.5***	***2.6***	***1.8***	***2.0***	4.7	***3.9***	***3.2***	4.8	3.2	***2.3***	***595***
615	3.7	3.6	2.4	3.1	2.4	1.7	4.7	5.1	3.5	2.1	3.4	2.8	615
630	4.3	4.0	4.2	2.5	1.8	2.5	5.2	3.2	3.2	2.8	3.4	2.8	630
660	***2.4***	2.0	***2.0***	***2.1***	***1.7***	***1.2***	4.1	3.7	3.8	2.1	3.2	***1.9***	***660***
700	-	***2.0***	2.6	-	-	-	***2.2***	***2.1***	***2.5***	***2.0***	***1.8***	-	***700***

Table 4-17 The minimum CIE 1976 color difference (ΔE^*_{ab}) in each channel observed by participants wearing BVG at the distances of 70 and 35 cm.

ΔE^*_{ab} BVG													
	70 cm						35 cm						
CH	R-Y	R-G	R-B	Y-G	Y-B	G-B	R-Y	R-G	R-B	Y-G	Y-B	G-B	CH
410	18.4	5.8	***4.7***	10.9	9.0	6.3	16.2	2.8	4.3	5.6	6.2	4.3	410
420	14.3	4.4	5.0	9.5	6.2	***5.0***	12.2	3.6	2.1	8.0	3.1	4.4	420
435	***4.4***	10.8	6.9	6.9	4.6	6.0	***3.7***	2.2	***1.2***	3.2	4.2	4.9	***435***
455	5.9	11.7	5.8	9.0	8.2	11.2	5.0	3.4	4.7	***2.3***	3.9	***2.2***	455
475	5.8	4.3	10.6	***5.5***	***1.8***	11.5	6.2	2.7	9.6	5.3	***2.0***	10.0	***475***
495	10.3	***1.9***	5.2	14.7	6.7	9.3	10.7	***2.0***	5.3	15.1	7.1	9.5	495
525	***2.0***	4.0	***3.1***	5.1	***3.6***	4.8	***2.2***	4.8	***3.7***	5.2	4.0	4.8	***525***
540	10.7	32.4	31.6	18.0	12.4	7.7	10.1	28.2	27.6	17.2	12.0	7.3	540
555	22.5	53.0	19.2	60.3	31.3	29.8	22.0	54.8	18.1	60.9	33.9	31.8	555
595	5.1	***3.7***	6.1	***3.2***	3.9	***3.6***	2.2	***3.6***	5.8	***3.3***	***3.9***	***3.8***	***595***
615	7.8	***3.1***	7.0	4.5	***2.9***	2.7	***1.9***	3.4	***1.5***	4.4	2.9	1.7	615
630	***5.0***	5.8	3.5	5.7	6.7	4.9	4.6	3.1	3.8	5.6	6.6	***1.3***	630
660	7.5	4.0	***2.9***	***3.3***	4.2	***2.6***	2.0	***2.1***	2.6	***3.4***	***1.5***	2.6	***660***
700	5.1	10.2	8.0	7.5	7.6	-	3.1	10.2	7.9	7.9	7.5	1.4	700

Table 4-18 Percentages of luminance (LC) and chromaticity contrast (CC) thresholds (LC/CC) for CVG at 70 cm and 35 cm.

CH (70 cm)	R-Y	R-G	R-B	Y-G	Y-B	G-B
410	1.8/124.4	1.8/185.4	5.9/47.9	1.8/159.7	5.4/84.7	1.3/260.1
420	1.8/152.3	2.6/268.3	7/33.9	2.2/37.6	12.9/170.8	14.8/177.2
435	1.3/262.8	3/73.6	12.9/171.5	2.6/207.1	6.5/10.4	5.2/95.3
455	2.2/163.2	3.8/99.7	9.4/73.7	2.1/94.3	7.8/230.7	2/56.4
475	3.1/43	6.8/114.8	21.1/22.5	10.5/63.6	21.6/26.2	10.2/109.5
495	1.1/13.7*	4.2/11.5*	6.2/21.7*	5.5/15.9*	8.4/1.2*	2.8/9.1*
525	6.7/17.7	7.1/13.8*	8.7/21.1	10/18.2	8.1/19.3	8/12.5*
540	6.8/5.6	3.9/29.1	8.4/33.3	10.4/2.5*	14.3/11.5	12.8/17.3
555	16.5/0*	2/102.5	202.9/181.3	28.8/13.8	29.6/19.5	33.6/23.2
595	11.7/12	6.5/14	8.1/7.1*	11.6/18.1	9.8/11.3*	9.4/13.5
615	6.8/20.6	5.4/25.1	7.4/18.7	5.5/19.8	3.6/15	5/12.8
630	8.7/19.9	10/29.3	7.3/30.3	3.7/16.8	5.6/13.1	3.2/16.1
660	7.4/16.8*	5.5/14.2	5.3/11.9	6.5/15*	4.4/9.5*	2.2/6.1*
700	-	3.1/7.6*	13.2/6.7*	-	-	-
CH (35 cm)	R-Y	R-G	R-B	Y-G	Y-B	G-B
410	6.1/1.2*	4.4/162.5	0.7/68.6	4.5/64.4	4.5/102.3	0.7/131.5
420	5.1/195.2	6.8/61.4	5.6/88.1	3.5/77.3	11.3/228.6	6.2/43.1
435	1.4/38.4	9.3/31	8.8/36.1	8.3/60.6	7.8/58.4	21.7/25.2
455	5/58.6	8.7/30.4	5.3/37.6	4.1/36.7	7/59.1	11.3/31.2
475	7.9/18.9	8.9/38.4	14.5/0.4*	1.3/315.3	4.1/60.5	21.5/7.2*
495	4.8/19.4	7.6/18.4*	6.4/5.2	11.4/20.3*	13/1.6*	3.1/13.1
525	15.6/20.8	19.3/31.9	19.3/29.8	7.7/5.3	7.3/10.8	12.5/8
540	13.1/1.5*	7.7/35.1	15.8/47.6	18.2/1.9*	23.7/5*	9.7/8.2
555	19.5/4.1	1.8/142.1	0.3/8.3*	35.8/41.7	5.1/37.1	22.8/39
595	19.9/14	9.9/17.7*	14.4/10.2	17.6/23.4	9.4/12.2	9.9/7.1*
615	15.2/17.3	16.8/29	9.9/20.1	5.5/12.7*	7.9/21.3	7.5/21
630	17.1/15.7*	9.9/15.1*	6.7/20.8	8/16.1	8.7/22.4	5.5/22.1
660	10.5/22.5	8.6/33.5	9.2/40.1	1.9/18.4	5.4/32.8	2.8/17*
700	6.7/16.3	7.6/18.6	6.8/15.8*	4.3/20.1	6.1/16.1*	-

(shaded) least ΔE^*_{ab}

* least % chromaticity contrast

Table 4-19 Percentages of luminance (LC) and chromaticity contrast (CC) thresholds (LC/CC) for BVG at 70 cm and 35 cm.

CH (70 cm)	R-Y	R-G	R-B	Y-G	Y-B	G-B
410	53.6/88.9	17.2/20.4	16.2/13.2	25.5/65.6	16.7/79.6	13.8/26.7
420	40.6/50.4	14.5/8.5	17.9/12.1	26.7/26.7	17.5/22	15.7/10
435	12.9/10.8	31.4/16.7	23.7/12.7	21.3/15.8	10.2/11	18.6/9.1
455	16.7/12.9	33.8/16.4	17.8/9.5	24.2/17.2	23.4/19	32/15.9
475	32.1/14.6	37.6/6.8	52.1/20.4	26.7/11.5*	14/8.3	61.3/11
495	46.4/5.5*	10.9/2.1*	13.3/4.6*	21/18.5	23.6/2.9*	26.5/4.2*
525	16.8/1.2*	13.4/3	18.3/1.7*	15.4/1.7	7.8/3.7	21.9/3.9
540	23.2/6.4	13.8/50.8	30.3/56	56.8/0.9*	36.9/4.3	14.6/2.6*
555	23.1/12.9	2.4/107.4	0.8/6.1	42.4/31.4	5.2/38.4	26.2/34.3
595	13.7/7.5	10.2/0.4*	0/7.5	15.5/4.6	8.8/1.6*	17/6.9
615	29.1/12.3	13.6/6.6*	25.8/17.8	18.2/10.9	6/7.7*	8.1/8.8
630	16.4/6.8*	23.3/11.2	15/7.7*	23.1/12.7	29/17.3	22.9/14
660	33.2/15.3	17.6/11.9	10.9/11.5	15.4/10.2*	17.2/18.3	12.2/11.9*
700	23.2/66	53.3/357.1	43.2/291.7	41.9/330.3	42.9/436.8	-
CH (35 cm)	**R-Y**	**R-G**	**R-B**	**Y-G**	**Y-B**	**G-B**
410	63.8/76.3	5/9.3	14.9/12.7	16.7/32	21.1/46.8	7.4/16.6
420	48.1/43.5	16.2/7.2	9/3.5	29.2/23.2	10.3/10.2	13/9.5
435	13.5/9.4*	10.8/3.3	5/1.2*	11/6.8	14.3/10.4	17/8.1
455	15.5/12.1	11.1/5	17.3/8.3	7/4.8*	13.9/8.5	6.5/3.1*
475	38/14.2	11.5/5.2	58/15.5	28/10.8	16.2/8.1	65.2/7.2
495	24.2/16.7	11.2/1.6*	13.9/4.9	21.5/20.7	24.1/4.7*	26.8/4.6
525	16.3/2.6	15.8/6.5	20.1/4.2*	15.8/0.5*	14.7/4.8	23.2/3.5
540	0.4/12.4	14.1/39.2	29.9/46.4	28.5/4.8	38.2/1	7/3.4*
555	22.9/14.5	2.3/137.2	0.3/9	42/53	5.6/44.9	26/43.2
595	5.2/0.2*	9.6/0.4*	1.6/6.7	10/6.9	10.4/0.7*	19/6.9
615	5.7/3.1*	13.6/7.6	8.5/1.1*	19.4/10*	5.7/7.8	9.4/1.7*
630	16/6.3	12.3/5.9	15/8.3	24.8/12	32.2/16.7	5.6/3.4
660	8.6/3.9	11.4/5.7*	15/9.2	15.6/10.9	4.8/6.2*	10.8/12.2
700	9.8/35.9	55.3/353.3	43.2/314.3	44.4/382.3	42.9/456.1	7.7/36

(shaded)	least ΔE^*_{ab}
*	least % chromaticity contrast

Table 4-20 Summary of minimum ΔE^*_{ab} and chromaticity contrast (*) of colored pairs under following channels by participants with CVG observed at 70 and 35 cm.

CVG	Distances (cm)	R-Y	R-G	R-B	Y-G	Y-B	G-B
Short wavelength	70	**475** 495*	**495***	**410** 495*	**475** 495*	**495***	**475** 495*
	35	**475** 410*	**495***	**495** 475*	**475** 495*	**475** 495*	**475***
Medium wavelength	70	**540** 555*	**525** 595*	**595***	**595** 540*	**595** 540*	**595** 525*
	35	525 540*	**595***	**595** 555*	525 540*	525 540*	**595***
Long wavelength	70	**660***	**700***	**660** 700*	**660***	**660***	**660***
	35	**700** 630*	**700** 630*	**700***	**700** 615*	**700***	**660***

Table 4-21 Summary of minimum ΔE^*_{ab} and chromaticity contrast (*) of colored pairs under following channels by participants with BVG observed at 70 and 35 cm.

CVG	Distances (cm)	R-Y	R-G	R-B	Y-G	Y-B	G-B
Short wavelength	70	**435** 495*	**495***	**410** 495*	**475***	**475** 495*	**420** 495*
	35	**435***	**495***	**435***	**455***	**475** 495*	**455***
Medium wavelength	70	**525***	**595***	**525***	**595** 540*	**525** 595*	**595** 540*
	35	**525** 595*	**595***	**525***	**595** 525*	**595***	**595** 540*
Long wavelength	70	**630***	**615***	**660** 630*	**660***	**615***	**660** 615*
	35	**615***	**660** 630*	**615***	**660** 615*	**660***	**630** 615*

4.4 Testing the performance of optimized LED channels by simulated low vision subjects

In the previous experiment, we used the tunable LED lamp equipped with 14 LED channels. After the optimized LED channels were determined, we needed to mix these channels to obtain white light using the LEDs that were commercially available. After discussing with the LED manufacturer, we found that some optimized channels were not available. Table 4-22 shows the optimized channels for constructing lamps, according to the fastest response time, (fastest response-lamp, FR-L), the cloudy vision glasses (cloudy vision lamp, CV-L) and the blurred vision glasses (blurred vision lamp, BV-L), and the available LEDs that meet and close to our requirements. Figure 4-2, Figure 4-3 and Figure 4-4 show the SPD of the optimized LEDs and the available LEDs selected for the next experiment. These 3 lighting conditions and commercial white LED light (control) with CCT of 6000 K were used for testing their performance in terms of color discrimination. Figure 3-9 presented the spectral power distribution (SPD) of 4 lighting conditions, CCT, and chromaticity coordinates on the chromaticity diagram. The CCT of FR-L was 6000 K similar to the control white LED, whereas the CCT of CV-L and BV-L did not show because it was out of the black body locus.

Table 4-22 Optimized and selected wavelengths of 3 lighting conditions; FR-L, CV-L and BV-L

Lighting conditions	FR-L		CV-L		BV-L	
	Optimized	Selected	Optimized	Selected	Optimized	Selected
Short (nm)	410, 420, 435	425	475, 495	475	435, 495	425
Medium (nm)	555	540	595, 540	595	525, 595	525
Long (nm)	615, 630, 660	635	700, 660	700	660, 615	660

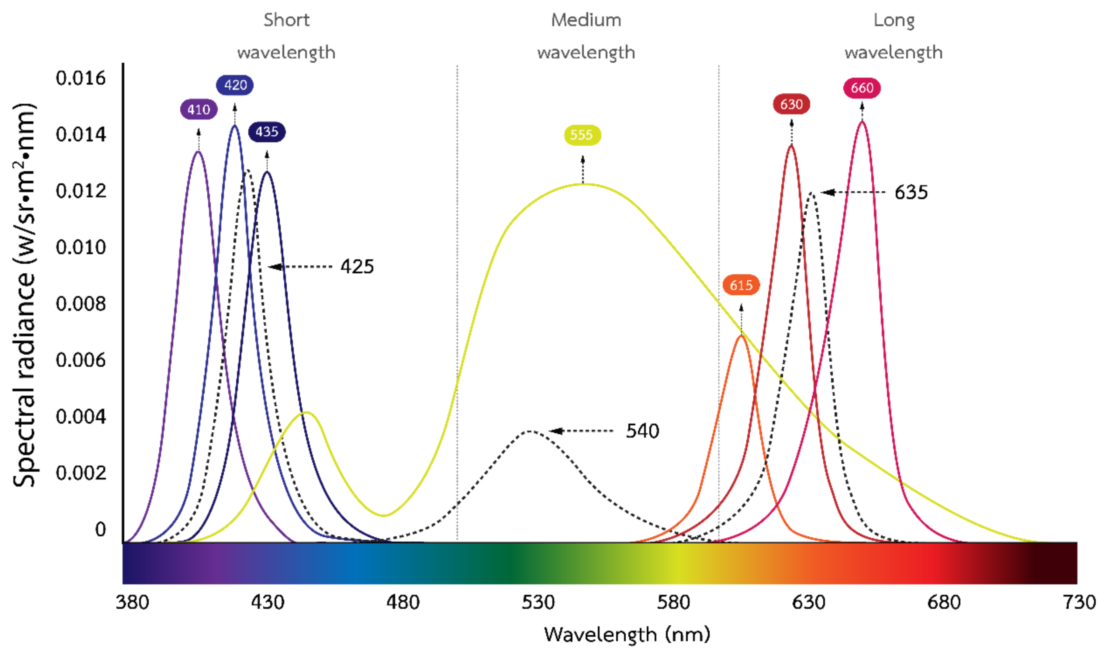

Figure 4-2 Optimized (straight line) and selected (dot line) SPD for FR-L

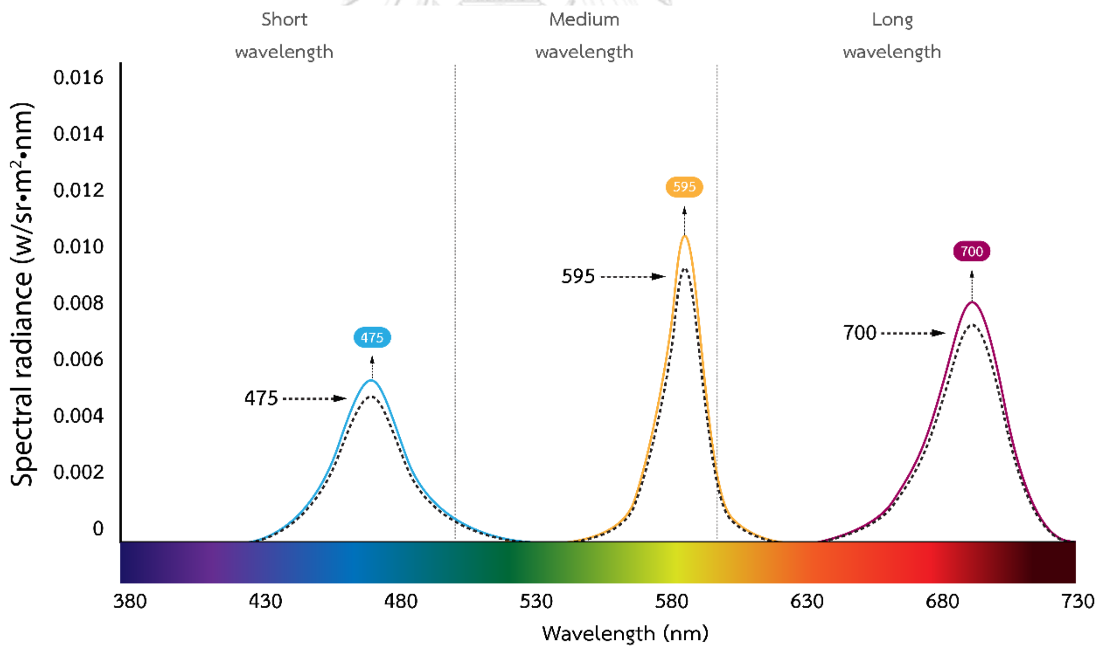

Figure 4-3 Optimized (straight line) and selected (dot line) SPD for CV-L

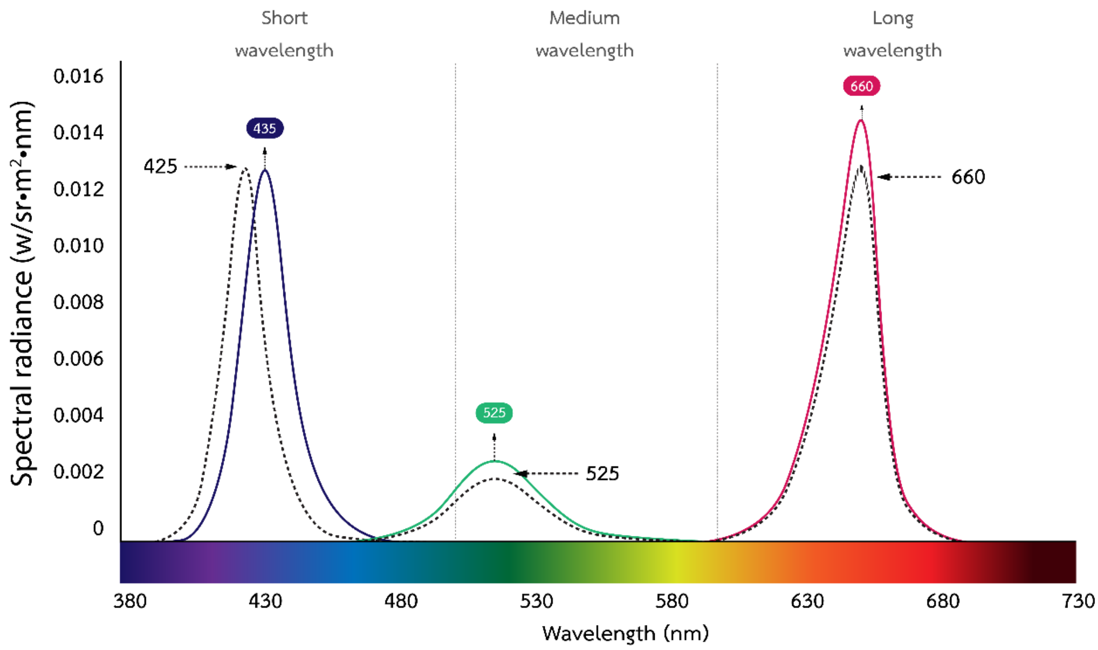

Figure 4-4 Optimized (straight line) and selected (dot line) SPD for BV-L

Table 4-23 shows the staticics of response time in 4 lighting conditions observed by participants wearing CVG and BVG. We applied the paired *t*-test and found that the response time of the optimized lightings, CV-L and BV-L, significantly was lower than the control lighting, LED white ($p<.05$) as shown in Table 4-24. The response time under FR-L was not significatly different from the control light.

Table 4-23 Summary of statistics of response times in 4 lighting conditions observed by participants wearing both types of low vision glasses.

Time (s)	W-L		FR-L		CV-L		BV-L	
	CVG	BVG	CVG	BVG	CVG	BVG	CVG	BVG
Min	542	489	586	453	672	460	408	421
Mean	941	985.6	972.2	774.6	897.1	726.5	887.6	741.2
±SD	±230.9	±417.9	±276.3	±182.3	±162.6	±168.3	±298.7	±259.9
Max	1383	2139	1772	1338	1278	1071	1593	1573

Table 4-24 The *t*-test results comparing between lighting conditions on total response time for judging colored pairs by participants with simulated low vision glasses.

Lighting conditions		t	Df	P-value
W-L	FR-L	1.35	72.504	0.1782
W-L	CV-L	2.51	60.825	0.0147 *
W-L	BV-L	2.14	76.206	0.0354 *
FR-L	CV-L	1.25	71.562	0.2165
FR-L	BV-L	0.99	76.757	0.3307
CV-L	BV-L	-0.04	66.705	0.9620

Table 4-25 and Table 4-26 are presented the summary of statistics of total response time in color discrimination for 2 types of glasses and the *t*-test results for comparing both types of glasses irrespective of lighting conditions. The average total response time on color discrimination on BVG (M=807, SD=290.1) was significantly lower [t(153.76)=2.766, p=0.006] than CVG (M=924.5, SD=245.3). This result was supported by the previous experiment (Table 4-13) which indicated that the BVG perceived the color difference better than CVG. The CVG has visual acuity lower than BVG 0.02 unit. This slightly contribute to the results.

Table 4-25 Summary statistics of total response time on both types of glasses

Time (s)	CVG	BVG
Min	408	421
Mean	924.5	807
±SD	±245.3	±290.1
Max	1772	2139

Table 4-26 The *t*-test results of CVG and BVG on response time in judging colored pairs.

Types of glasses		t	Df	P-value
CVG	BVG	2.7663	153.76	0.006 **

The results of 2-way ANOVA (Table 4-27) shows that the response time eas significantly affected by the lighting conditions [F(3,1520)=22.945, p=0.000], types of glasses [F(1,1520)=62.838, p=0.000] and the main color in the experiment [F(9,1520)=1.971, p=0.039]. Also, the combined effect of lighting conditions and types of glasses was significatly [F(3,1520=13.784, p=0.000)].

Table 4-27 Two-way ANOVA for the effect of lighting conditions, types of glasses and main colored pairs on the response time

Time (s)	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Lighting conditions (L)	3	60497	20166	22.945	0.000 ***
Types of glasses (TG)	1	55225	55225	62.838	0.000 ***
Main color (MC)	9	15589	1732	1.971	0.0391 *
L:TG	3	36342	12114	13.784	0.000 ***
L:MC	27	19021	704	0.802	0.7541
TG:MC	9	4017	446	0.508	0.8697
L:TG:MC	27	6618	245	0.279	0.9999
Residuals	1520	1335844	879		

Next, we present as analysis of the psychophysics results of judging colored pairs under 4 lighting conditions and 2 types of low vision glasses (Figure 4-5). The percentage of the group "seeing the color difference" through BVG was higher than CVG in all of the lightijng conditions. The BV-L was lighting that enhancing color discrimination better than other lighting. Under BV-L, the percentage of group "seeing the color difference" through BVG (91%) was higher than other lighting condition because the wavelengths in BVL were selected from the color channels were provided with the minimum color differences that the participants with BVG perceived. Similar to CV-L, the percentage of the group “seeing the color difference” through CVG (63%) was higher than W-L (56%) and FR-L (55%) except for BV-L (64%). Data colledted shows that the 3 lighting conditions with the combination of wavelengths obtained from the previous experiment are better than commercial white lighting in terms of color discrimination.

Figure 4-6, Figure 4-7, Figure 4-8 , and Figure 4-9 demonstrate percentages of participant, with 2 types of simulated low vision glasses, who judged main color pair samples under W-L, FR-L, CV-L and BV-L respectively. On average, the BV-L shows the best performance with the highest percentages of “see the difference” in 10 main colors, then the CV-L, FR-L and W-L respectively.

Under BV-L, more than 80% of participants with BVG could see the difference in all main pairs. The participants with CVG could not discriminate R pairs and BG pairs well (<50%) compared to other colors.

Under CV-L, more than 80% of participants with BVG could see the difference in all main pairs except for Y and B. The participants with CVG could not discriminate B well (<50%) compared to other colors.

Under FR-L, more than 80% of participants with BVG could see the difference in all main pairs except for RG, G and BG. The participants with CVG could not discriminate R and BG well (<50%) compared to other colors.

Under W-L, only GY and P could be perceived the difference by more than 80% of participants with BVG. Through CVG, YR, BG and R could not be perceived well (<50%) by participants.

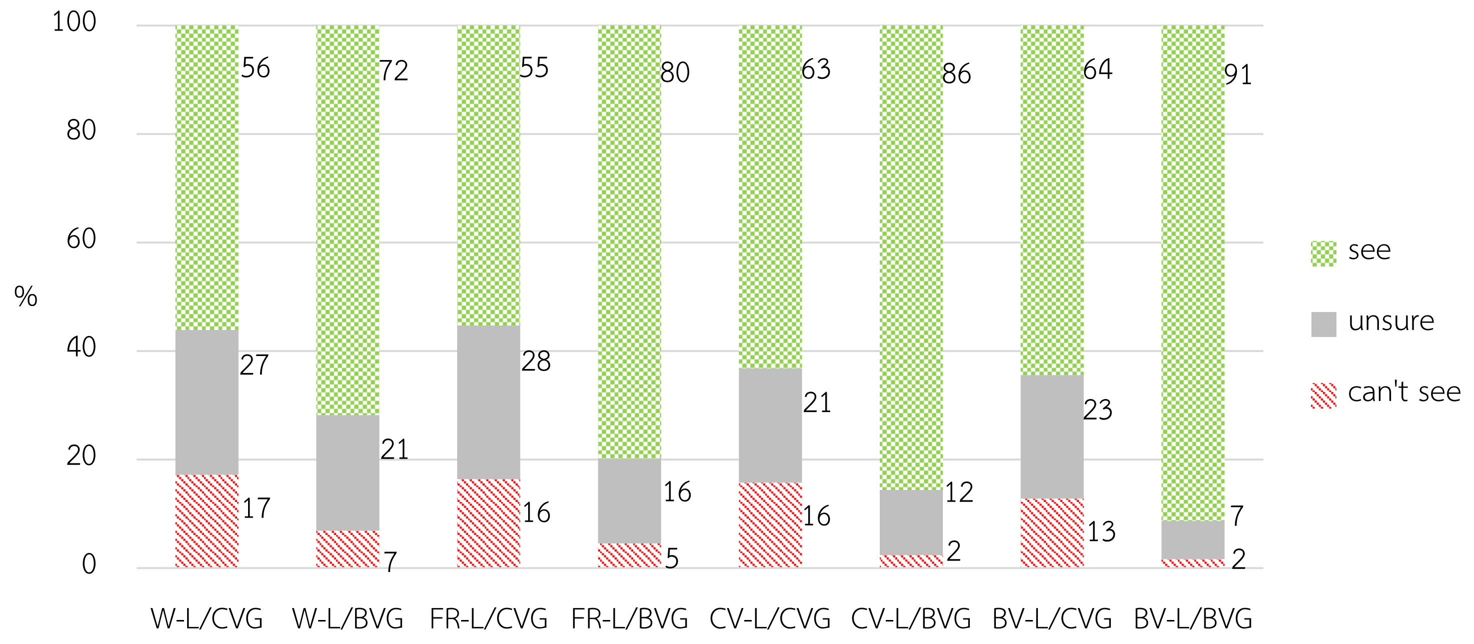

Figure 4-5 The percentages of participant with 2 types of simulated low vision glasses (CVG and BVG) judged main colored pairs under W-L, FR-L, CV-L and BV-L.

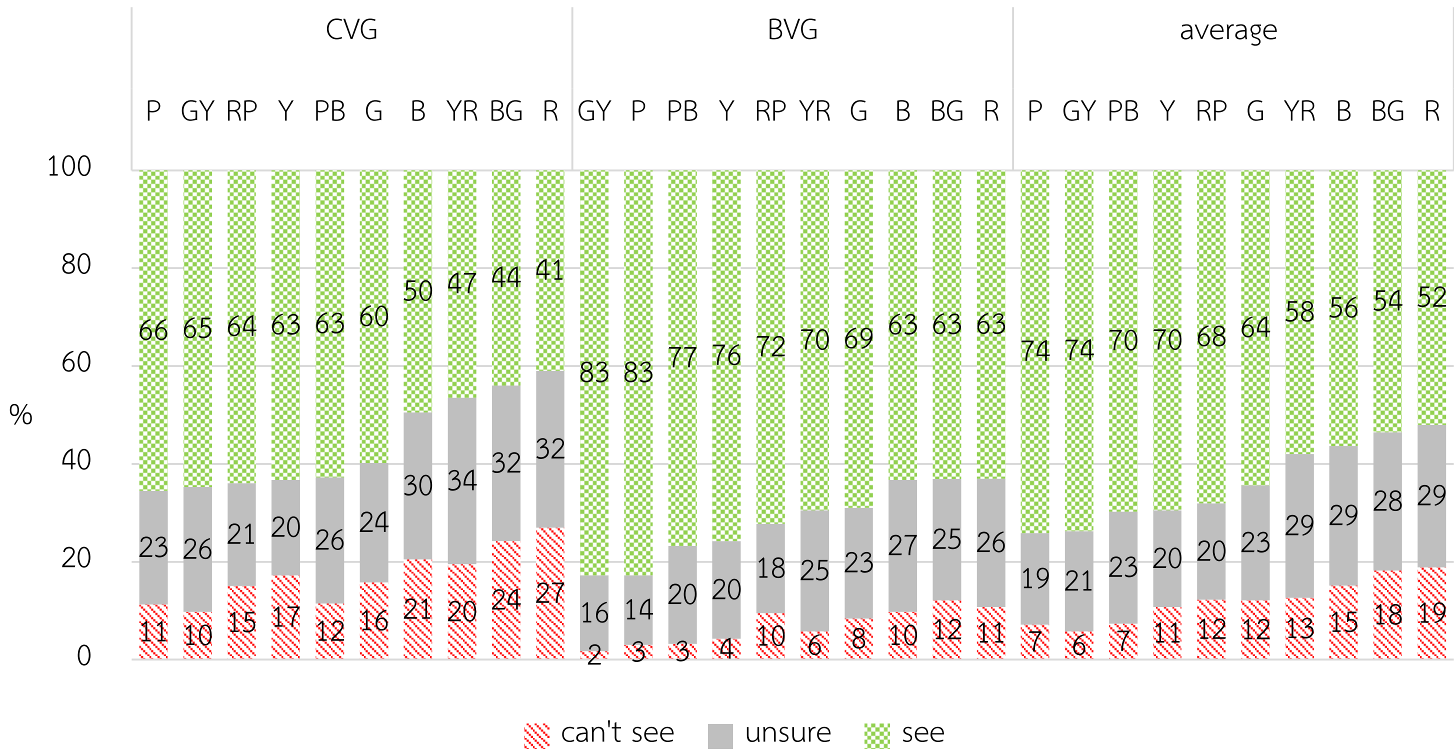

Figure 4-6 The percentages of participant with 2 types of simulated low vision glasses (CVG and BVG) judged main colored pairs under W-L.

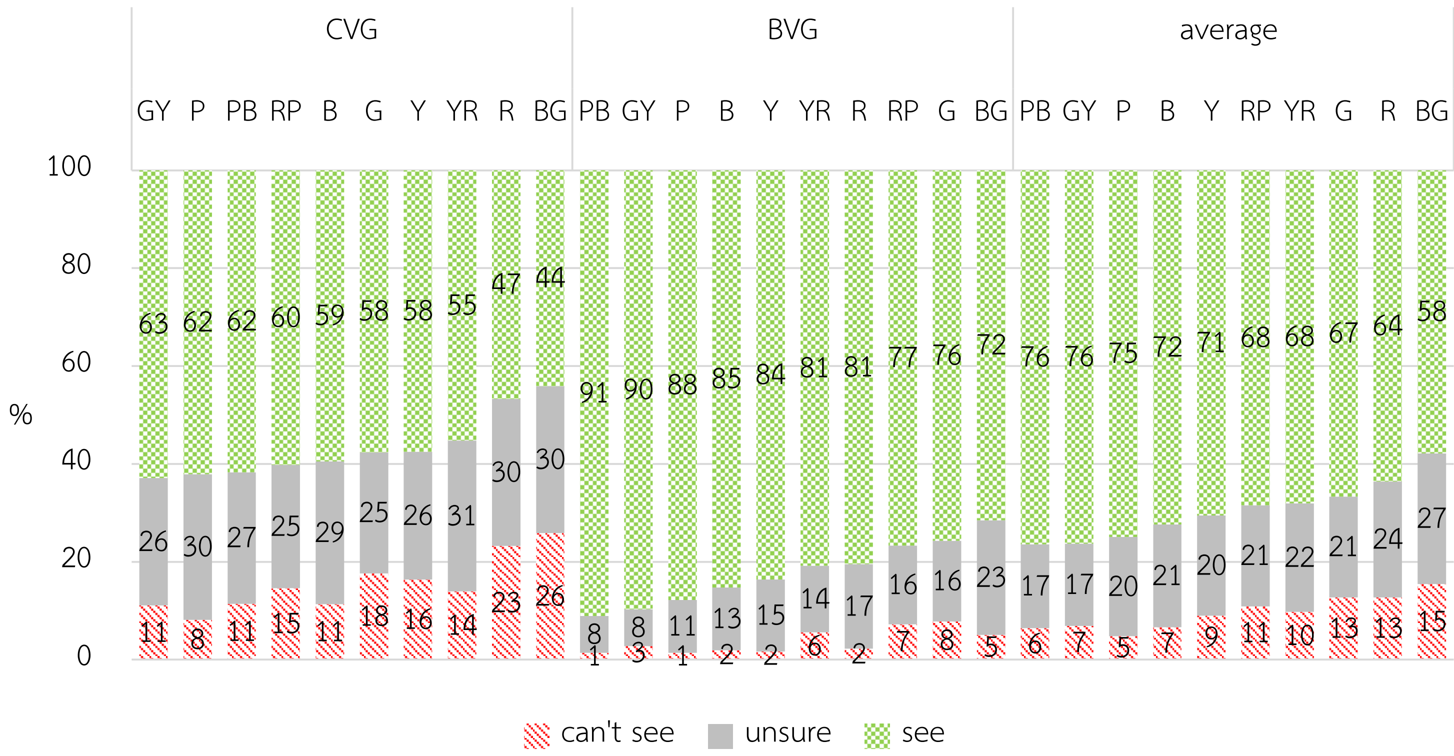

Figure 4-7 The percentages of participant with 2 types of simulated low vision glasses (CVG and BVG) judged main colored pairs under FR-L.

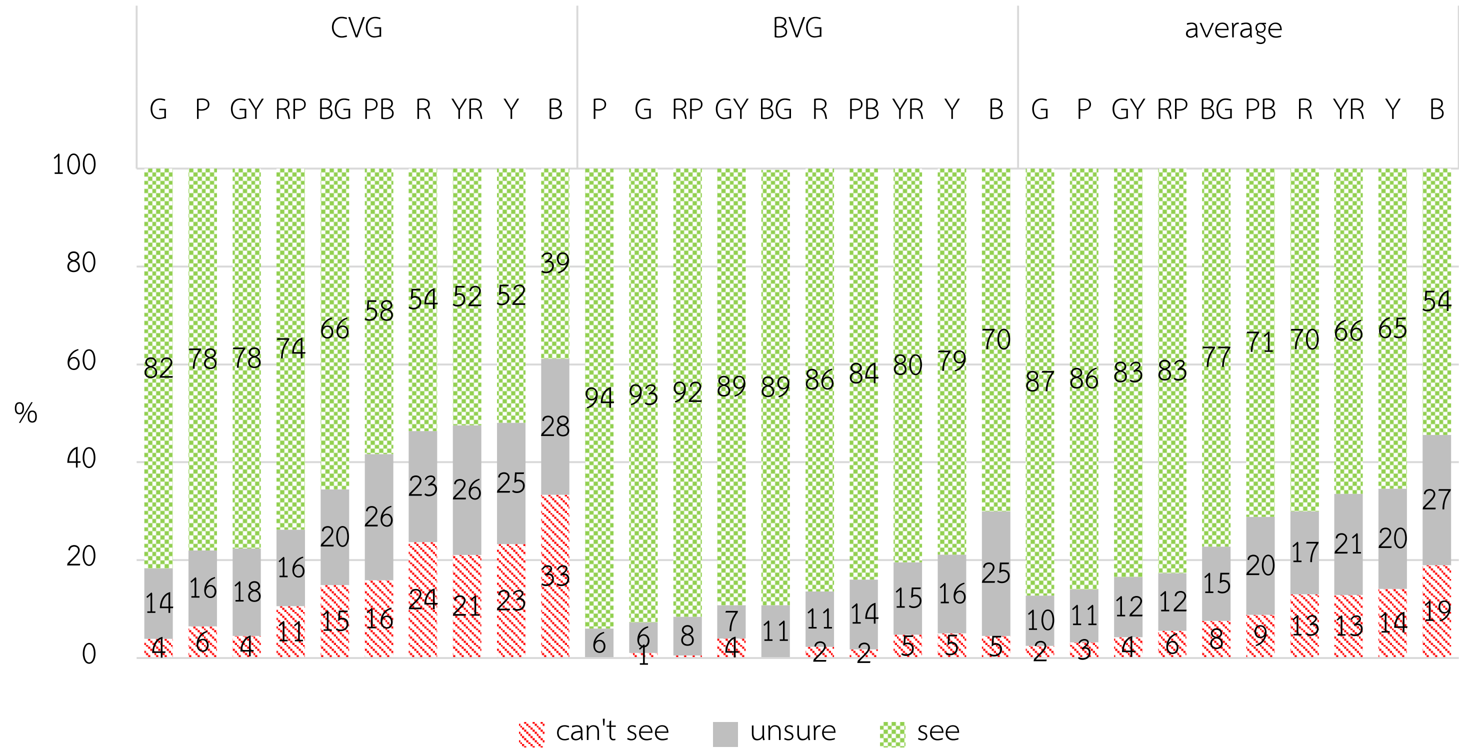

Figure 4-8 The percentages of participant with 2 types of simulated low vision glasses (CVG and BVG) judged main colored pairs under CV-L.

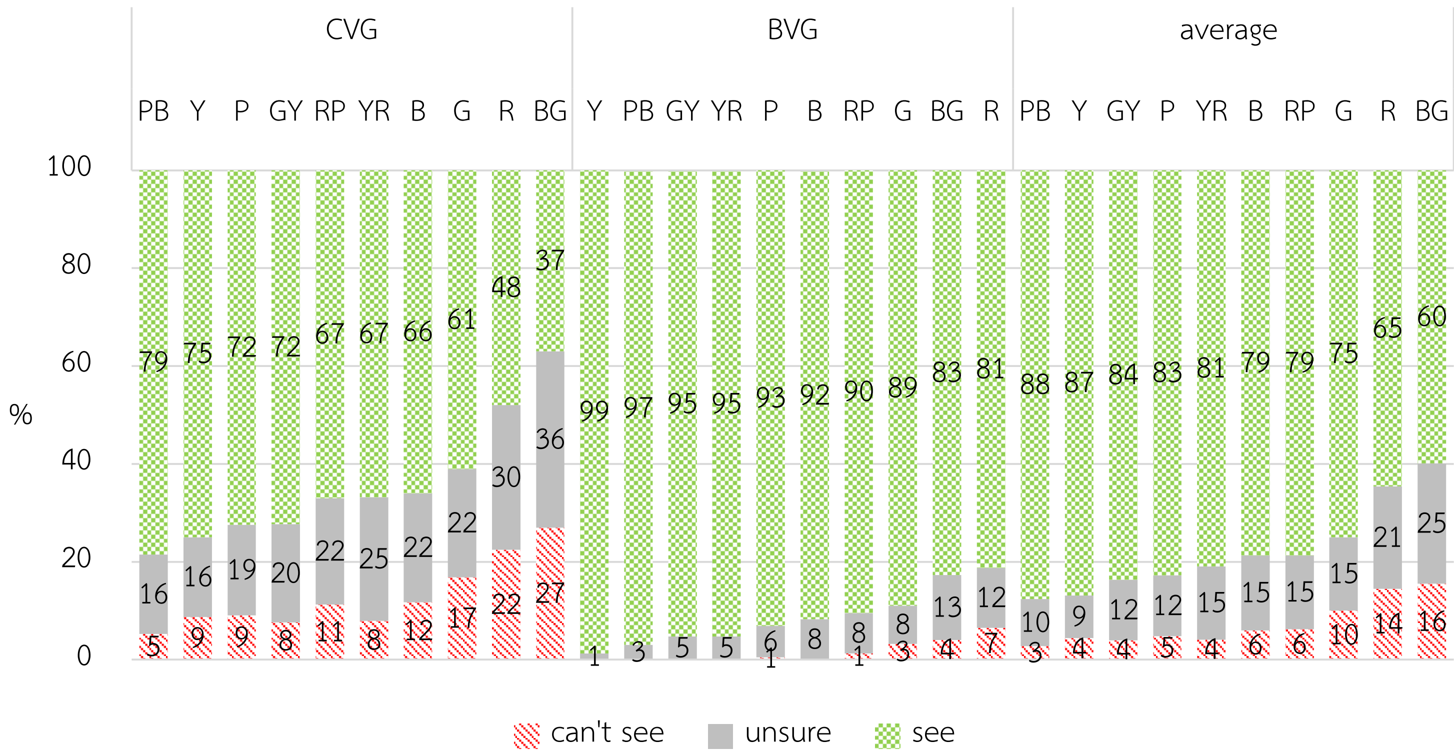

Figure 4-9 The percentages of participant with 2 types of simulated low vision glasses (CVG and BVG) judged main colored pairs under BV-L.

The color difference (ΔE^*_{94}) ranges of colored pair sample judged into 3 groups under W-L, FR-L, CV-L and BV-L is presented in Figure 4-10, Figure 4-11, Figure 4-12 and Figure 4-13 respectively. In addition to the percentages of participants who categorized the pairs into 3 groups, we analyzed the ΔE^*_{94} between the pairs of individual groups. The range of ΔE^*_{94} of each category overlapped. We selected the maximum ΔE^*_{94} of the "unsure of seeing the difference" as a threshold for a types of low vision glasses under each lighting condition. The maximum ΔE^*_{94} was the range of the "see the difference". The lower the threshold the better the capability in contrast enhancement of the light. For the simulated BVG, the thresholds under W-L, FR-L, CV-L and BV-L were 7.7 (23.2%), 7.6 (8.4%), 5.0 (9.6%) and 1.5 (0.3%) respectively. For the simulated CVG, the thresholds under W-L, FR-L, CV-L and BV-L were 12.7 (23.4%), 11.2 (19.9%), 12.7 (21.8%) and 9.7 (11.5%) respectively. The chromaticity contrast (%) also shows the same trend. It shows that the BV-L could enhance color contrast in both types of low vision glasses.

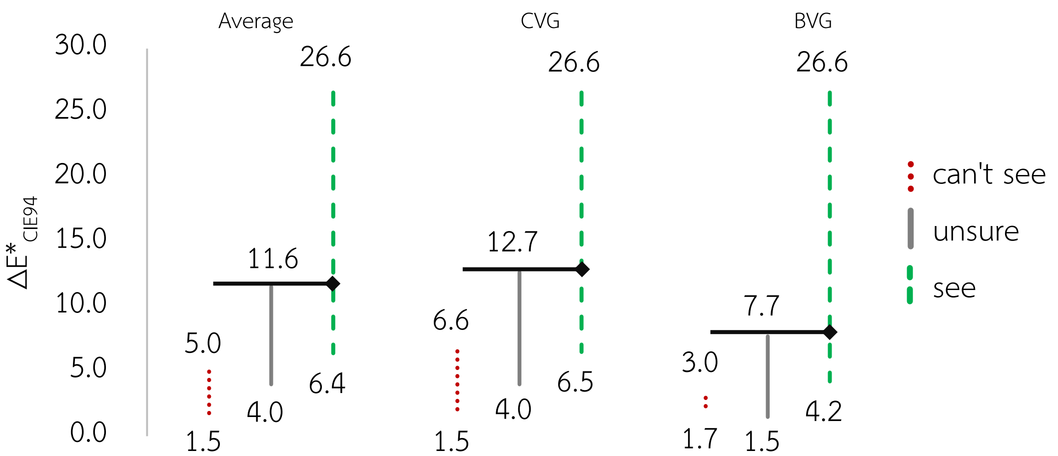

Figure 4-10 The color difference (ΔE^*_{94}) ranges of colored pairs that judged into 3 groups under W-L were shown in the average of data by the participants wearing simulated low vision glasses.

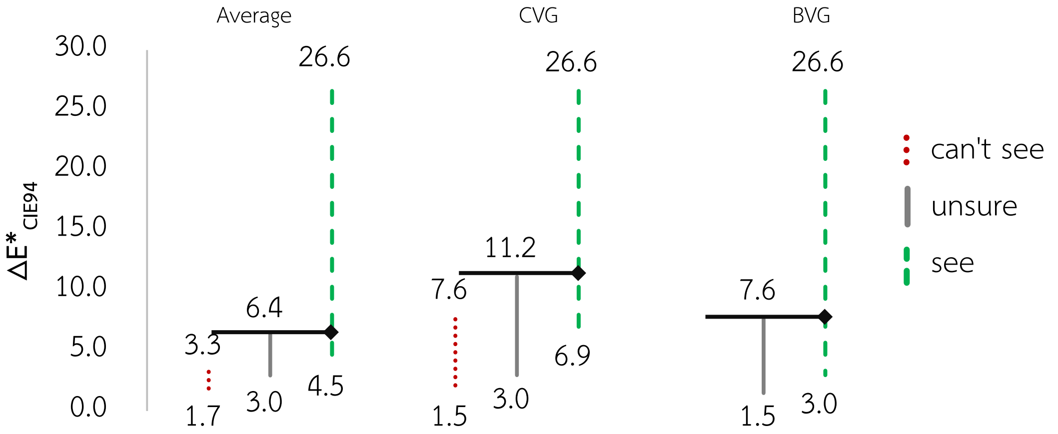

Figure 4-11 The color difference (ΔE*$_{94}$) ranges of colored pairs that judged into 3 groups under FR-L were shown in the average of data by the participants wearing simulated low vision glasses.

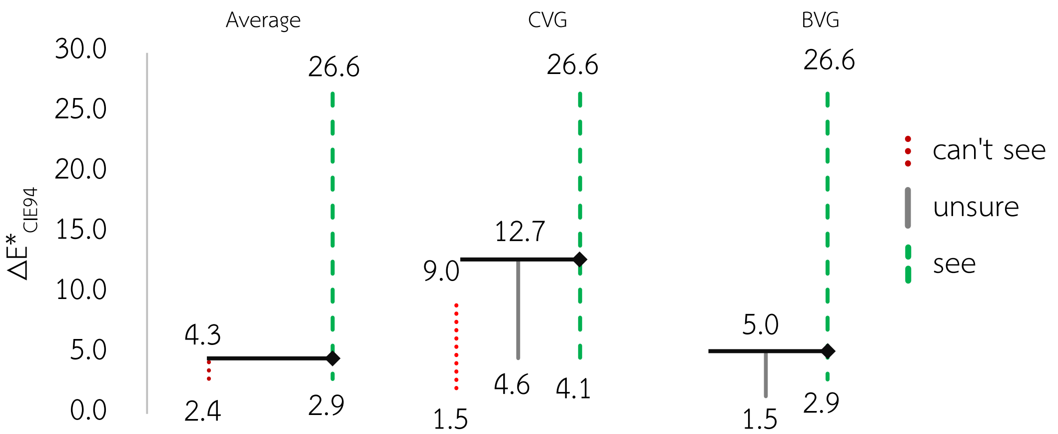

Figure 4-12 The color difference (ΔE*$_{94}$) ranges of colored pairs that judged into 3 groups under CV-L were shown in the average of data by the participants wearing simulated low vision glasses.

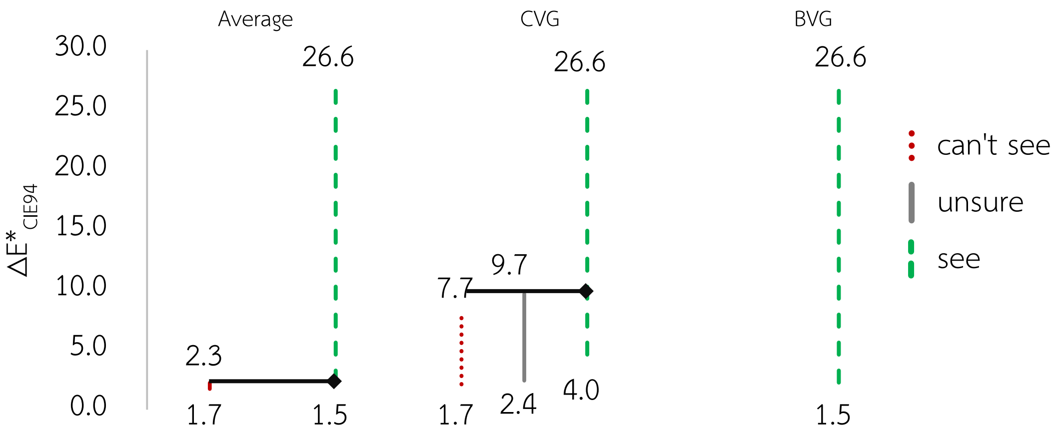

Figure 4-13 The color difference (ΔE^*_{94}) ranges of colored pairs that judged into 3 groups under BV-L were shown in the average of data by the participants wearing simulated low vision glasses.

4.5 Testing the performance of optimized LED channels by the patients with low vision

The summary of statistics of total response time under 3 lighting conditions is shown in Table 4-28. The average total response time on BV-L (M=967.4, SD=388.2) was lower than FR-L (M=1109, SD=414.2) and CV-L (M=1041.3, SD=376.5). The paired *t*-test presented that the response time under BV-L was not significantly different from under other lighting conditions. The result from the 1-way ANOVA was shown that the total response time was not significantly affected by lighting conditions as shown in Table 4-29 [F(2,27)=0.324, p=0.726]. The 2-way ANOVA of the effects of lighting conditions and main colors on response time shows that there is not a significant effect on response time (p<.05). The results are different from performing by the participants wearing low vision glasses. The percentages of the group seeing the difference are the major factor for considering lighting conditions.

Table 4-28 Summary of statistics of total response time in FR-L, CV-L and BV-L for participants with low vision

Time (s)	FR-L	CV-L	BV-L
Min	583	553	439
Mean±SD	1109±414.2	1041.3±376.5	967.4±388.2
Max	1736	1574	1514

Table 4-29 One-way ANOVA of the effect of lighting conditions (L) on response time for judging colored pairs by participants with low vision.

Time (s)	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Lighting conditions (L)	2	100317	50158	0.324	0.726
Residuals	27	4275896	154663		

The percentage of participants with low vision pbtained from judging colored pairs into 3 groups under 3 lighting conditions is shown in Figure 4-14. The percentages of the group “seeing color difference” under CV-L (53%) was lower than FR-L (62%) and BV-L (66%). The BV-L still gave a better performance than FR-L and CV-L respectively which is similar to the results perfomed by the participants wearing the simulated low vision glasses.

Figure 4-15 presents the percentages of participants with low vision judged 10 main colored pairs under 3 lighting conditions. Next, we analyzed the capability of lighting conditions in enhancing colored pairs. Figure 4-15 shows that the BG and B paired with the neighbor colors could not be enhanced well under are lighting conditions. The YR paired with the neighbor colors could not be enhanced well under CV-L but the BV-L and the FR-L enhanced the contrast of the YR pairs.

The color difference (ΔE^*_{94}) threshold Figure 4-16 shows that the RF-L gave the minimum value of 7.7, then BV-L of 9.7 and CV-L of 12.7. Comparing the results obtained from the participant with low vision glasses (VA=0.06-0.08) and from the patients with low vision (0.10-0.29), the maximum volot difference (ΔE^*_{94}) thresholds under FR-L for “low vision glasses” vs “patients” were 11.2 and 7.7, under CV-L were 12.7 and 12.7 and under BV-L were 9.7 and 9.7.

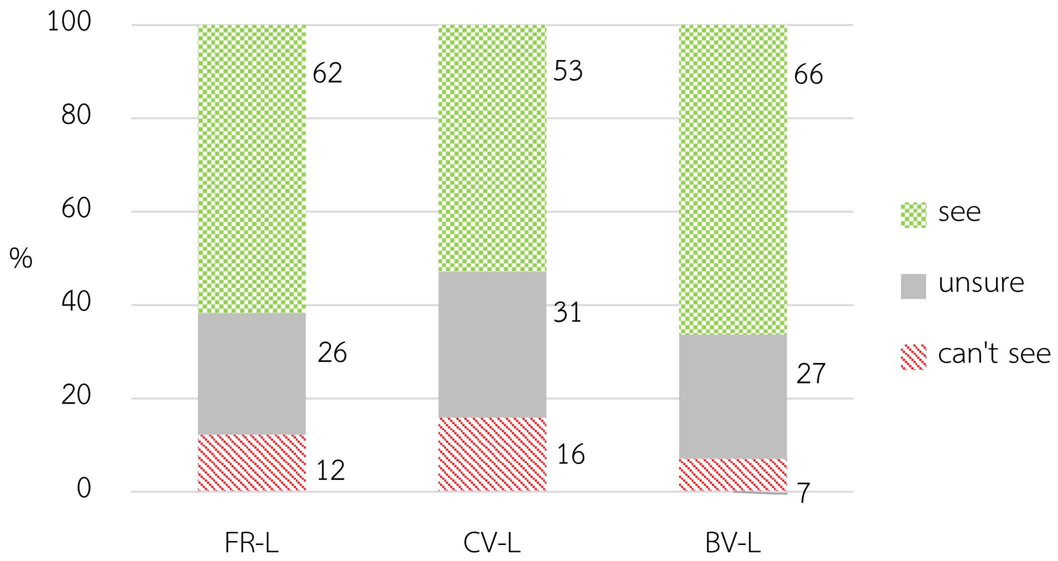

Figure 4-14 The percentages of participants with low vision judged colored pairs into 3 groups under FR-L, CV-L and BV-L.

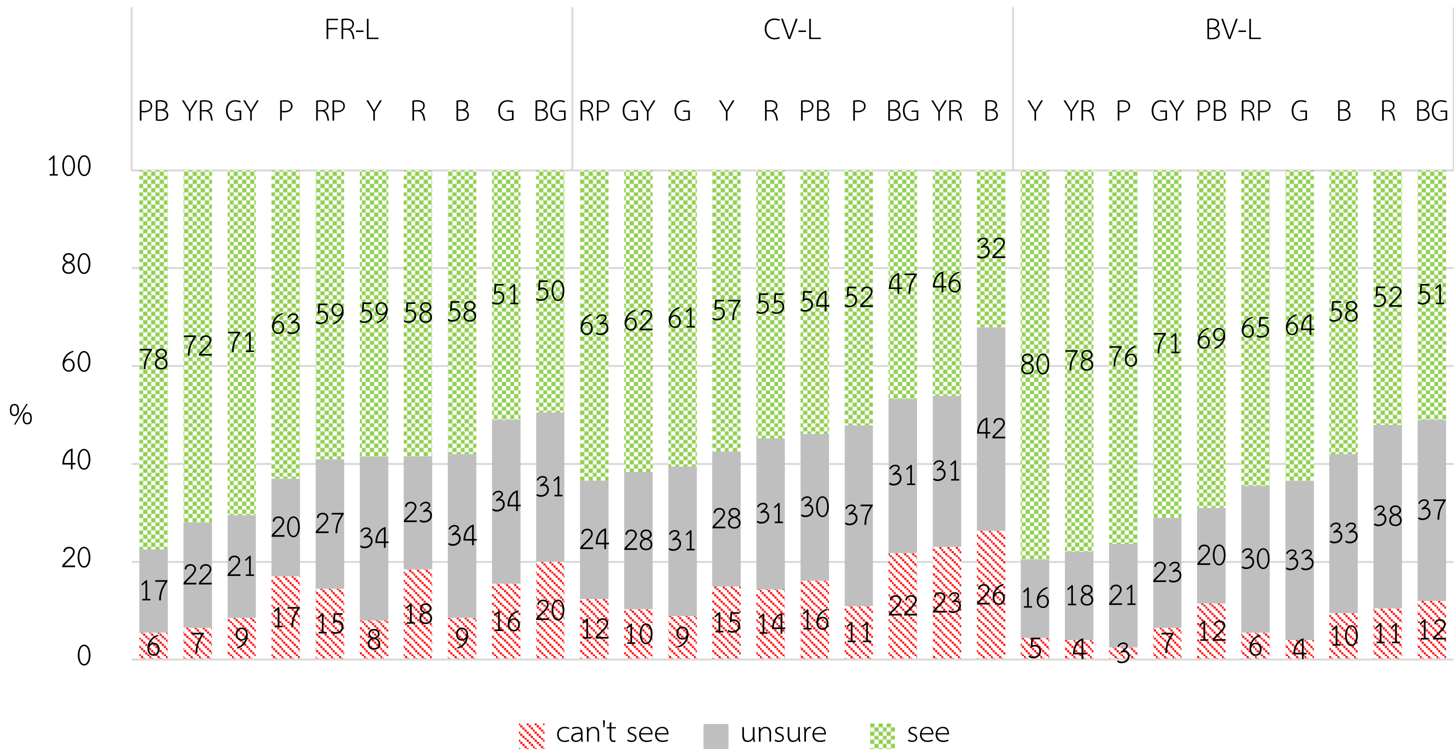

Figure 4-15 The percentages of participants with low vision judged main colored pairs into 3 groups under FR-L, CV-L and BV-L.

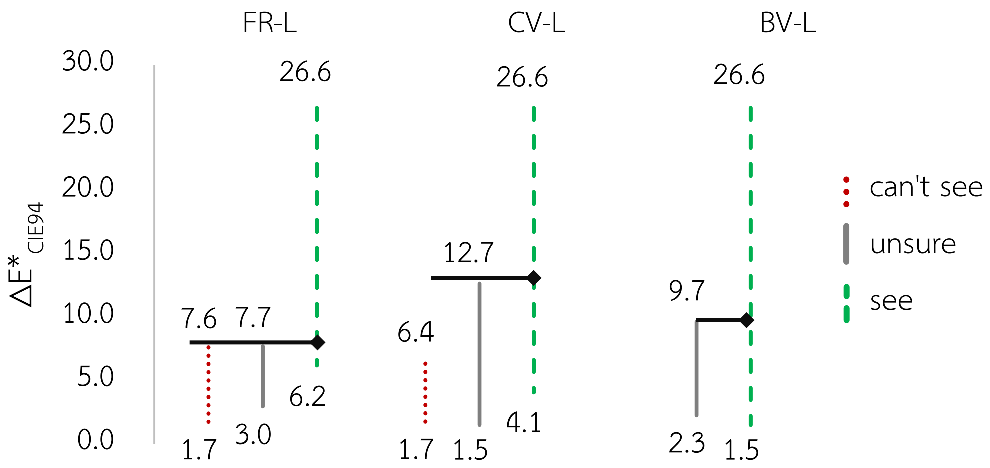

Figure 4-16 The color difference (ΔE^*_{94}) ranges of colored pairs judged into 3 groups under FR-L, CV-L and BV-L by participants with low vision.

CHAPTER 5
CONCLUSION

5.1 Conclusion

5.1.1 Mobility and activities

The levels of illuminance and CCT employed in this study did not influence the walking speed of the low vision subjects having blurred/blurred, blurred/blind vision and the elderly wearing narrow visual field/blind glasses. On the other hand, the walking speed of the low vision was slower than those with blurred/blind vision at low illuminance. The walking speed of the elderly wearing blurred/blind vision glasses was slower than the low vision at higher illuminance. The reason for this might be that the adaptation to the low vision glasses of the elderly in short period was less likely. Another reason was that the blurred/blind vision glasses could cause the diffused light at the lens, consequently reduced the walking speed. In comparison to wearing the narrow visual field glasses, the elderly could move their heads to scan the surrounding environment, hence the variations in the illuminance and CCT did not affect their walking speed. The elderly subjects with naked eye, having the average age of 66.08±3.73, exhibited better mobility than the low vision in the highest and the lowest sessions. Furthermore, they did not show the unintentional contact with obstacle.

The participant's performance on accuracy activities between groups describes the visual ability to see details of the targets. The participants with low vision and the elderly with simulated low vision glasses were examined on accuracy activities. The results indicated the elderly with low vision glasses did the activity with less accurate than the low vision people. This might be clarified by adaptation of visibility on their surrounding and probably maintain some activities in daily life similar to people with normal vision, and also better than the elderly who did not familiar on their simulated low vision glasses. Nevertheless, the elderly with narrow visual field/blind low vision glasses showed better performance than the elderly with blurred/ blind glasses on visibility. The accuracy activities testing has not taken at various illuminance and CCT which might affect on the discrepancy scale. It is possible that other levels of illuminance may provide better or lower discrepancy scale. In addition, it is important to emphasize that the VA of participant is the main factor which should be considered.

5.1.2 Obtaining spectral reflectance of Munsell color under LED with different spectral power distributions

The luminance contrasts of 6-hue pairs were obtained by 14 LED channels. All data were collected and measured by the equipment using repeated measurement. The color samples were selected following the opponent color theory (Gulrajani, 2010) using a middle value and chroma. The luminance of channel 555 nm was higher than other channels because the spectral power distribution (SPD) of the channel almost covers the visible range which more energy than different channels. However, other channels except for 555 nm provided a narrow brand of SPD. This case of channel 555 nm with a wide range of SPD might affect the visual perception of target and may interfere other channels.

5.1.3 Determination of LED channels enhancing the contrast of selected hues for simulated low vision subjects

The optimized spectral power distributions of supplement light sources for people with low vision were obtained by a combination of wavelengths or LED channels. The findings had 3 suitable combinations of lighting conditions for supplement light. The first one was the fast response lighting conditions (FR-L). It was selected based on short response time in color discrimination. The second one was the cloudy vision lighting condition (CV-L). It was chosen based on it capability in enhancing color discrimination of the pairs with less ΔE^*_{ab} or less chromaticity contrast when viewed through CVG. Lastly, it was the blurred vision lighting condition (BV-L); the selection principle was similar to the second one but viewed through BVG. The lighting conditions were the mixing of 3 LED channels from 3 regions of wavelengths and the intensity each channels were adjusted to produce white light with CCT of approximately 6000 K. The different wavelengths in lighting conditions may result in different color perceptions.

5.1.4 Testing the performance of optimized LED channels by simulated low vision subjects

The performance of enhancing color discrimination of 3 lighting conditions from the previous experiment was verified and compared with commercial white lighting. The results showed the 3 lightings were better than commercial white light (W-L) in terms of total response time and percentage of participants in perceiving color difference. For the response time, the CV-L and BV-L were significantly lower than W-L but the CV-L was not significantly different from BV-L. There was a similar trend in the response time in each main color. It was statistically affected by lighting conditions, types of glasses, main color and lighting conditions. In percentages of seeing different color, the BV-L had higher percentages of seeing difference of color than other lighting conditions on both types of glasses. Nevertheless, the visual perception with CVG under CV-L had a similar percentage as that with CVG under BV-L. This indicates that the participants perceive color difference better under CV-L and BV-L when comparing with W-L and FR-L. The main colored pairs prepared from Munsell color had different percentages of being driscriminated under CV-L and BV-L. The color consists of R-PR-P and BG-G were efficiently enhanced by CV-L. The BV-L improved perception of contrast of the colored pairs: Y-YR and PB-B. The findings show that the different combinations of wavelengths of both lightings had an effect on discrimination of colored pairs in the participants with simulated low vision glasses because different SPDs were absorbed and reflected by colored object differently. Under CV-L and BV-L, the lower average color difference thresholds could be obtained, compared to FR-L and W-L. The color difference range perceived by the BVG under BV-L covered color difference of all colored pairs. This shows that the color perception under BV-L is enhanced by the combination of optimized wavelengths. These findings demonstrate that CV-L and BV-L efficiently enhance color discrimination for people with low vision, although FR-L is a good performance compared to W-L, it has lower capability in color discrimination than other lighting conditions. The testing used simulated low vision glasses that might give the results different from the low vision participants.

5.1.5 Testing the performance of optimized LED channels by the patients with low vision

The performance of enhancing color discrimination of 3 lighting conditions was tested with people with low vision. The results showed that the BV-L gave less response time than FR-L and CV-L but not significantly different. The total response time was not significantly affected by lighting conditions, the main color, and the combined effect of lighting conditions and main color. This indicates that the FR-L, CV-L and BV-L may provide similar visual perception in people with low vision because the participants took time equally for observing and judging all colored pairs. The percentage of seeing color difference under CV-L was lower than FR-L and BV-L respectively. However, the percentages of all lighting were over 50%. These findings suggest that improving the lighting condition for people with low vision will enhance the performance of color discrimination and increase the color contrast between 2 areas of similar colors. The colors of Y-YR and P-PB-B were enhanced by BV-L; a similar finding found in the participants wearing simulated low vision glasses. Similarly, for the threshold of color difference, the results showed that the CV-L had a higher threshold compared to FR-L and BV-L respectively. These cases are explained by the different visual acuity of participants in the experiment. The patients who came to follow up the symptom at the hospital had variations in visual acuity, age and ability to make decisions due to certain symptoms. These causes may affect the results. However, this results in part of the experiment indicated that the BV-L provided better color discrimination for the low vision people which corresponds to the previous experiment with simulated low vision glasses. The limitation on this part of the experiment has various visual acuity on participants and better than VA of simulated low vision glasses from the previous experiment. It is possible to control the VA on participants with low vision but it may take a long time for screening eligible patients.

5.2 Suggestion

The selected wavelengths of the optimized LED channels in the experiment should be equal to the optimized wavelength. The commercial LED white light should be used for comparing the performance of optimized lighting in patients with low vision. The criteria of visual acuity (VA) of patients with low vision supposed to be equal the simulated low vision glasses. As the future work, the illuminance levels and correlated color temperature (CCT) of the optimized light sources should be varied for different activities in people with low vision.

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APPENDICES

Appendix A

Table A-1 Average luminance (cd/m^2) of floor obstacle, hanging obstacle, and walls under 7 lighting conditions

Luminance (cd/m^2)							
illuminance (lx)	1000		100		10		LED off
CCT (K)	6500	3000	6500	3000	6500	3000	
Floor obstacle	24.63 ±2.71	25.46 ±2.02	3.07 ±0.32	3.01 ±0.3	0.68 ±0.14	0.61 ±0.15	0.38 ±0.11
Hanging obstacle	41.64 ±10.11	42.23 ±10.42	5.23 ±1.21	5.58 ±1.03	0.91 ±0.18	0.78 ±0.17	0.18 ±0.1
Walls	160.05 ±10.04	161.86 ±9.32	20.73 ±1.33	19.52 ±1.81	3.57 ±0.45	3.42 ±0.28	0.49 ±0.12
Uniformity illuminance (U_o)	0.64	0.69	0.75	0.71	0.72	0.68	-

Table A-2 Number of low vision participants with types of eyes side

Participants with low vision (n)	Left eye	Right eye
1-24	Blurred	Blurred
25-32	Blindness	Blurred
33-41	Blurred	Blindness
42	Blurred	Center blind
43	Center blind	Center blind
44	Narrow	Blindness
45	Blurred	Center blind
46	Center blind	Center blind
47	Narrow	Blurred
48	Narrow	Blindness
49	Blurred	Narrow
50	Narrow	Blindness

```
const int AR=A0;
const int AG=A1;
const int AB=A2;
const int LedRcolor=3;
const int LedGcolor=5;
const int LedBcolor=6;
int ValRcolor = 0;
int ValGcolor = 0;
int ValBcolor = 0;
int BieRcolor = 255;
int BieGcolor = 255;
int BieBcolor = 255;
void setup()
{
Serial.begin(9600);
pinMode(LedRcolor, OUTPUT);
pinMode(LedGcolor, OUTPUT);
pinMode(LedBcolor, OUTPUT);
}
void loop()
{
ValRcolor = analogRead(AR);
BieRcolor = (ValRcolor)/4;
ValGcolor = analogRead(AG);
BieGcolor = (ValGcolor)/4;
ValBcolor = analogRead(AB);
BieBcolor = (ValBcolor)/4;
analogWrite (LedRcolor,BieRcolor);
analogWrite (LedGcolor,BieGcolor);
analogWrite (LedBcolor,BieBcolor);
}
```

Figure A-1 Arduino code for control illuminance levels in walking path

Appendix B

Table B-1 Average, min, max and uniformity illuminance of 14 LEDs channels

Channels (nm)	Illuminance	Min	Max	U_o
410	2.7±0.72	1.7	3.8	0.64
420	6.2±1.61	3.6	8.5	0.58
435	14.8±3.04	10.2	21.1	0.69
455	54.4±10.74	39.9	77.7	0.73
475	65.6±15.81	41.1	92.7	0.63
495	280.2±54.73	209.4	396.6	0.75
525	204.5±46.23	131.2	288.6	0.64
540	381.1±66.97	290.7	538.1	0.76
555	2134.2±385.86	1640	2921	0.77
595	334.5±77.04	235.2	471	0.70
615	160.5±44.2	87.8	225.9	0.55
630	173.5±45.1	104	247.5	0.60
660	66.4±15.1	42	94.6	0.63
700	5.2±1.24	3.5	7.6	0.67

Table B-2 Luminance, CIEx, CIEy, u',v' and spectral power distribution of 14 LEDs channels

W	Channels													
	410	420	435	455	475	495	525	540	555	595	615	630	660	700
L	0.34	0.89	2.44	4.86	16.26	19.19	82.1	59.62	110.72	619.18	100.09	49.94	50.5	20.08
x	0.175	0.171	0.169	0.164	0.145	0.116	0.084	0.186	0.274	0.399	0.588	0.663	0.698	0.718
y	0.022	0.014	0.013	0.016	0.042	0.126	0.452	0.703	0.662	0.474	0.411	0.337	0.301	0.280
u'	0.240	0.242	0.240	0.229	0.181	0.108	0.041	0.067	0.106	0.203	0.349	0.464	0.535	0.583
v'	0.067	0.043	0.040	0.049	0.118	0.264	0.493	0.572	0.573	0.541	0.547	0.530	0.520	0.512
380	1.14	0.29	0.16	0.13	0.07	0.04	0.02	0.08	0.14	0.04	0.02	0.03	0.00	0.00
390	10.00	0.77	0.20	0.08	0.01	0.03	0.00	0.02	0.15	0.07	0.00	0.02	0.00	0.00
400	56.16	4.83	0.74	0.08	0.05	0.09	0.11	0.11	0.20	0.02	0.00	0.00	0.00	0.00
410	99.20	30.15	4.83	0.34	0.09	0.06	0.10	0.30	1.03	0.06	0.02	0.08	0.00	0.01
420	45.60	91.79	25.83	1.88	0.28	0.07	0.18	0.38	5.33	0.02	0.00	0.00	0.01	0.01
430	13.84	64.03	79.58	9.12	1.23	0.13	0.13	0.46	15.21	0.00	0.01	0.00	0.00	0.00
440	4.03	19.93	85.83	32.74	5.41	0.52	0.20	0.51	28.29	0.01	0.04	0.03	0.00	0.02
450	1.26	5.75	32.75	80.35	18.53	1.81	0.39	0.73	37.52	0.00	0.02	0.00	0.01	0.02
460	0.46	1.78	10.67	92.92	46.99	6.12	0.94	1.28	23.76	0.02	0.00	0.06	0.00	0.00
470	0.20	0.65	3.57	50.09	86.84	17.52	2.47	2.70	12.05	0.00	0.00	0.01	0.00	0.00
480	0.10	0.27	1.29	22.48	94.36	43.69	6.42	5.87	8.72	0.00	0.01	0.00	0.01	0.01

W	Channels													
	410	420	435	455	475	495	525	540	555	595	615	630	660	700
490	0.07	0.15	0.53	9.29	53.20	85.55	16.00	12.09	11.62	0.02	0.02	0.00	0.00	0.01
500	0.04	0.09	0.24	3.76	25.00	96.47	36.14	23.25	24.36	0.00	0.00	0.00	0.00	0.00
510	0.03	0.06	0.13	1.60	10.77	64.28	69.12	42.06	48.80	0.01	0.00	0.00	0.01	0.00
520	0.02	0.05	0.08	0.72	4.68	35.84	97.54	68.25	73.50	0.01	0.01	0.01	0.00	0.01
530	0.01	0.03	0.05	0.36	2.09	18.09	91.58	93.65	89.74	0.01	0.01	0.01	0.00	0.00
540	0.02	0.03	0.04	0.20	0.99	8.86	60.70	98.68	97.44	0.09	0.00	0.00	0.00	0.00
550	0.01	0.03	0.04	0.11	0.49	4.29	35.02	79.63	100.00	0.47	0.06	0.01	0.00	0.00
560	0.01	0.02	0.03	0.08	0.26	2.08	18.84	54.50	99.15	1.80	0.19	0.04	0.01	0.01
570	0.01	0.02	0.03	0.06	0.16	1.05	9.89	34.39	96.58	6.17	0.78	0.14	0.00	0.00
580	0.01	0.01	0.01	0.03	0.10	0.55	5.16	20.37	91.45	20.57	2.57	0.48	0.05	0.00
590	0.00	0.01	0.02	0.04	0.06	0.31	2.67	11.69	84.44	63.87	8.10	1.49	0.17	0.02
600	0.01	0.01	0.02	0.03	0.06	0.19	1.43	6.59	75.90	86.08	25.07	4.09	0.47	0.03
610	0.00	0.01	0.02	0.02	0.04	0.12	0.78	3.76	66.84	18.22	69.10	10.87	1.30	0.06
620	0.01	0.01	0.01	0.03	0.03	0.09	0.44	2.16	57.26	3.51	90.96	29.13	3.56	0.19
630	0.00	0.00	0.01	0.03	0.02	0.06	0.24	1.23	48.46	0.83	22.01	74.41	9.19	0.50
640	0.00	0.01	0.01	0.01	0.03	0.05	0.17	0.76	40.17	0.26	3.95	85.83	22.07	1.19
650	0.01	0.01	0.01	0.02	0.03	0.03	0.10	0.46	32.91	0.10	0.90	18.98	46.89	2.64
660	0.01	0.01	0.01	0.02	0.01	0.04	0.10	0.30	26.58	0.05	0.26	3.91	90.37	5.68
670	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.21	21.20	0.03	0.11	1.02	68.37	11.89
680	0.00	0.00	0.02	0.01	0.02	0.04	0.07	0.16	16.84	0.04	0.06	0.33	13.33	24.08
690	0.00	0.00	0.01	0.01	0.01	0.03	0.04	0.12	13.42	0.04	0.03	0.15	2.81	47.77
700	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.07	10.60	0.04	0.06	0.06	0.81	85.99
710	0.00	0.02	0.00	0.04	0.02	0.00	0.02	0.07	8.38	0.01	0.04	0.08	0.28	95.29
720	0.00	0.00	0.01	0.01	0.00	0.02	0.03	0.08	6.60	0.04	0.06	0.04	0.17	54.52
730	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.06	5.24	0.00	0.10	0.11	0.13	19.87
740	0.00	0.02	0.04	0.00	0.00	0.01	0.00	0.04	4.09	0.00	0.07	0.04	0.13	6.08
750	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.09	3.28	0.05	0.08	0.05	0.09	1.87
760	0.02	0.04	0.01	0.02	0.00	0.04	0.05	0.03	2.50	0.00	0.08	0.02	0.01	0.64
770	0.00	0.05	0.05	0.00	0.00	0.02	0.03	0.00	2.11	0.07	0.00	0.10	0.08	0.31
780	0.00	0.11	0.07	0.13	0.02	0.03	0.04	0.00	1.60	0.11	0.17	0.01	0.11	0.15

W=wavelength (nm)

L=luminance (cd/m^2)

Appendix C

```
clc, clear
A=importdata('1RGB1-192.xlsx');                %color#1(1-192) color#2(193-384) color#3(385-576) color#4(577-768)
savePath='/Users/Admin/Desktop/TestChannels/DATA';
cK = randperm(192)';                                              %Random Permutation
results = zeros(192,1);
RTime = zeros(192,1);
Final = zeros (192,3);
RGBss=A';
C = 0;
userName=input('insert the name of the observer... ','s');
for i = 1:192                                                     %number of color
axis off
C3=rectangle('Position',[1,1,2,1],'FaceColor',[0.32,0.32,0.32],'LineStyle','none');
pause(1);
tic;
C1=rectangle('Position',[1,1,1,1],'FaceColor',[RGBss(1,cK(i)),RGBss(2,cK(i)),RGBss(3,cK(i))],'LineStyle','none');
C2=rectangle('Position',[2,1,1,1],'FaceColor',[RGBss(4,cK(i)),RGBss(5,cK(i)),RGBss(6,cK(i))],'LineStyle','none');
x=input('insert the user input... ','s');
while not (strcmp(x,'4') || strcmp(x,'6'));
    x=input('insert 4 or 6 only... ','s');
end
  if strcmp(x,'4')
    results(i)=1;
  else
    results(i)=0;
  end
toc;
RTime(i) = toc;
C = C+1;
if C == 48                                                        %Break
  C = 0 ;
  C4=rectangle('Position',[1,1,2,1],'FaceColor',[1,1,1],'LineStyle','none');
  pause(3);
end
end
Final = [cK,results,RTime];
save([savePath '\Results_' userName],'Final');
```

Figure C-1 MATLAB code for display color pair samples

Table C-1 AdobeRBG values of 768 colored pairs

	Color pair	C1			C2		
		R	G	B	R	G	B
1	410R65-410Y35	0.0890	0.0000	0.2800	0.0420	0.0000	0.1360
2	410R70-410Y30	0.0930	0.0000	0.2900	0.0390	0.0000	0.1270
3	410R75-410Y25	0.0950	0.0000	0.2990	0.0360	0.0000	0.1170
4	410R80-410Y20	0.0980	0.0000	0.3080	0.0330	0.0000	0.1050
5	410R85-410Y15	0.1010	0.0000	0.3170	0.0290	0.0000	0.0920
6	410R90-410Y10	0.1040	0.0000	0.3250	0.0240	0.0000	0.0770
7	410R30-410G70	0.0630	0.0000	0.1970	0.1170	0.0000	0.4180
8	410R35-410G65	0.0680	0.0000	0.2120	0.1130	0.0000	0.4040
9	410R40-410G60	0.0720	0.0000	0.2250	0.1090	0.0000	0.3900
10	410R45-410G55	0.0760	0.0000	0.2370	0.1050	0.0000	0.3750
11	410R50-410G50	0.0790	0.0000	0.2490	0.1010	0.0000	0.3590
12	410R55-410G45	0.0830	0.0000	0.2600	0.0960	0.0000	0.3420
13	410R60-410G40	0.0860	0.0000	0.2700	0.0910	0.0000	0.3240
14	410R65-410G35	0.0890	0.0000	0.2800	0.0860	0.0000	0.3050
15	410R70-410G30	0.0930	0.0000	0.2900	0.0800	0.0000	0.2840
16	410R75-410G25	0.0950	0.0000	0.2990	0.0730	0.0000	0.2620
17	410R80-410G20	0.0980	0.0000	0.3080	0.0660	0.0000	0.2370
18	410R85-410G15	0.1010	0.0000	0.3170	0.0580	0.0000	0.2080
19	410R10-410B90	0.0380	0.0000	0.1200	0.0860	0.0000	0.2880
20	410R15-410B85	0.0460	0.0000	0.1440	0.0840	0.0000	0.2800
21	410R20-410B80	0.0520	0.0000	0.1640	0.0820	0.0000	0.2730
22	410R25-410B75	0.0580	0.0000	0.1820	0.0790	0.0000	0.2650
23	410R30-410B70	0.0630	0.0000	0.1970	0.0770	0.0000	0.2570
24	410R35-410B65	0.0680	0.0000	0.2120	0.0740	0.0000	0.2480
25	410R40-410B60	0.0720	0.0000	0.2250	0.0720	0.0000	0.2390
26	410R45-410B55	0.0760	0.0000	0.2370	0.0690	0.0000	0.2300
27	410R50-410B50	0.0790	0.0000	0.2490	0.0660	0.0000	0.2200
28	410R55-410B45	0.0830	0.0000	0.2600	0.0630	0.0000	0.2100
29	410R60-410B40	0.0860	0.0000	0.2700	0.0600	0.0000	0.1990
30	410R65-410B35	0.0890	0.0000	0.2800	0.0560	0.0000	0.1870
31	410R70-410B30	0.0930	0.0000	0.2900	0.0520	0.0000	0.1750
32	410R75-410B25	0.0950	0.0000	0.2990	0.0480	0.0000	0.1610

	Color pair	C1			C2		
		R	G	B	R	G	B
33	410R80-410B20	0.0980	0.0000	0.3080	0.0430	0.0000	0.1450
34	410Y55-410G45	0.0520	0.0000	0.1670	0.0960	0.0000	0.3420
35	410Y60-410G40	0.0540	0.0000	0.1740	0.0910	0.0000	0.3240
36	410Y65-410G35	0.0560	0.0000	0.1800	0.0860	0.0000	0.3050
37	410Y70-410G30	0.0580	0.0000	0.1860	0.0800	0.0000	0.2840
38	410Y75-410G25	0.0600	0.0000	0.1920	0.0730	0.0000	0.2620
39	410Y80-410G20	0.0620	0.0000	0.1980	0.0660	0.0000	0.2370
40	410Y25-410B75	0.0360	0.0000	0.1170	0.0790	0.0000	0.2650
41	410Y30-410B70	0.0390	0.0000	0.1270	0.0770	0.0000	0.2570
42	410Y35-410B65	0.0420	0.0000	0.1360	0.0740	0.0000	0.2480
43	410Y40-410B60	0.0450	0.0000	0.1440	0.0720	0.0000	0.2390
44	410Y45-410B55	0.0470	0.0000	0.1520	0.0690	0.0000	0.2300
45	410Y50-410B50	0.0500	0.0000	0.1600	0.0660	0.0000	0.2200
46	410Y55-410B45	0.0520	0.0000	0.1670	0.0630	0.0000	0.2100
47	410G10-410B90	0.0480	0.0000	0.1730	0.0860	0.0000	0.2880
48	410G15-410B85	0.0580	0.0000	0.2080	0.0840	0.0000	0.2800
49	410G20-410B80	0.0660	0.0000	0.2370	0.0820	0.0000	0.2730
50	410G25-410B75	0.0730	0.0000	0.2620	0.0790	0.0000	0.2650
51	410G30-410B70	0.0800	0.0000	0.2840	0.0770	0.0000	0.2570
52	410G35-410B65	0.0860	0.0000	0.3050	0.0740	0.0000	0.2480
53	410G40-410B60	0.0910	0.0000	0.3240	0.0720	0.0000	0.2390
54	410G45-410B55	0.0960	0.0000	0.3420	0.0690	0.0000	0.2300
55	410G50-410B50	0.1010	0.0000	0.3590	0.0660	0.0000	0.2200
56	410G55-410B45	0.1050	0.0000	0.3750	0.0630	0.0000	0.2100
57	420R45-420Y55	0.1080	0.0000	0.3620	0.0770	0.0000	0.2620
58	420R50-420Y50	0.1130	0.0000	0.3800	0.0740	0.0000	0.2510
59	420R55-420Y45	0.1180	0.0000	0.3970	0.0710	0.0000	0.2390
60	420R60-420Y40	0.1230	0.0000	0.4130	0.0670	0.0000	0.2270
61	420R65-420Y35	0.1280	0.0000	0.4280	0.0630	0.0000	0.2140
62	420R70-420Y30	0.1320	0.0000	0.4430	0.0590	0.0000	0.1990
63	420R45-420G55	0.1080	0.0000	0.3620	0.1700	0.0000	0.6030
64	420R50-420G50	0.1130	0.0000	0.3800	0.1630	0.0000	0.5780
65	420R55-420G45	0.1180	0.0000	0.3970	0.1550	0.0000	0.5510

	Color pair	C1			C2		
		R	G	B	R	G	B
66	420R60-420G40	0.1230	0.0000	0.4130	0.1470	0.0000	0.5220
67	420R65-420G35	0.1280	0.0000	0.4280	0.1390	0.0000	0.4910
68	420R70-420G30	0.1320	0.0000	0.4430	0.1290	0.0000	0.4580
69	420R75-420G25	0.1360	0.0000	0.4570	0.1190	0.0000	0.4220
70	420R80-420G20	0.1400	0.0000	0.4710	0.1070	0.0000	0.3810
71	420R85-420G15	0.1440	0.0000	0.4840	0.0940	0.0000	0.3340
72	420R90-420G10	0.1480	0.0000	0.4970	0.0780	0.0000	0.2780
73	420R20-420B80	0.0750	0.0000	0.2510	0.1280	0.0000	0.4480
74	420R25-420B75	0.0830	0.0000	0.2770	0.1240	0.0000	0.4350
75	420R30-420B70	0.0900	0.0000	0.3010	0.1200	0.0000	0.4210
76	420R35-420B65	0.0960	0.0000	0.3230	0.1160	0.0000	0.4070
77	420R40-420B60	0.1020	0.0000	0.3440	0.1120	0.0000	0.3930
78	420R45-420B55	0.1080	0.0000	0.3620	0.1080	0.0000	0.3780
79	420R50-420B50	0.1130	0.0000	0.3800	0.1030	0.0000	0.3620
80	420R55-420B45	0.1180	0.0000	0.3970	0.0990	0.0000	0.3450
81	420R60-420B40	0.1230	0.0000	0.4130	0.0930	0.0000	0.3270
82	420R65-420B35	0.1280	0.0000	0.4280	0.0880	0.0000	0.3080
83	420R70-420B30	0.1320	0.0000	0.4430	0.0820	0.0000	0.2870
84	420R75-420B25	0.1360	0.0000	0.4570	0.0750	0.0000	0.2640
85	420Y55-420G45	0.0770	0.0000	0.2620	0.1550	0.0000	0.5510
86	420Y60-420G40	0.0810	0.0000	0.2730	0.1470	0.0000	0.5220
87	420Y65-420G35	0.0830	0.0000	0.2830	0.1390	0.0000	0.4910
88	420Y70-420G30	0.0860	0.0000	0.2930	0.1290	0.0000	0.4580
89	420Y75-420G25	0.0890	0.0000	0.3020	0.1190	0.0000	0.4220
90	420Y80-420G20	0.0920	0.0000	0.3110	0.1070	0.0000	0.3810
91	420Y45-420B55	0.0710	0.0000	0.2390	0.1080	0.0000	0.3780
92	420Y50-420B50	0.0740	0.0000	0.2510	0.1030	0.0000	0.3620
93	420Y55-420B45	0.0770	0.0000	0.2620	0.0990	0.0000	0.3450
94	420Y60-420B40	0.0810	0.0000	0.2730	0.0930	0.0000	0.3270
95	420Y65-420B35	0.0830	0.0000	0.2830	0.0880	0.0000	0.3080
96	420Y70-420B30	0.0860	0.0000	0.2930	0.0820	0.0000	0.2870
97	420Y75-420B25	0.0890	0.0000	0.3020	0.0750	0.0000	0.2640
98	420Y80-420B20	0.0920	0.0000	0.3110	0.0680	0.0000	0.2380

	Color pair	C1			C2		
		R	G	B	R	G	B
99	420Y85-420B15	0.0940	0.0000	0.3200	0.0600	0.0000	0.2090
100	420Y90-420B10	0.0970	0.0000	0.3280	0.0500	0.0000	0.1740
101	420G5-420B95	0.0570	0.0000	0.2030	0.1380	0.0000	0.4840
102	420G10-420B90	0.0780	0.0000	0.2780	0.1350	0.0000	0.4720
103	420G15-420B85	0.0940	0.0000	0.3340	0.1320	0.0000	0.4600
104	420G20-420B80	0.1070	0.0000	0.3810	0.1280	0.0000	0.4480
105	420G25-420B75	0.1190	0.0000	0.4220	0.1240	0.0000	0.4350
106	420G30-420B70	0.1290	0.0000	0.4580	0.1200	0.0000	0.4210
107	420G35-420B65	0.1390	0.0000	0.4910	0.1160	0.0000	0.4070
108	420G40-420B60	0.1470	0.0000	0.5220	0.1120	0.0000	0.3930
109	420G45-420B55	0.1550	0.0000	0.5510	0.1080	0.0000	0.3780
110	420G50-420B50	0.1630	0.0000	0.5780	0.1030	0.0000	0.3620
111	435R5-435Y95	0.0450	0.0000	0.1690	0.1120	0.0000	0.4290
112	435R10-435Y90	0.0610	0.0000	0.2310	0.1090	0.0000	0.4180
113	435R15-435Y85	0.0740	0.0000	0.2780	0.1070	0.0000	0.4080
114	435R20-435Y80	0.0840	0.0000	0.3170	0.1040	0.0000	0.3970
115	435R25-435Y75	0.0930	0.0000	0.3510	0.1010	0.0000	0.3850
116	435R30-435Y70	0.1010	0.0000	0.3810	0.0980	0.0000	0.3730
117	435R35-435Y65	0.1080	0.0000	0.4090	0.0940	0.0000	0.3610
118	435R40-435Y60	0.1150	0.0000	0.4340	0.0910	0.0000	0.3480
119	435R45-435Y55	0.1220	0.0000	0.4580	0.0870	0.0000	0.3340
120	435R50-435Y50	0.1270	0.0000	0.4810	0.0840	0.0000	0.3200
121	435R55-435Y45	0.1330	0.0000	0.5020	0.0800	0.0000	0.3050
122	435R60-435Y40	0.1380	0.0000	0.5220	0.0760	0.0000	0.2890
123	435R45-435G55	0.1220	0.0000	0.4580	0.1980	0.0000	0.7920
124	435R50-435G50	0.1270	0.0000	0.4810	0.1890	0.0000	0.7580
125	435R55-435G45	0.1330	0.0000	0.5020	0.1810	0.0000	0.7230
126	435R60-435G40	0.1380	0.0000	0.5220	0.1710	0.0000	0.6850
127	435R65-435G35	0.1440	0.0000	0.5410	0.1610	0.0000	0.6450
128	435R70-435G30	0.1490	0.0000	0.5600	0.1500	0.0000	0.6010
129	435R75-435G25	0.1530	0.0000	0.5780	0.1380	0.0000	0.5530
130	435R80-435G20	0.1580	0.0000	0.5950	0.1250	0.0000	0.5000
131	435R85-435G15	0.1620	0.0000	0.6120	0.1100	0.0000	0.4390

	Color pair	C1			C2		
		R	G	B	R	G	B
132	435R90-435G10	0.1670	0.0000	0.6280	0.0910	0.0000	0.3650
133	435R20-435B80	0.0840	0.0000	0.3170	0.1460	0.0000	0.5830
134	435R25-435B75	0.0930	0.0000	0.3510	0.1410	0.0000	0.5660
135	435R30-435B70	0.1010	0.0000	0.3810	0.1370	0.0000	0.5480
136	435R35-435B65	0.1080	0.0000	0.4090	0.1320	0.0000	0.5300
137	435R40-435B60	0.1150	0.0000	0.4340	0.1280	0.0000	0.5110
138	435R45-435B55	0.1220	0.0000	0.4580	0.1230	0.0000	0.4910
139	435R50-435B50	0.1270	0.0000	0.4810	0.1180	0.0000	0.4710
140	435R55-435B45	0.1330	0.0000	0.5020	0.1120	0.0000	0.4490
141	435R60-435B40	0.1380	0.0000	0.5220	0.1060	0.0000	0.4250
142	435R65-435B35	0.1440	0.0000	0.5410	0.1000	0.0000	0.4000
143	435R70-435B30	0.1490	0.0000	0.5600	0.0930	0.0000	0.3730
144	435R75-435B25	0.1530	0.0000	0.5780	0.0860	0.0000	0.3430
145	435Y60-435G40	0.0910	0.0000	0.3480	0.1710	0.0000	0.6850
146	435Y65-435G35	0.0940	0.0000	0.3610	0.1610	0.0000	0.6450
147	435Y70-435G30	0.0980	0.0000	0.3730	0.1500	0.0000	0.6010
148	435Y75-435G25	0.1010	0.0000	0.3850	0.1380	0.0000	0.5530
149	435Y80-435G20	0.1040	0.0000	0.3970	0.1250	0.0000	0.5000
150	435Y85-435G15	0.1070	0.0000	0.4080	0.1100	0.0000	0.4390
151	435Y90-435G10	0.1090	0.0000	0.4180	0.0910	0.0000	0.3650
152	435Y95-435G5	0.1120	0.0000	0.4290	0.0670	0.0000	0.2660
153	435Y45-435B55	0.0800	0.0000	0.3050	0.1230	0.0000	0.4910
154	435Y50-435B50	0.0840	0.0000	0.3200	0.1180	0.0000	0.4710
155	435Y55-435B45	0.0870	0.0000	0.3340	0.1120	0.0000	0.4490
156	435Y60-435B40	0.0910	0.0000	0.3480	0.1060	0.0000	0.4250
157	435Y65-435B35	0.0940	0.0000	0.3610	0.1000	0.0000	0.4000
158	435Y70-435B30	0.0980	0.0000	0.3730	0.0930	0.0000	0.3730
159	435Y75-435B25	0.1010	0.0000	0.3850	0.0860	0.0000	0.3430
160	435Y80-435B20	0.1040	0.0000	0.3970	0.0780	0.0000	0.3100
161	435Y85-435B15	0.1070	0.0000	0.4080	0.0680	0.0000	0.2720
162	435Y90-435B10	0.1090	0.0000	0.4180	0.0570	0.0000	0.2260
163	435G10-435B90	0.0910	0.0000	0.3650	0.1540	0.0000	0.6150
164	435G15-435B85	0.1100	0.0000	0.4390	0.1500	0.0000	0.5990

	Color pair	C1			C2		
		R	G	B	R	G	B
165	435G20-435B80	0.1250	0.0000	0.5000	0.1460	0.0000	0.5830
166	435G25-435B75	0.1380	0.0000	0.5530	0.1410	0.0000	0.5660
167	435G30-435B70	0.1500	0.0000	0.6010	0.1370	0.0000	0.5480
168	435G35-435B65	0.1610	0.0000	0.6450	0.1320	0.0000	0.5300
169	435G40-435B60	0.1710	0.0000	0.6850	0.1280	0.0000	0.5110
170	435G45-435B55	0.1810	0.0000	0.7230	0.1230	0.0000	0.4910
171	435G50-435B50	0.1890	0.0000	0.7580	0.1180	0.0000	0.4710
172	455R5-455Y95	0.0000	0.0000	0.1770	0.0000	0.0000	0.4590
173	455R10-455Y90	0.0000	0.0000	0.2430	0.0000	0.0000	0.4480
174	455R15-455Y85	0.0000	0.0000	0.2920	0.0000	0.0000	0.4360
175	455R20-455Y80	0.0000	0.0000	0.3330	0.0000	0.0000	0.4240
176	455R25-455Y75	0.0000	0.0000	0.3690	0.0000	0.0000	0.4120
177	455R30-455Y70	0.0000	0.0000	0.4000	0.0000	0.0000	0.3990
178	455R35-455Y65	0.0000	0.0000	0.4290	0.0000	0.0000	0.3860
179	455R40-455Y60	0.0000	0.0000	0.4560	0.0000	0.0000	0.3720
180	455R45-455Y55	0.0000	0.0000	0.4810	0.0000	0.0000	0.3580
181	455R50-455Y50	0.0000	0.0000	0.5050	0.0000	0.0000	0.3430
182	455R55-455Y45	0.0000	0.0000	0.5270	0.0000	0.0000	0.3270
183	455R60-455Y40	0.0000	0.0000	0.5490	0.0000	0.0000	0.3100
184	455R55-455G45	0.0000	0.0000	0.5270	0.0000	0.0000	0.8390
185	455R60-455G40	0.0000	0.0000	0.5490	0.0000	0.0000	0.7960
186	455R65-455G35	0.0000	0.0000	0.5690	0.0000	0.0000	0.7490
187	455R70-455G30	0.0000	0.0000	0.5890	0.0000	0.0000	0.6980
188	455R75-455G25	0.0000	0.0000	0.6070	0.0000	0.0000	0.6430
189	455R80-455G20	0.0000	0.0000	0.6250	0.0000	0.0000	0.5810
190	455R85-455G15	0.0000	0.0000	0.6430	0.0000	0.0000	0.5090
191	455R90-455G10	0.0000	0.0000	0.6600	0.0000	0.0000	0.4240
192	455R30-455B70	0.0000	0.0000	0.4000	0.0000	0.0000	0.6480
193	455R35-455B65	0.0000	0.0000	0.4290	0.0000	0.0000	0.6270
194	455R40-455B60	0.0000	0.0000	0.4560	0.0000	0.0000	0.6040
195	455R45-455B55	0.0000	0.0000	0.4810	0.0000	0.0000	0.5810
196	455R50-455B50	0.0000	0.0000	0.5050	0.0000	0.0000	0.5560
197	455R55-455B45	0.0000	0.0000	0.5270	0.0000	0.0000	0.5300

	Color pair	C1			C2		
		R	G	B	R	G	B
198	455R60-455B40	0.0000	0.0000	0.5490	0.0000	0.0000	0.5020
199	455R65-455B35	0.0000	0.0000	0.5690	0.0000	0.0000	0.4730
200	455R70-455B30	0.0000	0.0000	0.5890	0.0000	0.0000	0.4410
201	455R75-455B25	0.0000	0.0000	0.6070	0.0000	0.0000	0.4060
202	455R80-455B20	0.0000	0.0000	0.6250	0.0000	0.0000	0.3670
203	455Y70-455G30	0.0000	0.0000	0.3990	0.0000	0.0000	0.6980
204	455Y75-455G25	0.0000	0.0000	0.4120	0.0000	0.0000	0.6430
205	455Y80-455G20	0.0000	0.0000	0.4240	0.0000	0.0000	0.5810
206	455Y85-455G15	0.0000	0.0000	0.4360	0.0000	0.0000	0.5090
207	455Y90-455G10	0.0000	0.0000	0.4480	0.0000	0.0000	0.4240
208	455Y95-455G5	0.0000	0.0000	0.4590	0.0000	0.0000	0.3090
209	455Y45-455B55	0.0000	0.0000	0.3270	0.0000	0.0000	0.5810
210	455Y50-455B50	0.0000	0.0000	0.3430	0.0000	0.0000	0.5560
211	455Y55-455B45	0.0000	0.0000	0.3580	0.0000	0.0000	0.5300
212	455Y60-455B40	0.0000	0.0000	0.3720	0.0000	0.0000	0.5020
213	455Y65-455B35	0.0000	0.0000	0.3860	0.0000	0.0000	0.4730
214	455Y70-455B30	0.0000	0.0000	0.3990	0.0000	0.0000	0.4410
215	455Y75-455B25	0.0000	0.0000	0.4120	0.0000	0.0000	0.4060
216	455Y80-455B20	0.0000	0.0000	0.4240	0.0000	0.0000	0.3670
217	455Y85-455B15	0.0000	0.0000	0.4360	0.0000	0.0000	0.3220
218	455Y90-455B10	0.0000	0.0000	0.4480	0.0000	0.0000	0.2680
219	455G5-455B95	0.0000	0.0000	0.3090	0.0000	0.0000	0.7450
220	455G10-455B90	0.0000	0.0000	0.4240	0.0000	0.0000	0.7260
221	455G15-455B85	0.0000	0.0000	0.5090	0.0000	0.0000	0.7080
222	455G20-455B80	0.0000	0.0000	0.5810	0.0000	0.0000	0.6890
223	455G25-455B75	0.0000	0.0000	0.6430	0.0000	0.0000	0.6690
224	455G30-455B70	0.0000	0.0000	0.6980	0.0000	0.0000	0.6480
225	455G35-455B65	0.0000	0.0000	0.7490	0.0000	0.0000	0.6270
226	455G40-455B60	0.0000	0.0000	0.7960	0.0000	0.0000	0.6040
227	455G45-455B55	0.0000	0.0000	0.8390	0.0000	0.0000	0.5810
228	475R10-475Y90	0.0000	0.0640	0.1460	0.0000	0.1650	0.2820
229	475R15-475Y85	0.0000	0.0770	0.1760	0.0000	0.1600	0.2740
230	475R20-475Y80	0.0000	0.0870	0.2000	0.0000	0.1560	0.2670

	Color pair	C1			C2		
		R	G	B	R	G	B
231	475R25-475Y75	0.0000	0.0970	0.2220	0.0000	0.1520	0.2590
232	475R30-475Y70	0.0000	0.1050	0.2410	0.0000	0.1470	0.2510
233	475R35-475Y65	0.0000	0.1130	0.2580	0.0000	0.1420	0.2430
234	475R40-475Y60	0.0000	0.1200	0.2750	0.0000	0.1370	0.2340
235	475R45-475Y55	0.0000	0.1260	0.2900	0.0000	0.1320	0.2250
236	475R50-475Y50	0.0000	0.1320	0.3040	0.0000	0.1260	0.2160
237	475R55-475Y45	0.0000	0.1380	0.3170	0.0000	0.1200	0.2050
238	475R60-475Y40	0.0000	0.1440	0.3300	0.0000	0.1140	0.1950
239	475R65-475Y35	0.0000	0.1490	0.3420	0.0000	0.1070	0.1830
240	475R60-475G40	0.0000	0.1440	0.3300	0.0000	0.2480	0.5190
241	475R65-475G35	0.0000	0.1490	0.3420	0.0000	0.2340	0.4890
242	475R70-475G30	0.0000	0.1540	0.3540	0.0000	0.2180	0.4550
243	475R75-475G25	0.0000	0.1590	0.3650	0.0000	0.2010	0.4190
244	475R80-475G20	0.0000	0.1640	0.3760	0.0000	0.1810	0.3790
245	475R85-475G15	0.0000	0.1690	0.3870	0.0000	0.1590	0.3320
246	475R90-475G10	0.0000	0.1730	0.3970	0.0000	0.1320	0.2760
247	475R95-475G5	0.0000	0.1770	0.4070	0.0000	0.0970	0.2020
248	475R50-475B50	0.0000	0.1320	0.3040	0.0000	0.2320	0.3890
249	475R55-475B45	0.0000	0.1380	0.3170	0.0000	0.2210	0.3700
250	475R60-475B40	0.0000	0.1440	0.3300	0.0000	0.2090	0.3510
251	475R65-475B35	0.0000	0.1490	0.3420	0.0000	0.1970	0.3300
252	475R70-475B30	0.0000	0.1540	0.3540	0.0000	0.1840	0.3080
253	475R75-475B25	0.0000	0.1590	0.3650	0.0000	0.1690	0.2840
254	475R80-475B20	0.0000	0.1640	0.3760	0.0000	0.1530	0.2560
255	475R85-475B15	0.0000	0.1690	0.3870	0.0000	0.1340	0.2250
256	475R90-475B10	0.0000	0.1730	0.3970	0.0000	0.1120	0.1870
257	475Y65-475G35	0.0000	0.1420	0.2430	0.0000	0.2340	0.4890
258	475Y70-475G30	0.0000	0.1470	0.2510	0.0000	0.2180	0.4550
259	475Y75-475G25	0.0000	0.1520	0.2590	0.0000	0.2010	0.4190
260	475Y80-475G20	0.0000	0.1560	0.2670	0.0000	0.1810	0.3790
261	475Y85-475G15	0.0000	0.1600	0.2740	0.0000	0.1590	0.3320
262	475Y90-475G10	0.0000	0.1650	0.2820	0.0000	0.1320	0.2760
263	475Y95-475G5	0.0000	0.1690	0.2890	0.0000	0.0970	0.2020

	Color pair	C1			C2		
		R	G	B	R	G	B
264	475Y55-475B45	0.0000	0.1320	0.2250	0.0000	0.2210	0.3700
265	475Y60-475B40	0.0000	0.1370	0.2340	0.0000	0.2090	0.3510
266	475Y65-475B35	0.0000	0.1420	0.2430	0.0000	0.1970	0.3300
267	475Y70-475B30	0.0000	0.1470	0.2510	0.0000	0.1840	0.3080
268	475Y75-475B25	0.0000	0.1520	0.2590	0.0000	0.1690	0.2840
269	475Y80-475B20	0.0000	0.1560	0.2670	0.0000	0.1530	0.2560
270	475Y85-475B15	0.0000	0.1600	0.2740	0.0000	0.1340	0.2250
271	475Y90-475B10	0.0000	0.1650	0.2820	0.0000	0.1120	0.1870
272	475Y95-475B5	0.0000	0.1690	0.2890	0.0000	0.0810	0.1360
273	475G15-475B85	0.0000	0.1590	0.3320	0.0000	0.2950	0.4950
274	475G20-475B80	0.0000	0.1810	0.3790	0.0000	0.2870	0.4810
275	475G25-475B75	0.0000	0.2010	0.4190	0.0000	0.2790	0.4670
276	475G30-475B70	0.0000	0.2180	0.4550	0.0000	0.2700	0.4530
277	475G35-475B65	0.0000	0.2340	0.4890	0.0000	0.2610	0.4380
278	475G40-475B60	0.0000	0.2480	0.5190	0.0000	0.2520	0.4220
279	475G45-475B55	0.0000	0.2620	0.5480	0.0000	0.2420	0.4060
280	475G50-475B50	0.0000	0.2750	0.5750	0.0000	0.2320	0.3890
281	475G55-475B45	0.0000	0.2870	0.6000	0.0000	0.2210	0.3700
282	495R35-495Y65	0.0000	0.2580	0.2040	0.0000	0.3780	0.2040
283	495R40-495Y60	0.0000	0.2740	0.2170	0.0000	0.3650	0.1970
284	495R45-495Y55	0.0000	0.2890	0.2290	0.0000	0.3510	0.1890
285	495R50-495Y50	0.0000	0.3030	0.2400	0.0000	0.3360	0.1810
286	495R55-495Y45	0.0000	0.3160	0.2510	0.0000	0.3200	0.1730
287	495R60-495Y40	0.0000	0.3290	0.2610	0.0000	0.3030	0.1640
288	495R65-495Y35	0.0000	0.3410	0.2710	0.0000	0.2860	0.1540
289	495R70-495Y30	0.0000	0.3530	0.2800	0.0000	0.2660	0.1440
290	495R75-495Y25	0.0000	0.3640	0.2890	0.0000	0.2450	0.1320
291	495R65-495G35	0.0000	0.3410	0.2710	0.0000	0.5090	0.4120
292	495R70-495G30	0.0000	0.3530	0.2800	0.0000	0.4750	0.3850
293	495R75-495G25	0.0000	0.3640	0.2890	0.0000	0.4370	0.3540
294	495R80-495G20	0.0000	0.3750	0.2980	0.0000	0.3950	0.3200
295	495R85-495G15	0.0000	0.3860	0.3060	0.0000	0.3470	0.2810
296	495R90-495G10	0.0000	0.3960	0.3140	0.0000	0.2880	0.2330

	Color pair	C1			C2		
		R	G	B	R	G	B
297	495R95-495G5	0.0000	0.4060	0.3220	0.0000	0.2100	0.1700
298	495R60-495B40	0.0000	0.3290	0.2610	0.0000	0.4900	0.3320
299	495R65-495B35	0.0000	0.3410	0.2710	0.0000	0.4610	0.3130
300	495R70-495B30	0.0000	0.3530	0.2800	0.0000	0.4300	0.2920
301	495R75-495B25	0.0000	0.3640	0.2890	0.0000	0.3960	0.2680
302	495R80-495B20	0.0000	0.3750	0.2980	0.0000	0.3570	0.2420
303	495R85-495B15	0.0000	0.3860	0.3060	0.0000	0.3140	0.2130
304	495R90-495B10	0.0000	0.3960	0.3140	0.0000	0.2610	0.1770
305	495R95-495B5	0.0000	0.4060	0.3220	0.0000	0.1900	0.1290
306	495Y60-495G40	0.0000	0.3650	0.1970	0.0000	0.5410	0.4380
307	495Y65-495G35	0.0000	0.3780	0.2040	0.0000	0.5090	0.4120
308	495Y70-495G30	0.0000	0.3910	0.2110	0.0000	0.4750	0.3850
309	495Y75-495G25	0.0000	0.4040	0.2180	0.0000	0.4370	0.3540
310	495Y80-495G20	0.0000	0.4160	0.2250	0.0000	0.3950	0.3200
311	495Y85-495G15	0.0000	0.4270	0.2310	0.0000	0.3470	0.2810
312	495Y90-495G10	0.0000	0.4390	0.2370	0.0000	0.2880	0.2330
313	495Y55-495B45	0.0000	0.3510	0.1890	0.0000	0.5170	0.3510
314	495Y60-495B40	0.0000	0.3650	0.1970	0.0000	0.4900	0.3320
315	495Y65-495B35	0.0000	0.3780	0.2040	0.0000	0.4610	0.3130
316	495Y70-495B30	0.0000	0.3910	0.2110	0.0000	0.4300	0.2920
317	495Y75-495B25	0.0000	0.4040	0.2180	0.0000	0.3960	0.2680
318	495Y80-495B20	0.0000	0.4160	0.2250	0.0000	0.3570	0.2420
319	495Y85-495B15	0.0000	0.4270	0.2310	0.0000	0.3140	0.2130
320	495Y90-495B10	0.0000	0.4390	0.2370	0.0000	0.2610	0.1770
321	495G25-495B75	0.0000	0.4370	0.3540	0.0000	0.6520	0.4420
322	495G30-495B70	0.0000	0.4750	0.3850	0.0000	0.6320	0.4280
323	495G35-495B65	0.0000	0.5090	0.4120	0.0000	0.6110	0.4140
324	495G40-495B60	0.0000	0.5410	0.4380	0.0000	0.5890	0.3990
325	495G45-495B55	0.0000	0.5710	0.4620	0.0000	0.5660	0.3840
326	495G50-495B50	0.0000	0.5990	0.4850	0.0000	0.5420	0.3680
327	495G55-495B45	0.0000	0.6260	0.5070	0.0000	0.5170	0.3510
328	495G60-495B40	0.0000	0.6510	0.5270	0.0000	0.4900	0.3320
329	525R45-525Y55	0.0680	0.2480	0.0480	0.0640	0.3700	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
330	525R50-525Y50	0.0710	0.2600	0.0500	0.0610	0.3540	0.0000
331	525R55-525Y45	0.0740	0.2720	0.0530	0.0580	0.3380	0.0000
332	525R60-525Y40	0.0770	0.2830	0.0550	0.0550	0.3200	0.0000
333	525R65-525Y35	0.0800	0.2930	0.0570	0.0520	0.3010	0.0000
334	525R70-525Y30	0.0830	0.3030	0.0590	0.0480	0.2810	0.0000
335	525R75-525Y25	0.0850	0.3130	0.0600	0.0440	0.2580	0.0000
336	525R80-525Y20	0.0880	0.3220	0.0620	0.0400	0.2340	0.0000
337	525R85-525Y15	0.0900	0.3310	0.0640	0.0350	0.2050	0.0000
338	525R60-525G40	0.0770	0.2830	0.0550	0.0000	0.4120	0.1180
339	525R65-525G35	0.0800	0.2930	0.0570	0.0000	0.3880	0.1110
340	525R70-525G30	0.0830	0.3030	0.0590	0.0000	0.3620	0.1030
341	525R75-525G25	0.0850	0.3130	0.0600	0.0000	0.3330	0.0950
342	525R80-525G20	0.0880	0.3220	0.0620	0.0000	0.3010	0.0860
343	525R85-525G15	0.0900	0.3310	0.0640	0.0000	0.2640	0.0750
344	525R90-525G10	0.0930	0.3400	0.0660	0.0000	0.2190	0.0630
345	525R95-525G5	0.0950	0.3490	0.0670	0.0000	0.1600	0.0460
346	525R60-525B40	0.0770	0.2830	0.0550	0.0000	0.4100	0.0770
347	525R65-525B35	0.0800	0.2930	0.0570	0.0000	0.3860	0.0720
348	525R70-525B30	0.0830	0.3030	0.0590	0.0000	0.3600	0.0670
349	525R75-525B25	0.0850	0.3130	0.0600	0.0000	0.3310	0.0620
350	525R80-525B20	0.0880	0.3220	0.0620	0.0000	0.2990	0.0560
351	525R85-525B15	0.0900	0.3310	0.0640	0.0000	0.2630	0.0490
352	525R90-525B10	0.0930	0.3400	0.0660	0.0000	0.2180	0.0410
353	525R95-525B5	0.0950	0.3490	0.0670	0.0000	0.1590	0.0300
354	525Y45-525G55	0.0580	0.3380	0.0000	0.0000	0.4760	0.1360
355	525Y50-525G50	0.0610	0.3540	0.0000	0.0000	0.4560	0.1300
356	525Y55-525G45	0.0640	0.3700	0.0000	0.0000	0.4350	0.1240
357	525Y60-525G40	0.0660	0.3850	0.0000	0.0000	0.4120	0.1180
358	525Y65-525G35	0.0690	0.3990	0.0000	0.0000	0.3880	0.1110
359	525Y70-525G30	0.0710	0.4130	0.0000	0.0000	0.3620	0.1030
360	525Y75-525G25	0.0730	0.4260	0.0000	0.0000	0.3330	0.0950
361	525Y80-525G20	0.0750	0.4390	0.0000	0.0000	0.3010	0.0860
362	525Y45-525B55	0.0580	0.3380	0.0000	0.0000	0.4740	0.0890

	Color pair	C1			C2		
		R	G	B	R	G	B
363	525Y50-525B50	0.0610	0.3540	0.0000	0.0000	0.4540	0.0850
364	525Y55-525B45	0.0640	0.3700	0.0000	0.0000	0.4330	0.0810
365	525Y60-525B40	0.0660	0.3850	0.0000	0.0000	0.4100	0.0770
366	525Y65-525B35	0.0690	0.3990	0.0000	0.0000	0.3860	0.0720
367	525Y70-525B30	0.0710	0.4130	0.0000	0.0000	0.3600	0.0670
368	525Y75-525B25	0.0730	0.4260	0.0000	0.0000	0.3310	0.0620
369	525Y80-525B20	0.0750	0.4390	0.0000	0.0000	0.2990	0.0560
370	525G35-525B65	0.0000	0.3880	0.1110	0.0000	0.5110	0.0960
371	525G40-525B60	0.0000	0.4120	0.1180	0.0000	0.4930	0.0920
372	525G45-525B55	0.0000	0.4350	0.1240	0.0000	0.4740	0.0890
373	525G50-525B50	0.0000	0.4560	0.1300	0.0000	0.4540	0.0850
374	525G55-525B45	0.0000	0.4760	0.1360	0.0000	0.4330	0.0810
375	525G60-525B40	0.0000	0.4960	0.1420	0.0000	0.4100	0.0770
376	525G65-525B35	0.0000	0.5140	0.1470	0.0000	0.3860	0.0720
377	525G70-525B30	0.0000	0.5320	0.1520	0.0000	0.3600	0.0670
378	540R50-540Y50	0.2440	0.3410	0.0000	0.2480	0.4710	0.0000
379	540R55-540Y45	0.2550	0.3560	0.0000	0.2370	0.4490	0.0000
380	540R60-540Y40	0.2650	0.3700	0.0000	0.2240	0.4260	0.0000
381	540R65-540Y35	0.2750	0.3840	0.0000	0.2110	0.4010	0.0000
382	540R70-540Y30	0.2840	0.3970	0.0000	0.1970	0.3730	0.0000
383	540R75-540Y25	0.2940	0.4100	0.0000	0.1810	0.3440	0.0000
384	540R80-540Y20	0.3020	0.4220	0.0000	0.1640	0.3110	0.0000
385	540R85-540Y15	0.3110	0.4340	0.0000	0.1440	0.2720	0.0000
386	540R35-540G65	0.2080	0.2900	0.0000	0.0500	0.5940	0.1190
387	540R40-540G60	0.2210	0.3080	0.0000	0.0480	0.5730	0.1150
388	540R45-540G55	0.2330	0.3250	0.0000	0.0460	0.5510	0.1110
389	540R50-540G50	0.2440	0.3410	0.0000	0.0440	0.5270	0.1060
390	540R55-540G45	0.2550	0.3560	0.0000	0.0420	0.5030	0.1010
391	540R60-540G40	0.2650	0.3700	0.0000	0.0400	0.4760	0.0960
392	540R65-540G35	0.2750	0.3840	0.0000	0.0380	0.4480	0.0900
393	540R35-540B65	0.2080	0.2900	0.0000	0.1760	0.6230	0.0000
394	540R40-540B60	0.2210	0.3080	0.0000	0.1690	0.6010	0.0000
395	540R45-540B55	0.2330	0.3250	0.0000	0.1630	0.5770	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
396	540R50-540B50	0.2440	0.3410	0.0000	0.1560	0.5530	0.0000
397	540R55-540B45	0.2550	0.3560	0.0000	0.1490	0.5270	0.0000
398	540R60-540B40	0.2650	0.3700	0.0000	0.1410	0.5000	0.0000
399	540R65-540B35	0.2750	0.3840	0.0000	0.1330	0.4700	0.0000
400	540Y35-540G65	0.2110	0.4010	0.0000	0.0500	0.5940	0.1190
401	540Y40-540G60	0.2240	0.4260	0.0000	0.0480	0.5730	0.1150
402	540Y45-540G55	0.2370	0.4490	0.0000	0.0460	0.5510	0.1110
403	540Y50-540G50	0.2480	0.4710	0.0000	0.0440	0.5270	0.1060
404	540Y55-540G45	0.2590	0.4920	0.0000	0.0420	0.5030	0.1010
405	540Y60-540G40	0.2700	0.5120	0.0000	0.0400	0.4760	0.0960
406	540Y65-540G35	0.2800	0.5310	0.0000	0.0380	0.4480	0.0900
407	540Y40-540B60	0.2240	0.4260	0.0000	0.1690	0.6010	0.0000
408	540Y45-540B55	0.2370	0.4490	0.0000	0.1630	0.5770	0.0000
409	540Y50-540B50	0.2480	0.4710	0.0000	0.1560	0.5530	0.0000
410	540Y55-540B45	0.2590	0.4920	0.0000	0.1490	0.5270	0.0000
411	540Y60-540B40	0.2700	0.5120	0.0000	0.1410	0.5000	0.0000
412	540Y65-540B35	0.2800	0.5310	0.0000	0.1330	0.4700	0.0000
413	540Y70-540B30	0.2890	0.5490	0.0000	0.1240	0.4380	0.0000
414	540G35-540B65	0.0380	0.4480	0.0900	0.1760	0.6230	0.0000
415	540G40-540B60	0.0400	0.4760	0.0960	0.1690	0.6010	0.0000
416	540G45-540B55	0.0420	0.5030	0.1010	0.1630	0.5770	0.0000
417	540G50-540B50	0.0440	0.5270	0.1060	0.1560	0.5530	0.0000
418	540G55-540B45	0.0460	0.5510	0.1110	0.1490	0.5270	0.0000
419	540G60-540B40	0.0480	0.5730	0.1150	0.1410	0.5000	0.0000
420	540G65-540B35	0.0500	0.5940	0.1190	0.1330	0.4700	0.0000
421	540G70-540B30	0.0510	0.6140	0.1240	0.1240	0.4380	0.0000
422	555R35-555Y65	0.9400	0.5930	0.2090	1.0000	1.0000	0.0000
423	555R40-555Y60	0.9990	0.6300	0.2220	1.0000	0.9800	0.0000
424	555R45-555Y55	1.0000	0.6650	0.2350	1.0000	0.9420	0.0000
425	555R50-555Y50	1.0000	0.6970	0.2460	0.9660	0.9020	0.0000
426	555R55-555Y45	1.0000	0.7280	0.2570	0.9200	0.8600	0.0000
427	555R60-555Y40	1.0000	0.7580	0.2680	0.8720	0.8150	0.0000
428	555R65-555Y35	1.0000	0.7860	0.2770	0.8210	0.7670	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
429	555R35-555G65	0.9400	0.5930	0.2090	0.6610	1.0000	0.6500
430	555R40-555G60	0.9990	0.6300	0.2220	0.6370	1.0000	0.6270
431	555R45-555G55	1.0000	0.6650	0.2350	0.6120	0.9730	0.6030
432	555R50-555G50	1.0000	0.6970	0.2460	0.5860	0.9310	0.5770
433	555R55-555G45	1.0000	0.7280	0.2570	0.5590	0.8880	0.5500
434	555R60-555G40	1.0000	0.7580	0.2680	0.5300	0.8410	0.5220
435	555R65-555G35	1.0000	0.7860	0.2770	0.4990	0.7920	0.4910
436	555R35-555B65	0.9400	0.5930	0.2090	0.7350	1.0000	0.3450
437	555R40-555B60	0.9990	0.6300	0.2220	0.7090	1.0000	0.3330
438	555R45-555B55	1.0000	0.6650	0.2350	0.6810	1.0000	0.3200
439	555R50-555B50	1.0000	0.6970	0.2460	0.6530	1.0000	0.3060
440	555R55-555B45	1.0000	0.7280	0.2570	0.6220	0.9560	0.2920
441	555R60-555B40	1.0000	0.7580	0.2680	0.5900	0.9060	0.2770
442	555R65-555B35	1.0000	0.7860	0.2770	0.5550	0.8530	0.2610
443	555Y35-555G65	0.8210	0.7670	0.0000	0.6610	1.0000	0.6500
444	555Y40-555G60	0.8720	0.8150	0.0000	0.6370	1.0000	0.6270
445	555Y45-555G55	0.9200	0.8600	0.0000	0.6120	0.9730	0.6030
446	555Y50-555G50	0.9660	0.9020	0.0000	0.5860	0.9310	0.5770
447	555Y55-555G45	1.0000	0.9420	0.0000	0.5590	0.8880	0.5500
448	555Y60-555G40	1.0000	0.9800	0.0000	0.5300	0.8410	0.5220
449	555Y65-555G35	1.0000	1.0000	0.0000	0.4990	0.7920	0.4910
450	555Y35-555B65	0.8210	0.7670	0.0000	0.7350	1.0000	0.3450
451	555Y40-555B60	0.8720	0.8150	0.0000	0.7090	1.0000	0.3330
452	555Y45-555B55	0.9200	0.8600	0.0000	0.6810	1.0000	0.3200
453	555Y50-555B50	0.9660	0.9020	0.0000	0.6530	1.0000	0.3060
454	555Y55-555B45	1.0000	0.9420	0.0000	0.6220	0.9560	0.2920
455	555Y60-555B40	1.0000	0.9800	0.0000	0.5900	0.9060	0.2770
456	555Y65-555B35	1.0000	1.0000	0.0000	0.5550	0.8530	0.2610
457	555G35-555B65	0.4990	0.7920	0.4910	0.7350	1.0000	0.3450
458	555G40-555B60	0.5300	0.8410	0.5220	0.7090	1.0000	0.3330
459	555G45-555B55	0.5590	0.8880	0.5500	0.6810	1.0000	0.3200
460	555G50-555B50	0.5860	0.9310	0.5770	0.6530	1.0000	0.3060
461	555G55-555B45	0.6120	0.9730	0.6030	0.6220	0.9560	0.2920

	Color pair	C1			C2		
		R	G	B	R	G	B
462	555G60-555B40	0.6370	1.0000	0.6270	0.5900	0.9060	0.2770
463	555G65-555B35	0.6610	1.0000	0.6500	0.5550	0.8530	0.2610
464	595R25-595Y75	0.5150	0.2330	0.0000	0.7140	0.3440	0.0000
465	595R30-595Y70	0.5590	0.2540	0.0000	0.6920	0.3330	0.0000
466	595R35-595Y65	0.6000	0.2720	0.0000	0.6690	0.3220	0.0000
467	595R40-595Y60	0.6370	0.2890	0.0000	0.6450	0.3110	0.0000
468	595R45-595Y55	0.6730	0.3050	0.0000	0.6200	0.2990	0.0000
469	595R50-595Y50	0.7060	0.3200	0.0000	0.5940	0.2860	0.0000
470	595R55-595Y45	0.7370	0.3340	0.0000	0.5660	0.2730	0.0000
471	595R60-595Y40	0.7660	0.3480	0.0000	0.5370	0.2580	0.0000
472	595R5-595G95	0.2480	0.1120	0.0000	0.5090	0.2580	0.0000
473	595R10-595G90	0.3390	0.1540	0.0000	0.4960	0.2520	0.0000
474	595R15-595G85	0.4080	0.1850	0.0000	0.4840	0.2450	0.0000
475	595R20-595G80	0.4650	0.2110	0.0000	0.4700	0.2390	0.0000
476	595R25-595G75	0.5150	0.2330	0.0000	0.4570	0.2320	0.0000
477	595R30-595G70	0.5590	0.2540	0.0000	0.4430	0.2250	0.0000
478	595R35-595G65	0.6000	0.2720	0.0000	0.4280	0.2170	0.0000
479	595R40-595G60	0.6370	0.2890	0.0000	0.4130	0.2090	0.0000
480	595R10-595B90	0.3390	0.1540	0.0000	0.5280	0.2840	0.0000
481	595R15-595B85	0.4080	0.1850	0.0000	0.5140	0.2770	0.0000
482	595R20-595B80	0.4650	0.2110	0.0000	0.5000	0.2690	0.0000
483	595R25-595B75	0.5150	0.2330	0.0000	0.4860	0.2610	0.0000
484	595R30-595B70	0.5590	0.2540	0.0000	0.4710	0.2530	0.0000
485	595R35-595B65	0.6000	0.2720	0.0000	0.4550	0.2450	0.0000
486	595R40-595B60	0.6370	0.2890	0.0000	0.4390	0.2360	0.0000
487	595R45-595B55	0.6730	0.3050	0.0000	0.4220	0.2270	0.0000
488	595Y10-595G90	0.2860	0.1380	0.0000	0.4960	0.2520	0.0000
489	595Y15-595G85	0.3430	0.1650	0.0000	0.4840	0.2450	0.0000
490	595Y20-595G80	0.3910	0.1890	0.0000	0.4700	0.2390	0.0000
491	595Y25-595G75	0.4330	0.2090	0.0000	0.4570	0.2320	0.0000
492	595Y30-595G70	0.4710	0.2270	0.0000	0.4430	0.2250	0.0000
493	595Y35-595G65	0.5050	0.2430	0.0000	0.4280	0.2170	0.0000
494	595Y40-595G60	0.5370	0.2580	0.0000	0.4130	0.2090	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
495	595Y45-595G55	0.5660	0.2730	0.0000	0.3970	0.2010	0.0000
496	595Y15-595B85	0.3430	0.1650	0.0000	0.5140	0.2770	0.0000
497	595Y20-595B80	0.3910	0.1890	0.0000	0.5000	0.2690	0.0000
498	595Y25-595B75	0.4330	0.2090	0.0000	0.4860	0.2610	0.0000
499	595Y30-595B70	0.4710	0.2270	0.0000	0.4710	0.2530	0.0000
500	595Y35-595B65	0.5050	0.2430	0.0000	0.4550	0.2450	0.0000
501	595Y40-595B60	0.5370	0.2580	0.0000	0.4390	0.2360	0.0000
502	595Y45-595B55	0.5660	0.2730	0.0000	0.4220	0.2270	0.0000
503	595Y50-595B50	0.5940	0.2860	0.0000	0.4040	0.2170	0.0000
504	595G35-595B65	0.3230	0.1640	0.0000	0.4550	0.2450	0.0000
505	595G40-595B60	0.3430	0.1740	0.0000	0.4390	0.2360	0.0000
506	595G45-595B55	0.3620	0.1840	0.0000	0.4220	0.2270	0.0000
507	595G50-595B50	0.3800	0.1930	0.0000	0.4040	0.2170	0.0000
508	595G55-595B45	0.3970	0.2010	0.0000	0.3850	0.2070	0.0000
509	595G60-595B40	0.4130	0.2090	0.0000	0.3650	0.1960	0.0000
510	595G65-595B35	0.4280	0.2170	0.0000	0.3430	0.1850	0.0000
511	595G70-595B30	0.4430	0.2250	0.0000	0.3200	0.1720	0.0000
512	595G75-595B25	0.4570	0.2320	0.0000	0.2950	0.1590	0.0000
513	615R20-615Y80	0.4120	0.0000	0.0000	0.6190	0.0000	0.0000
514	615R25-615Y75	0.4560	0.0000	0.0000	0.6010	0.0000	0.0000
515	615R30-615Y70	0.4950	0.0000	0.0000	0.5830	0.0000	0.0000
516	615R35-615Y65	0.5310	0.0000	0.0000	0.5630	0.0000	0.0000
517	615R40-615Y60	0.5650	0.0000	0.0000	0.5430	0.0000	0.0000
518	615R45-615Y55	0.5960	0.0000	0.0000	0.5220	0.0000	0.0000
519	615R50-615Y50	0.6250	0.0000	0.0000	0.5000	0.0000	0.0000
520	615R55-615Y45	0.6530	0.0000	0.0000	0.4770	0.0000	0.0000
521	615R60-615Y40	0.6790	0.0000	0.0000	0.4520	0.0000	0.0000
522	615R5-615G95	0.2190	0.0000	0.0000	0.4150	0.0000	0.0000
523	615R10-615G90	0.3010	0.0000	0.0000	0.4050	0.0000	0.0000
524	615R15-615G85	0.3620	0.0000	0.0000	0.3940	0.0000	0.0000
525	615R20-615G80	0.4120	0.0000	0.0000	0.3840	0.0000	0.0000
526	615R25-615G75	0.4560	0.0000	0.0000	0.3730	0.0000	0.0000
527	615R30-615G70	0.4950	0.0000	0.0000	0.3610	0.0000	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
528	615R35-615G65	0.5310	0.0000	0.0000	0.3490	0.0000	0.0000
529	615R5-615B95	0.2190	0.0000	0.0000	0.3860	0.0640	0.0000
530	615R10-615B90	0.3010	0.0000	0.0000	0.3770	0.0620	0.0000
531	615R15-615B85	0.3620	0.0000	0.0000	0.3670	0.0600	0.0000
532	615R20-615B80	0.4120	0.0000	0.0000	0.3570	0.0590	0.0000
533	615R25-615B75	0.4560	0.0000	0.0000	0.3470	0.0570	0.0000
534	615R30-615B70	0.4950	0.0000	0.0000	0.3360	0.0550	0.0000
535	615R35-615B65	0.5310	0.0000	0.0000	0.3250	0.0540	0.0000
536	615Y10-615G90	0.2410	0.0000	0.0000	0.4050	0.0000	0.0000
537	615Y15-615G85	0.2890	0.0000	0.0000	0.3940	0.0000	0.0000
538	615Y20-615G80	0.3300	0.0000	0.0000	0.3840	0.0000	0.0000
539	615Y25-615G75	0.3650	0.0000	0.0000	0.3730	0.0000	0.0000
540	615Y30-615G70	0.3960	0.0000	0.0000	0.3610	0.0000	0.0000
541	615Y35-615G65	0.4250	0.0000	0.0000	0.3490	0.0000	0.0000
542	615Y40-615G60	0.4520	0.0000	0.0000	0.3370	0.0000	0.0000
543	615Y45-615G55	0.4770	0.0000	0.0000	0.3240	0.0000	0.0000
544	615Y5-615B95	0.1760	0.0000	0.0000	0.3860	0.0640	0.0000
545	615Y10-615B90	0.2410	0.0000	0.0000	0.3770	0.0620	0.0000
546	615Y15-615B85	0.2890	0.0000	0.0000	0.3670	0.0600	0.0000
547	615Y20-615B80	0.3300	0.0000	0.0000	0.3570	0.0590	0.0000
548	615Y25-615B75	0.3650	0.0000	0.0000	0.3470	0.0570	0.0000
549	615Y30-615B70	0.3960	0.0000	0.0000	0.3360	0.0550	0.0000
550	615Y35-615B65	0.4250	0.0000	0.0000	0.3250	0.0540	0.0000
551	615Y40-615B60	0.4520	0.0000	0.0000	0.3130	0.0520	0.0000
552	615Y45-615B55	0.4770	0.0000	0.0000	0.3010	0.0500	0.0000
553	615G25-615B75	0.2260	0.0000	0.0000	0.3470	0.0570	0.0000
554	615G30-615B70	0.2460	0.0000	0.0000	0.3360	0.0550	0.0000
555	615G35-615B65	0.2640	0.0000	0.0000	0.3250	0.0540	0.0000
556	615G40-615B60	0.2800	0.0000	0.0000	0.3130	0.0520	0.0000
557	615G45-615B55	0.2950	0.0000	0.0000	0.3010	0.0500	0.0000
558	615G50-615B50	0.3100	0.0000	0.0000	0.2890	0.0480	0.0000
559	615G55-615B45	0.3240	0.0000	0.0000	0.2750	0.0450	0.0000
560	615G60-615B40	0.3370	0.0000	0.0000	0.2610	0.0430	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
561	615G65-615B35	0.3490	0.0000	0.0000	0.2450	0.0400	0.0000
562	615G70-615B30	0.3610	0.0000	0.0000	0.2290	0.0380	0.0000
563	630R20-630Y80	0.4780	0.0000	0.0000	0.7220	0.0000	0.0000
564	630R25-630Y75	0.5290	0.0000	0.0000	0.7020	0.0000	0.0000
565	630R30-630Y70	0.5740	0.0000	0.0000	0.6800	0.0000	0.0000
566	630R35-630Y65	0.6160	0.0000	0.0000	0.6570	0.0000	0.0000
567	630R40-630Y60	0.6550	0.0000	0.0000	0.6340	0.0000	0.0000
568	630R45-630Y55	0.6910	0.0000	0.0000	0.6090	0.0000	0.0000
569	630R50-630Y50	0.7240	0.0000	0.0000	0.5830	0.0000	0.0000
570	630R55-630Y45	0.7570	0.0000	0.0000	0.5560	0.0000	0.0000
571	630R5-630G95	0.2540	0.0000	0.0000	0.4640	0.0000	0.0000
572	630R10-630G90	0.3480	0.0000	0.0000	0.4530	0.0000	0.0000
573	630R15-630G85	0.4190	0.0000	0.0000	0.4410	0.0000	0.0000
574	630R20-630G80	0.4780	0.0000	0.0000	0.4290	0.0000	0.0000
575	630R25-630G75	0.5290	0.0000	0.0000	0.4170	0.0000	0.0000
576	630R30-630G70	0.5740	0.0000	0.0000	0.4040	0.0000	0.0000
577	630R5-630B95	0.2540	0.0000	0.0000	0.4070	0.0000	0.0000
578	630R10-630B90	0.3480	0.0000	0.0000	0.3980	0.0000	0.0000
579	630R15-630B85	0.4190	0.0000	0.0000	0.3870	0.0000	0.0000
580	630R20-630B80	0.4780	0.0000	0.0000	0.3770	0.0000	0.0000
581	630R25-630B75	0.5290	0.0000	0.0000	0.3660	0.0000	0.0000
582	630R30-630B70	0.5740	0.0000	0.0000	0.3550	0.0000	0.0000
583	630Y10-630G90	0.2810	0.0000	0.0000	0.4530	0.0000	0.0000
584	630Y15-630G85	0.3370	0.0000	0.0000	0.4410	0.0000	0.0000
585	630Y20-630G80	0.3850	0.0000	0.0000	0.4290	0.0000	0.0000
586	630Y25-630G75	0.4260	0.0000	0.0000	0.4170	0.0000	0.0000
587	630Y30-630G70	0.4620	0.0000	0.0000	0.4040	0.0000	0.0000
588	630Y35-630G65	0.4960	0.0000	0.0000	0.3910	0.0000	0.0000
589	630Y40-630G60	0.5270	0.0000	0.0000	0.3770	0.0000	0.0000
590	630Y5-630B95	0.2050	0.0000	0.0000	0.4070	0.0000	0.0000
591	630Y10-630B90	0.2810	0.0000	0.0000	0.3980	0.0000	0.0000
592	630Y15-630B85	0.3370	0.0000	0.0000	0.3870	0.0000	0.0000
593	630Y20-630B80	0.3850	0.0000	0.0000	0.3770	0.0000	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
594	630Y25-630B75	0.4260	0.0000	0.0000	0.3660	0.0000	0.0000
595	630Y30-630B70	0.4620	0.0000	0.0000	0.3550	0.0000	0.0000
596	630Y35-630B65	0.4960	0.0000	0.0000	0.3430	0.0000	0.0000
597	630Y40-630B60	0.5270	0.0000	0.0000	0.3310	0.0000	0.0000
598	630G20-630B80	0.2290	0.0000	0.0000	0.3770	0.0000	0.0000
599	630G25-630B75	0.2530	0.0000	0.0000	0.3660	0.0000	0.0000
600	630G30-630B70	0.2750	0.0000	0.0000	0.3550	0.0000	0.0000
601	630G35-630B65	0.2950	0.0000	0.0000	0.3430	0.0000	0.0000
602	630G40-630B60	0.3130	0.0000	0.0000	0.3310	0.0000	0.0000
603	630G45-630B55	0.3300	0.0000	0.0000	0.3180	0.0000	0.0000
604	630G50-630B50	0.3470	0.0000	0.0000	0.3040	0.0000	0.0000
605	630G55-630B45	0.3620	0.0000	0.0000	0.2900	0.0000	0.0000
606	630G60-630B40	0.3770	0.0000	0.0000	0.2750	0.0000	0.0000
607	630G65-630B35	0.3910	0.0000	0.0000	0.2590	0.0000	0.0000
608	660R20-660Y80	0.3260	0.0000	0.0000	0.4810	0.0000	0.0000
609	660R25-660Y75	0.3610	0.0000	0.0000	0.4670	0.0000	0.0000
610	660R30-660Y70	0.3920	0.0000	0.0000	0.4520	0.0000	0.0000
611	660R35-660Y65	0.4200	0.0000	0.0000	0.4370	0.0000	0.0000
612	660R40-660Y60	0.4460	0.0000	0.0000	0.4220	0.0000	0.0000
613	660R45-660Y55	0.4710	0.0000	0.0000	0.4050	0.0000	0.0000
614	660R50-660Y50	0.4940	0.0000	0.0000	0.3880	0.0000	0.0000
615	660R55-660Y45	0.5160	0.0000	0.0000	0.3700	0.0000	0.0000
616	660R5-660G95	0.1730	0.0000	0.0000	0.3180	0.0000	0.0000
617	660R10-660G90	0.2380	0.0000	0.0000	0.3100	0.0000	0.0000
618	660R15-660G85	0.2860	0.0000	0.0000	0.3020	0.0000	0.0000
619	660R20-660G80	0.3260	0.0000	0.0000	0.2940	0.0000	0.0000
620	660R25-660G75	0.3610	0.0000	0.0000	0.2860	0.0000	0.0000
621	660R30-660G70	0.3920	0.0000	0.0000	0.2770	0.0000	0.0000
622	660R35-660G65	0.4200	0.0000	0.0000	0.2680	0.0000	0.0000
623	660R5-660B95	0.1730	0.0000	0.0000	0.2650	0.0000	0.0000
624	660R10-660B90	0.2380	0.0000	0.0000	0.2580	0.0000	0.0000
625	660R15-660B85	0.2860	0.0000	0.0000	0.2520	0.0000	0.0000
626	660R20-660B80	0.3260	0.0000	0.0000	0.2450	0.0000	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
627	660R25-660B75	0.3610	0.0000	0.0000	0.2380	0.0000	0.0000
628	660R30-660B70	0.3920	0.0000	0.0000	0.2300	0.0000	0.0000
629	660Y5-660G95	0.1360	0.0000	0.0000	0.3180	0.0000	0.0000
630	660Y10-660G90	0.1870	0.0000	0.0000	0.3100	0.0000	0.0000
631	660Y15-660G85	0.2240	0.0000	0.0000	0.3020	0.0000	0.0000
632	660Y20-660G80	0.2560	0.0000	0.0000	0.2940	0.0000	0.0000
633	660Y25-660G75	0.2830	0.0000	0.0000	0.2860	0.0000	0.0000
634	660Y30-660G70	0.3080	0.0000	0.0000	0.2770	0.0000	0.0000
635	660Y35-660G65	0.3300	0.0000	0.0000	0.2680	0.0000	0.0000
636	660Y40-660G60	0.3510	0.0000	0.0000	0.2580	0.0000	0.0000
637	660Y45-660G55	0.3700	0.0000	0.0000	0.2480	0.0000	0.0000
638	660Y5-660B95	0.1360	0.0000	0.0000	0.2650	0.0000	0.0000
639	660Y10-660B90	0.1870	0.0000	0.0000	0.2580	0.0000	0.0000
640	660Y15-660B85	0.2240	0.0000	0.0000	0.2520	0.0000	0.0000
641	660Y20-660B80	0.2560	0.0000	0.0000	0.2450	0.0000	0.0000
642	660Y25-660B75	0.2830	0.0000	0.0000	0.2380	0.0000	0.0000
643	660Y30-660B70	0.3080	0.0000	0.0000	0.2300	0.0000	0.0000
644	660Y35-660B65	0.3300	0.0000	0.0000	0.2230	0.0000	0.0000
645	660Y40-660B60	0.3510	0.0000	0.0000	0.2150	0.0000	0.0000
646	660G20-660B80	0.1570	0.0000	0.0000	0.2450	0.0000	0.0000
647	660G25-660B75	0.1730	0.0000	0.0000	0.2380	0.0000	0.0000
648	660G30-660B70	0.1880	0.0000	0.0000	0.2300	0.0000	0.0000
649	660G35-660B65	0.2020	0.0000	0.0000	0.2230	0.0000	0.0000
650	660G40-660B60	0.2150	0.0000	0.0000	0.2150	0.0000	0.0000
651	660G45-660B55	0.2270	0.0000	0.0000	0.2060	0.0000	0.0000
652	660G50-660B50	0.2380	0.0000	0.0000	0.1980	0.0000	0.0000
653	660G55-660B45	0.2480	0.0000	0.0000	0.1880	0.0000	0.0000
654	660G60-660B40	0.2580	0.0000	0.0000	0.1790	0.0000	0.0000
655	700R40-700Y60	0.1460	0.0000	0.0000	0.1370	0.0000	0.0000
656	700R45-700Y55	0.1540	0.0000	0.0000	0.1320	0.0000	0.0000
657	700R50-700Y50	0.1610	0.0000	0.0000	0.1260	0.0000	0.0000
658	700R55-700Y45	0.1690	0.0000	0.0000	0.1200	0.0000	0.0000
659	700R60-700Y40	0.1750	0.0000	0.0000	0.1140	0.0000	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
660	700R65-700Y35	0.1820	0.0000	0.0000	0.1070	0.0000	0.0000
661	700R50-700G50	0.1610	0.0000	0.0000	0.0780	0.0000	0.0000
662	700R55-700G45	0.1690	0.0000	0.0000	0.0740	0.0000	0.0000
663	700R60-700G40	0.1750	0.0000	0.0000	0.0700	0.0000	0.0000
664	700R65-700G35	0.1820	0.0000	0.0000	0.0660	0.0000	0.0000
665	700R70-700G30	0.1880	0.0000	0.0000	0.0620	0.0000	0.0000
666	700R75-700G25	0.1940	0.0000	0.0000	0.0570	0.0000	0.0000
667	700R40-700B60	0.1460	0.0000	0.0000	0.0730	0.0000	0.0000
668	700R45-700B55	0.1540	0.0000	0.0000	0.0700	0.0000	0.0000
669	700R50-700B50	0.1610	0.0000	0.0000	0.0670	0.0000	0.0000
670	700R55-700B45	0.1690	0.0000	0.0000	0.0640	0.0000	0.0000
671	700R60-700B40	0.1750	0.0000	0.0000	0.0610	0.0000	0.0000
672	700R65-700B35	0.1820	0.0000	0.0000	0.0570	0.0000	0.0000
673	700Y65-700G35	0.1420	0.0000	0.0000	0.0660	0.0000	0.0000
674	700Y70-700G30	0.1470	0.0000	0.0000	0.0620	0.0000	0.0000
675	700Y75-700G25	0.1510	0.0000	0.0000	0.0570	0.0000	0.0000
676	700Y80-700G20	0.1560	0.0000	0.0000	0.0510	0.0000	0.0000
677	700Y85-700G15	0.1600	0.0000	0.0000	0.0450	0.0000	0.0000
678	700Y90-700G10	0.1650	0.0000	0.0000	0.0370	0.0000	0.0000
679	700Y60-700B40	0.1370	0.0000	0.0000	0.0610	0.0000	0.0000
680	700Y65-700B35	0.1420	0.0000	0.0000	0.0570	0.0000	0.0000
681	700Y70-700B30	0.1470	0.0000	0.0000	0.0530	0.0000	0.0000
682	700Y75-700B25	0.1510	0.0000	0.0000	0.0490	0.0000	0.0000
683	700Y80-700B20	0.1560	0.0000	0.0000	0.0440	0.0000	0.0000
684	700Y85-700B15	0.1600	0.0000	0.0000	0.0390	0.0000	0.0000
685	410R-410Y	0.1090	0.0000	0.3410	0.0680	0.0000	0.2190
686	410R-410G	0.1090	0.0000	0.3410	0.1380	0.0000	0.4920
687	410R-410B	0.1090	0.0000	0.3410	0.0900	0.0000	0.3020
688	410Y-410G	0.0680	0.0000	0.2190	0.1380	0.0000	0.4920
689	410Y-410B	0.0680	0.0000	0.2190	0.0900	0.0000	0.3020
690	410G-410B	0.1380	0.0000	0.4920	0.0900	0.0000	0.3020
691	420R-420Y	0.1550	0.0000	0.5210	0.1020	0.0000	0.3440
692	420R-420G	0.1550	0.0000	0.5210	0.2230	0.0000	0.7920

	Color pair	C1			C2		
		R	G	B	R	G	B
693	420R-420B	0.1550	0.0000	0.5210	0.1420	0.0000	0.4960
694	420Y-420G	0.1020	0.0000	0.3440	0.2230	0.0000	0.7920
695	420Y-420B	0.1020	0.0000	0.3440	0.1420	0.0000	0.4960
696	420G-420B	0.2230	0.0000	0.7920	0.1420	0.0000	0.4960
697	435R-435Y	0.1750	0.0000	0.6590	0.1150	0.0000	0.4390
698	435R-435G	0.1750	0.0000	0.6590	0.2600	0.0000	1.0000
699	435R-435B	0.1750	0.0000	0.6590	0.1610	0.0000	0.6450
700	435Y-435G	0.1150	0.0000	0.4390	0.2600	0.0000	1.0000
701	435Y-435B	0.1150	0.0000	0.4390	0.1610	0.0000	0.6450
702	435G-435B	0.2600	0.0000	1.0000	0.1610	0.0000	0.6450
703	455R-455Y	0.0000	0.0000	0.6920	0.0000	0.0000	0.4700
704	455R-455G	0.0000	0.0000	0.6920	0.0000	0.0000	1.0000
705	455R-455B	0.0000	0.0000	0.6920	0.0000	0.0000	0.7620
706	455Y-455G	0.0000	0.0000	0.4700	0.0000	0.0000	1.0000
707	455Y-455B	0.0000	0.0000	0.4700	0.0000	0.0000	0.7620
708	455G-455B	0.0000	0.0000	1.0000	0.0000	0.0000	0.7620
709	475R-475Y	0.0000	0.1810	0.4170	0.0000	0.1730	0.2950
710	475R-475G	0.0000	0.1810	0.4170	0.0000	0.3770	0.7870
711	475R-475B	0.0000	0.1810	0.4170	0.0000	0.3180	0.5320
712	475Y-475G	0.0000	0.1730	0.2950	0.0000	0.3770	0.7870
713	475Y-475B	0.0000	0.1730	0.2950	0.0000	0.3180	0.5320
714	475G-475B	0.0000	0.3770	0.7870	0.0000	0.3180	0.5320
715	495R-495Y	0.0000	0.4150	0.3300	0.0000	0.4600	0.2490
716	495R-495G	0.0000	0.4150	0.3300	0.0000	0.8210	0.6650
717	495R-495B	0.0000	0.4150	0.3300	0.0000	0.7430	0.5040
718	495Y-495G	0.0000	0.4600	0.2490	0.0000	0.8210	0.6650
719	495Y-495B	0.0000	0.4600	0.2490	0.0000	0.7430	0.5040
720	495G-495B	0.0000	0.8210	0.6650	0.0000	0.7430	0.5040
721	525R-525Y	0.0970	0.3570	0.0690	0.0830	0.4850	0.0000
722	525R-525G	0.0970	0.3570	0.0690	0.0000	0.6250	0.1790
723	525R-525B	0.0970	0.3570	0.0690	0.0000	0.6220	0.1170
724	525Y-525G	0.0830	0.4850	0.0000	0.0000	0.6250	0.1790
725	525Y-525B	0.0830	0.4850	0.0000	0.0000	0.6220	0.1170

	Color pair	C1			C2		
		R	G	B	R	G	B
726	525G-525B	0.0000	0.6250	0.1790	0.0000	0.6220	0.1170
727	540R-540Y	0.3350	0.4670	0.0000	0.3400	0.6460	0.0000
728	540R-540G	0.3350	0.4670	0.0000	0.0610	0.7230	0.1450
729	540R-540B	0.3350	0.4670	0.0000	0.2140	0.7580	0.0000
730	540Y-540G	0.3400	0.6460	0.0000	0.0610	0.7230	0.1450
731	540Y-540B	0.3400	0.6460	0.0000	0.2140	0.7580	0.0000
732	540G-540B	0.0610	0.7230	0.1450	0.2140	0.7580	0.0000
733	555R-555Y	1.0000	0.9560	0.3370	1.0000	1.0000	0.0000
734	555R-555G	1.0000	0.9560	0.3370	0.8040	1.0000	0.7910
735	555R-555B	1.0000	0.9560	0.3370	0.8940	1.0000	0.4200
736	555Y-555G	1.0000	1.0000	0.0000	0.8040	1.0000	0.7910
737	555Y-555B	1.0000	1.0000	0.0000	0.8940	1.0000	0.4200
738	555G-555B	0.8040	1.0000	0.7910	0.8940	1.0000	0.4200
739	595R-595Y	0.9670	0.4380	0.0000	0.8140	0.3920	0.0000
740	595R-595G	0.9670	0.4380	0.0000	0.5210	0.2640	0.0000
741	595R-595B	0.9670	0.4380	0.0000	0.5540	0.2980	0.0000
742	595Y-595G	0.8140	0.3920	0.0000	0.5210	0.2640	0.0000
743	595Y-595B	0.8140	0.3920	0.0000	0.5540	0.2980	0.0000
744	595G-595B	0.5210	0.2640	0.0000	0.5540	0.2980	0.0000
745	615R-615Y	0.8570	0.0000	0.0000	0.6850	0.0000	0.0000
746	615R-615G	0.8570	0.0000	0.0000	0.4250	0.0000	0.0000
747	615R-615B	0.8570	0.0000	0.0000	0.3950	0.0650	0.0000
748	615Y-615G	0.6850	0.0000	0.0000	0.4250	0.0000	0.0000
749	615Y-615B	0.6850	0.0000	0.0000	0.3950	0.0650	0.0000
750	615G-615B	0.4250	0.0000	0.0000	0.3950	0.0650	0.0000
751	630R-630Y	0.9930	0.0000	0.0000	0.8000	0.0000	0.0000
752	630R-630G	0.9930	0.0000	0.0000	0.4750	0.0000	0.0000
753	630R-630B	0.9930	0.0000	0.0000	0.4170	0.0000	0.0000
754	630Y-630G	0.8000	0.0000	0.0000	0.4750	0.0000	0.0000
755	630Y-630B	0.8000	0.0000	0.0000	0.4170	0.0000	0.0000
756	630G-630B	0.4750	0.0000	0.0000	0.4170	0.0000	0.0000
757	660R-660Y	0.6770	0.0000	0.0000	0.5320	0.0000	0.0000
758	660R-660G	0.6770	0.0000	0.0000	0.3260	0.0000	0.0000

	Color pair	C1			C2		
		R	G	B	R	G	B
759	660R-660B	0.6770	0.0000	0.0000	0.2710	0.0000	0.0000
760	660Y-660G	0.5320	0.0000	0.0000	0.3260	0.0000	0.0000
761	660Y-660B	0.5320	0.0000	0.0000	0.2710	0.0000	0.0000
762	660G-660B	0.3260	0.0000	0.0000	0.2710	0.0000	0.0000
763	700R-700Y	0.2210	0.0000	0.0000	0.1730	0.0000	0.0000
764	700R-700G	0.2210	0.0000	0.0000	0.1070	0.0000	0.0000
765	700R-700B	0.2210	0.0000	0.0000	0.0920	0.0000	0.0000
766	700Y-700G	0.1730	0.0000	0.0000	0.1070	0.0000	0.0000
767	700Y-700B	0.1730	0.0000	0.0000	0.0920	0.0000	0.0000
768	700G-700B	0.1070	0.0000	0.0000	0.0920	0.0000	0.0000

Table C-2 Color difference (ΔE^*_{ab}) of 768 colored pairs

	Color pair	ΔE^*_{ab} Normal		ΔE^*_{ab} CVG		ΔE^*_{ab} BVG	
		35	70	35	70	35	70
1	410R65-410Y35	22.5	24.8	7	3.8	21.3	22.7
2	410R70-410Y30	25.1	27.3	8.1	4.3	23.9	25.8
3	410R75-410Y25	27.2	29.5	8.4	4.5	26	27.4
4	410R80-410Y20	30.2	32.6	9.7	5.2	28.4	30.6
5	410R85-410Y15	32.5	34.9	10.6	5.9	30.5	33.3
6	410R90-410Y10	34.6	37.4	11.5	6.2	33.1	35.4
7	410R30-410G70	28.6	33	13.1	8.1	28.1	32.3
8	410R35-410G65	24.3	28.2	11.4	6.9	24.1	27.5
9	410R40-410G60	20.9	23.9	9.9	5.7	20.6	23.6
10	410R45-410G55	18.5	21.5	8.6	4.9	17.8	20.5
11	410R50-410G50	14.3	17	6.8	3.7	13.5	16.5
12	410R55-410G45	10.7	12.4	4.8	2.9	10.2	12.4
13	410R60-410G40	7	8.4	3.4	2	6.8	8.5
14	410R65-410G35	3.1	2.6	1.5	0.8	2.8	3.3
15	410R70-410G30	1.2	1.5	0.6	0.4	1.2	1.2
16	410R75-410G25	5.3	6.1	1.9	1.1	4.9	5.8
17	410R80-410G20	10.8	12.8	4.3	2.3	10.6	11.8
18	410R85-410G15	16.5	18.8	6.3	3.6	16	18.1

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
19	410R10-410B90	24.2	25.9	7.9	3.6	23.3	24.9
20	410R15-410B85	19.9	21.1	6.8	3.2	19.3	21
21	410R20-410B80	17	17.9	5.6	2.7	16.4	17.7
22	410R25-410B75	12.8	13.7	4.6	1.9	12.6	13.6
23	410R30-410B70	8.8	9.5	3	1.5	8.9	9.5
24	410R35-410B65	4.9	5.5	1.8	0.7	5.2	5.4
25	410R40-410B60	1.8	2.4	0.7	0.4	2.2	2.2
26	410R45-410B55	1.3	1.4	0.5	0.6	1	1.5
27	410R50-410B50	4.8	4.9	1.5	1.4	4.6	4.9
28	410R55-410B45	8	8.6	2.8	1.7	7.6	8.3
29	410R60-410B40	11.9	12.5	4	2.5	10.9	12
30	410R65-410B35	14.9	17.2	5.1	3.2	14.1	15.6
31	410R70-410B30	17.9	20	5.9	3.7	16.8	19
32	410R75-410B25	21.1	23.4	7.1	4.1	20.3	21.8
33	410R80-410B20	25.2	27.9	8.5	4.7	23.7	25.9
34	410Y55-410G45	25.1	27.7	9.6	5.3	23.9	26.8
35	410Y60-410G40	22.5	25.1	8.2	4.5	21.5	24.5
36	410Y65-410G35	18.8	20.6	6.8	3.7	17.9	19.8
37	410Y70-410G30	15.6	17.3	5.6	2.8	15	16.6
38	410Y75-410G25	11	12.4	4	2	10.4	10.9
39	410Y80-410G20	6.3	6.6	2.3	1.1	5.6	6.1
40	410Y25-410B75	22	23.4	6.7	3.3	21.5	22.4
41	410Y30-410B70	19.5	20.3	6.1	2.8	18.9	19.8
42	410Y35-410B65	16.9	17.6	5	2.3	16.2	16.9
43	410Y40-410B60	14	15	4.2	1.8	14	14.7
44	410Y45-410B55	11.9	12.8	3.5	1.7	11.5	12.4
45	410Y50-410B50	9.1	9.6	2.8	1	8.8	9
46	410Y55-410B45	6.4	6.7	2	0.9	6.2	6.2
47	410G10-410B90	17.1	18.6	6	2.9	16.4	18
48	410G15-410B85	10.6	11.3	3.9	1.9	10.5	11.3
49	410G20-410B80	5.8	6.4	2	1.1	6	6.4
50	410G25-410B75	0.6	0.9	0.4	0.6	0.4	0.8
51	410G30-410B70	5	5.8	1.8	1.2	4.3	5.2

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
52	410G35-410B65	8.8	9.8	3.5	2.4	8	9.1
53	410G40-410B60	12.8	14.1	5.4	3.4	11.6	13.9
54	410G45-410B55	15.5	17.8	6.7	4	14.7	17.3
55	410G50-410B50	19.1	21.8	8.2	5	18	21.4
56	410G55-410B45	22.7	25.9	9.9	5.9	21.7	25.2
57	420R45-420Y55	12.2	14.8	6.1	3.7	12.2	14.3
58	420R50-420Y50	16.5	19.6	7.9	4.7	16.2	19.1
59	420R55-420Y45	19.9	23.3	9.8	5.6	19.3	23.2
60	420R60-420Y40	24	27.7	11.5	7.1	23.5	27.2
61	420R65-420Y35	28.1	32.4	13.4	8.3	27.3	31.3
62	420R70-420Y30	31.8	36.4	15	9.1	30.2	35.5
63	420R45-420G55	24.1	28.7	16	11.5	24.1	27.7
64	420R50-420G50	19.9	23.3	13.2	9.5	19.5	22.7
65	420R55-420G45	15.8	18.6	10.3	7.3	15.3	17.4
66	420R60-420G40	11.3	13.3	7.4	5.2	10.8	12.6
67	420R65-420G35	6.4	7.7	4.1	2.9	6.4	7.2
68	420R70-420G30	1.6	1.9	1.1	0.9	1.7	1.6
69	420R75-420G25	3.7	4.5	2.5	1.6	3.6	4.5
70	420R80-420G20	9.3	11.1	6.1	4.3	9.4	11
71	420R85-420G15	16.2	18.9	10.1	6.5	16.1	18.9
72	420R90-420G10	24.9	29.2	14.3	9.3	24.5	29
73	420R20-420B80	22.6	26.9	12.3	7.5	22.6	26.6
74	420R25-420B75	17.8	21	9.7	6	17.9	20.4
75	420R30-420B70	12.7	15.1	7.6	4.5	12.8	15.1
76	420R35-420B65	9	10.7	5.6	3.1	9.3	10.7
77	420R40-420B60	4.6	5.9	3.1	1.7	5	5
78	420R45-420B55	1.2	1.7	1	1.2	1.6	1.4
79	420R50-420B50	2.9	3.6	1.6	1.8	2.3	3.1
80	420R55-420B45	6.5	7.5	3.7	2.8	5.8	7.6
81	420R60-420B40	10.6	12.1	5.9	4.1	9.9	12
82	420R65-420B35	14.8	16.9	8.5	5.7	13.6	16.8
83	420R70-420B30	18.8	22.3	10.5	6.8	18.1	21.4
84	420R75-420B25	23.7	28	12.9	8.3	22.7	26.8

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
85	420Y55-420G45	31.9	38	18.7	12.4	31.3	36.3
86	420Y60-420G40	27.3	32.7	16.4	10.5	26.8	31.8
87	420Y65-420G35	23.3	27.8	13.5	8.8	23	27.2
88	420Y70-420G30	18.5	22.3	10.7	7	18.2	21.2
89	420Y75-420G25	13.9	16.4	7.8	5	13.8	16.2
90	420Y80-420G20	8.4	9.9	4.4	2.6	8	9.5
91	420Y45-420B55	17	20.1	8.4	4.6	17	19.8
92	420Y50-420B50	13.6	16	6.4	3.5	13.9	16
93	420Y55-420B45	9.6	12.1	4.8	2.7	10.3	11.4
94	420Y60-420B40	5.4	7.4	3.1	1.7	6.1	7.4
95	420Y65-420B35	2.2	3.2	1.9	1.1	3.1	3.2
96	420Y70-420B30	2	2	1.6	1.2	1.7	1.8
97	420Y75-420B25	6.2	7.3	2.9	2	5.3	6.2
98	420Y80-420B20	10.7	11.9	4.7	3	10	11.9
99	420Y85-420B15	17.3	18.9	6.9	3.8	15.9	18.5
100	420Y90-420B10	23	25.6	9	4.8	22.2	24.7
101	420G5-420B95	33.9	39.1	16.4	10.6	33.6	38.6
102	420G10-420B90	21.3	25.6	11.7	7.2	21.4	25.2
103	420G15-420B85	13	15.6	7.8	4.7	13.6	15.4
104	420G20-420B80	6.4	7.7	4.3	3	6.8	7.7
105	420G25-420B75	0.8	1.2	0.6	0.6	1	1
106	420G30-420B70	5	5.8	2.8	2.3	4.4	5
107	420G35-420B65	9.5	11	5.6	4.3	8.6	10.4
108	420G40-420B60	14.3	16.3	8.7	6.4	13.3	16
109	420G45-420B55	18.6	21.8	11.7	8.7	17.6	20.7
110	420G50-420B50	22.8	26.8	14.8	10.9	21.8	25.9
111	435R5-435Y95	34.3	39.3	15.5	9	33.3	38
112	435R10-435Y90	33.9	27.8	11.9	6.9	23	27
113	435R15-435Y85	15.5	18.2	8.3	5	15.2	17.8
114	435R20-435Y80	9	10.9	5.1	3.2	8.8	10.4
115	435R25-435Y75	3.8	4.7	2.3	1.5	3.8	4.4
116	435R30-435Y70	1	1	0.5	0.3	0.7	1
117	435R35-435Y65	5.1	6.4	3.4	2	5.4	6.2

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
118	435R40-435Y60	9.4	11.2	5.5	3.8	9.3	10.8
119	435R45-435Y55	13.7	16.6	8.4	5.4	13.7	16.1
120	435R50-435Y50	17.7	21	10.8	6.9	17.4	20.5
121	435R55-435Y45	21.5	25.6	13.2	8.5	21.1	24.9
122	435R60-435Y40	26.5	30.9	16.1	10.5	25	29.9
123	435R45-435G55	30.2	35.4	20.7	16.7	29.9	34.4
124	435R50-435G50	25.1	29.2	17.9	14.4	25	28.9
125	435R55-435G45	20.3	23.7	14.1	11.6	20.1	23.1
126	435R60-435G40	15	17.7	10.7	8.6	15.1	17.4
127	435R65-435G35	9.4	10.9	6.6	5.3	9.4	10.8
128	435R70-435G30	3.5	4.5	2.5	2.2	3.7	4.3
129	435R75-435G25	2.4	2.6	1.7	1.2	2.2	2.4
130	435R80-435G20	9.5	11.4	6.8	5	9.2	10.9
131	435R85-435G15	16.9	20	11.7	8.8	16.6	19.4
132	435R90-435G10	26.7	31.2	17.6	12.8	25.8	30.5
133	435R20-435B80	27.3	32.9	16.6	11.6	27.2	31.9
134	435R25-435B75	21.7	25.9	13.4	9.4	21.6	25.2
135	435R30-435B70	16.9	19.9	10.3	7.4	16.9	19.6
136	435R35-435B65	11.7	14.1	7.1	5	11.9	13.9
137	435R40-435B60	6.9	8.8	5	3	7.3	8.6
138	435R45-435B55	2.7	3.1	2.3	1.4	3.1	3.4
139	435R50-435B50	1.8	2	0.9	1.6	1.3	2
140	435R55-435B45	6.4	6.9	4.2	3.5	5.5	6.9
141	435R60-435B40	11	12.1	6.7	5.2	9.9	12
142	435R65-435B35	15.4	17.8	9.7	7.4	14.4	17.2
143	435R70-435B30	20	23.3	12.7	9.4	19.2	22.7
144	435R75-435B25	24.8	29.3	15.6	11.3	23.6	28
145	435Y60-435G40	33.3	39.1	22.1	16.4	32.9	38.5
146	435Y65-435G35	28.1	33.2	18.8	13.8	28	32.6
147	435Y70-435G30	23	26.9	15.2	11.1	22.5	26.5
148	435Y75-435G25	17.3	20.2	11.4	8.1	17	20.2
149	435Y80-435G20	10.6	12.3	6.7	4.8	10.4	12.3
150	435Y85-435G15	3.5	3.7	2	1.4	3.2	3.7

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
151	435Y90-435G10	6.3	7.2	3.7	2.2	5.8	6.9
152	435Y95-435G5	19.8	23.6	10.4	6.7	18.7	22.5
153	435Y45-435B55	19.7	23.6	12.3	7.4	20	23.3
154	435Y50-435B50	15.9	19.2	10	5.8	16.1	18.5
155	435Y55-435B45	11.8	14.6	7.3	4.3	12.3	14.3
156	435Y60-435B40	7.3	9.4	4.8	2.9	7.9	9.1
157	435Y65-435B35	3.4	4.6	2.6	1.4	4.2	4.7
158	435Y70-435B30	0.6	1.3	0.3	0.9	0.5	0.5
159	435Y75-435B25	5.2	6.6	2.6	2.1	4.4	5.5
160	435Y80-435B20	10.8	12.4	5.7	4	10	12.1
161	435Y85-435B15	17.3	20.1	9	5.7	16.5	19.8
162	435Y90-435B10	24.9	29.1	12.1	7.4	23.9	28.1
163	435G10-435B90	25	29.8	16.8	11.4	24.6	29
164	435G15-435B85	15.1	18.6	10.7	7.3	15.4	17.8
165	435G20-435B80	7.7	9.7	5	3.7	8.1	9.3
166	435G25-435B75	0.6	1.2	1.5	1.1	0.9	0.6
167	435G30-435B70	5.1	6	4.8	3.7	4.9	6
168	435G35-435B65	11.3	12.7	8.6	7	10.7	12.6
169	435G40-435B60	17	19.2	11.7	10	16.4	19
170	435G45-435B55	22.1	25.7	15	12.8	21.2	24.8
171	435G50-435B50	26.9	31.1	18.7	15.6	26.3	30.9
172	455R5-455Y95	36.7	42.7	17	10.1	35.7	41.5
173	455R10-455Y90	25.6	30.6	12.7	7.8	24.8	29.3
174	455R15-455Y85	17.2	21	9.4	5.9	17.2	20.3
175	455R20-455Y80	10.4	13	5.9	3.8	10.3	12.7
176	455R25-455Y75	4.8	6.1	2.8	1.8	5	6
177	455R30-455Y70	0.3	0	0.3	0.1	0	0
178	455R35-455Y65	5.1	6.1	3	2	5.1	5.9
179	455R40-455Y60	8.7	10.7	5.4	3.6	8.7	10.5
180	455R45-455Y55	13.6	16.3	8.5	5.6	13.2	16.1
181	455R50-455Y50	17.9	21.8	11	7.4	17.5	21.2
182	455R55-455Y45	21.7	26.5	13.4	8.8	21.5	25.6
183	455R60-455Y40	26.6	32	15.9	11.3	26.1	31

Color pair		ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
184	455R55-455G45	28.4	33.6	20.2	16.9	27.7	32.4
185	455R60-455G40	22.5	26.3	16	13.4	21.8	25.6
186	455R65-455G35	16.7	19.6	11.9	9.7	16.2	18.8
187	455R70-455G30	10.3	12	7.2	5.9	10	11.7
188	455R75-455G25	3.3	3.9	2.2	1.7	3.4	3.6
189	455R80-455G20	4	4.9	2.8	2.3	4	4.7
190	455R85-455G15	12.9	15.3	9.2	6.9	12.4	14.9
191	455R90-455G10	23	27.5	15.6	11.7	22.6	27
192	455R30-455B70	24.2	29.5	16.7	11.6	23.9	28.2
193	455R35-455B65	19.1	23	13.3	9.3	19	22.4
194	455R40-455B60	14.4	17.6	10.3	6.7	14.3	16.9
195	455R45-455B55	9.3	11.5	6.6	4.3	9.4	11
196	455R50-455B50	4.6	5.8	3.6	2.2	4.9	5.6
197	455R55-455B45	0.3	0.7	0.4	0.8	0.3	0.1
198	455R60-455B40	5.2	5.9	3.3	2.9	4.7	5.8
199	455R65-455B35	9.9	11.3	6.1	5.2	9.4	11.2
200	455R70-455B30	15.5	18	9.9	7.9	14.9	17.7
201	455R75-455B25	21.1	24.9	13.8	10.5	20.2	24.3
202	455R80-455B20	27.2	32	17.3	13	26.4	31.4
203	455Y70-455G30	29.6	34.9	19.8	14.9	28.7	33.8
204	455Y75-455G25	23.3	27.3	15.6	11.5	22.5	26.6
205	455Y80-455G20	16	18.8	10.6	7.6	15.6	18.5
206	455Y85-455G15	7.6	9	4.9	3.4	7.7	9
207	455Y90-455G10	2.6	2.9	1.4	1	2.3	3.1
208	455Y95-455G5	16.9	20.8	9.7	6.3	16.6	20.4
209	455Y45-455B55	26.7	32.9	17.2	10.9	26.6	31.5
210	455Y50-455B50	22.4	27.5	14.5	9.5	22.4	26.8
211	455Y55-455B45	17.8	21.8	11.6	7.3	17.8	21.2
212	455Y60-455B40	13.2	16.4	8.7	5.5	13.2	15.9
213	455Y65-455B35	9.2	11.1	6.1	3.6	9.3	11.1
214	455Y70-455B30	3.9	4.9	2.7	1.4	3.9	4.5
215	455Y75-455B25	1.2	1.6	0.5	1.1	1	1.2
216	455Y80-455B20	7.3	8.4	4	3.3	6.8	8.2

	Color pair	ΔE^*_{ab} Normal		ΔE^*_{ab} CVG		ΔE^*_{ab} BVG	
		35	70	35	70	35	70
217	455Y85-455B15	13.1	16.3	7.6	5.4	13	15.8
218	455Y90-455B10	22.1	26.6	11.5	7.5	21.6	25.9
219	455G5-455B95	44.1	53.2	28.7	19.6	43.4	51.1
220	455G10-455B90	29.2	34.6	20	13.8	28.7	33.5
221	455G15-455B85	18.5	21.9	13.1	9	18.1	21
222	455G20-455B80	9.8	12	7.3	5.1	10.1	11.2
223	455G25-455B75	2	2.6	1.6	1.3	2.2	2.4
224	455G30-455B70	5.2	5.4	3.3	3.5	4.8	5.6
225	455G35-455B65	11.7	13	7.8	7.1	10.9	12.9
226	455G40-455B60	17.7	20.2	12.2	11.4	16.8	19.8
227	455G45-455B55	23.5	27.2	16.4	14.8	22.6	26.5
228	475R10-475Y90	12.8	12.3	5.2	2.7	12.5	12
229	475R15-475Y85	9.3	8.9	3.7	2	9.1	8.7
230	475R20-475Y80	7.4	7.3	2.7	1.4	7.2	7.1
231	475R25-475Y75	6.7	6.8	1.7	0.7	6.7	6.4
232	475R30-475Y70	6.2	5.9	1.2	0.4	6.2	5.8
233	475R35-475Y65	7.5	8	1.5	0.8	7.1	7.6
234	475R40-475Y60	9.2	10.3	2.9	1.8	8.6	9.5
235	475R45-475Y55	11	12.4	3.9	2.2	11	12
236	475R50-475Y50	11.9	12.9	4.8	3.7	11.2	12.1
237	475R55-475Y45	14.7	16.2	6.2	3.9	14.1	15.3
238	475R60-475Y40	15.6	16.9	7.1	4.7	15	16.1
239	475R65-475Y35	17.6	18.5	8.1	5.1	16.9	17.8
240	475R60-475G40	14.7	14.6	9.5	6.6	14.3	14.1
241	475R65-475G35	11.6	11.4	7.4	5.2	11.3	11
242	475R70-475G30	8.1	7.8	5	3.4	8	7.6
243	475R75-475G25	4.5	4.4	2.6	1.8	4.4	4.3
244	475R80-475G20	2.7	3	0.8	0.1	2.7	2.9
245	475R85-475G15	6.3	7.4	3.3	2	6.5	7
246	475R90-475G10	12.2	12.8	6.6	4.7	11.9	12.7
247	475R95-475G5	20.2	21.3	10.6	7.1	19.6	20.8
248	475R50-475B50	11.6	11.9	4.2	2.7	11	11.4
249	475R55-475B45	11.3	12.4	3.1	2.4	10.6	11.5

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
250	475R60-475B40	10.5	10.9	2.4	2.7	9.6	10.6
251	475R65-475B35	11.4	12.1	3.2	3	10.2	11.6
252	475R70-475B30	12.4	13.9	4	3.3	11.7	13.2
253	475R75-475B25	13.7	15	5.5	4.2	12.9	14.8
254	475R80-475B20	16	17.4	7.2	5.3	15.3	16.8
255	475R85-475B15	19.2	20.4	9.1	6.2	18.5	19.9
256	475R90-475B10	22.1	23.2	10.8	7.2	21.3	22.4
257	475Y65-475G35	22.5	23.4	12.8	8.3	21.8	22.7
258	475Y70-475G30	19	19.9	10.9	6.7	18.6	19.2
259	475Y75-475G25	16.5	17.5	8.8	5.5	15.9	16.9
260	475Y80-475G20	12.8	14.1	6.3	3.9	12.6	13.6
261	475Y85-475G15	9.1	9.2	3.7	2	8.4	9.3
262	475Y90-475G10	4.9	5.3	1.1	1.4	5.3	5.5
263	475Y95-475G5	8.1	7.8	3.7	3	8.1	7.9
264	475Y55-475B45	12.2	12.2	6.5	3.5	12	11.5
265	475Y60-475B40	9.9	9.9	5.3	3	9.8	9.3
266	475Y65-475B35	7.3	7.3	3.8	2.5	7	6.8
267	475Y70-475B30	5	5.1	2.7	1.8	4.9	4.6
268	475Y75-475B25	2	2.3	1.1	1.7	2	1.9
269	475Y80-475B20	1.6	1.4	0.7	2.2	1.1	1.3
270	475Y85-475B15	4.7	4.5	2.2	2.7	4.4	4.5
271	475Y90-475B10	8.5	8.2	4	3.3	8.2	8.2
272	475Y95-475B5	14.5	13.8	6.1	3.3	14.1	13.7
273	475G15-475B85	14.8	14.5	7.5	4.8	14.1	14
274	475G20-475B80	11.9	12.6	4.9	3.1	11.3	11.8
275	475G25-475B75	10.8	11.4	3.4	2	10	11.5
276	475G30-475B70	10.6	12.2	3.9	2.1	10	11.7
277	475G35-475B65	12.1	13.7	5.3	3.5	11.2	13.3
278	475G40-475B60	14	15.4	6.9	4.8	12.9	15.1
279	475G45-475B55	17.4	18.7	9.3	6.6	16	18.1
280	475G50-475B50	19.1	20.5	10.7	8.7	17.9	20.1
281	475G55-475B45	22.1	23.7	12.9	10.4	21.2	23
282	495R35-495Y65	22.4	24.4	9.4	5.9	22.3	24.1

	Color pair	ΔE^*_{ab} Normal		ΔE^*_{ab} CVG		ΔE^*_{ab} BVG	
		35	70	35	70	35	70
283	495R40-495Y60	19.7	20.9	7.7	4.5	19.6	20.9
284	495R45-495Y55	16.7	17.7	6.2	4	16.7	17.1
285	495R50-495Y50	15.3	15.6	5.2	3	14.7	15.2
286	495R55-495Y45	12.8	12.5	4.3	2.3	12.2	12.1
287	495R60-495Y40	11.2	10.6	3.9	2.1	10.7	10.4
288	495R65-495Y35	11.3	10.5	4.2	2.5	10.8	10.4
289	495R70-495Y30	11.9	11.3	5.2	2.8	11.5	11.3
290	495R75-495Y25	14.6	14.4	6.6	3.9	14.3	14.5
291	495R65-495G35	17.6	18.9	10.1	7.4	17.4	18.7
292	495R70-495G30	12.5	13.4	7.4	5.3	12.6	13.3
293	495R75-495G25	7	7.9	4.2	3.2	7.3	7.8
294	495R80-495G20	2.1	2.3	1.3	0.8	2	2
295	495R85-495G15	4.4	5.5	2.4	1.6	5.2	5.5
296	495R90-495G10	12.7	14	6.1	4	13.1	13.9
297	495R95-495G5	22.4	24.3	10.3	6.2	22.5	24.2
298	495R60-495B40	21.9	23.7	11.7	7.6	21.4	23.2
299	495R65-495B35	17.8	19.4	9.3	6	17.1	18.7
300	495R70-495B30	13.3	14.6	6.4	4.1	12.8	14.1
301	495R75-495B25	9.1	9.7	4.1	2.4	8.6	9.3
302	495R80-495B20	5.7	5.4	2.3	1.4	5.3	5.2
303	495R85-495B15	8.1	8.2	4.1	2.7	8.2	8.1
304	495R90-495B10	14.7	15.8	7.7	4.8	14.9	15.7
305	495R95-495B5	24.2	25.9	11.4	6.7	24.4	26.4
306	495Y60-495G40	20.2	19.7	11.2	7.8	19.9	19.3
307	495Y65-495G35	17.4	16.7	8.9	5.8	17.1	16.3
308	495Y70-495G30	15.7	15.1	7.3	4.2	15.4	14.7
309	495Y75-495G25	15.5	15.2	6.2	3.4	15.1	14.7
310	495Y80-495G20	17.5	18.4	6.9	4.2	17.6	17.7
311	495Y85-495G15	21.6	23.4	9.3	5.8	21.8	23
312	495Y90-495G10	28.1	30.7	12.3	8.1	28.2	30.1
313	495Y55-495B45	17.5	18.5	11	6.9	17.1	18
314	495Y60-495B40	13.3	13.7	8	5.2	13	13.1
315	495Y65-495B35	9.9	9.8	5.7	3.3	9.6	9.4

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
316	495Y70-495B30	7.1	7	3.2	1.7	7.1	6.7
317	495Y75-495B25	8	8.3	3	2.1	8.2	8.2
318	495Y80-495B20	13.1	14.2	5.8	3.9	13.4	14
319	495Y85-495B15	18.4	20.5	8.8	5.9	18.6	20.1
320	495Y90-495B10	26.6	29.7	12.8	8.5	26.8	29.1
321	495G25-495B75	27.4	29.6	16.2	11.5	26.4	28.8
322	495G30-495B70	22.1	24	12.7	9	21.3	23.4
323	495G35-495B65	17.1	18.5	9.7	6.5	16.4	17.8
324	495G40-495B60	13.4	14.1	6.9	4.3	12.6	13.6
325	495G45-495B55	10.2	10.3	5	2.9	9.6	9.9
326	495G50-495B50	10	9.5	5.2	3.7	9.5	9.3
327	495G55-495B45	12	11.5	6.9	5.6	11.8	11.4
328	495G60-495B40	15.3	15.2	9.6	7.9	15.2	15.2
329	525R45-525Y55	23	23.5	9.3	5.4	22.4	24
330	525R50-525Y50	18.3	18.2	7	4	18.1	19.1
331	525R55-525Y45	13.5	13.4	5.1	3	13.5	14.3
332	525R60-525Y40	9.4	9.3	3.6	1.6	8.7	9.2
333	525R65-525Y35	3.5	3.3	1.4	0.2	3.3	4.2
334	525R70-525Y30	1.8	2	0.8	0.9	2.2	2
335	525R75-525Y25	7.7	7.5	3.3	2.2	8	8.1
336	525R80-525Y20	13.8	13.1	5.6	3.5	13.5	13.9
337	525R85-525Y15	21.1	21.5	8.1	4.7	21.1	21.4
338	525R60-525G40	20.7	21.9	10	6.2	20.5	22.3
339	525R65-525G35	15.3	16.2	7.5	4.4	15.1	17.4
340	525R70-525G30	9.9	11.9	5.1	2.4	9.9	12.1
341	525R75-525G25	4.8	6.2	2	1	4.9	6
342	525R80-525G20	4.6	4.1	1.4	1.2	4.8	4
343	525R85-525G15	11.5	11.1	4.6	2.9	11.7	10.5
344	525R90-525G10	20.9	20.7	8.1	5	20.9	21.2
345	525R95-525G5	34.2	34.9	11.9	6.7	34.5	35.3
346	525R60-525B40	23.1	24.7	11	6.2	22.4	25.1
347	525R65-525B35	16.8	18.1	8	4.1	16.5	18.9
348	525R70-525B30	11.9	13.7	5.4	2.7	11.6	13.4

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
349	525R75-525B25	4.8	6.4	2	0.8	4.9	6.1
350	525R80-525B20	3.2	3	1.4	1.2	3.7	3.2
351	525R85-525B15	10.1	10	4.4	2.6	10.7	9.7
352	525R90-525B10	20.1	20.1	7.9	4.9	20.4	20.5
353	525R95-525B5	34.3	34.7	11.6	6.9	34.2	35.1
354	525Y45-525G55	18	20.4	11	7.1	17.9	20.1
355	525Y50-525G50	13.3	15	8.4	5.4	13.3	14.7
356	525Y55-525G45	8.6	9.6	5.3	3.4	8.5	9.4
357	525Y60-525G40	5.5	5.5	2.2	1.3	5.3	5.1
358	525Y65-525G35	7.4	6.7	2	1.1	7.1	6.4
359	525Y70-525G30	12.5	11.4	4.7	3.5	12.2	11
360	525Y75-525G25	18.6	18.1	8.1	5.4	18.2	18
361	525Y80-525G20	25.4	25.4	11.4	7.5	25.3	25.3
362	525Y45-525B55	20.7	23.5	12.1	7.2	19.9	22.5
363	525Y50-525B50	15.2	17.7	9.3	5.2	15.1	17
364	525Y55-525B45	9.1	11.1	5.7	3.2	9	10.5
365	525Y60-525B40	4.4	5.8	2.8	1.2	4	5.3
366	525Y65-525B35	4.2	3.6	1.2	1.3	4.3	3.6
367	525Y70-525B30	9.5	8.8	4.2	3	9.5	8.8
368	525Y75-525B25	17.2	16.9	8	5.5	17.1	16.9
369	525Y80-525B20	24.3	24.6	11.6	7.5	24.4	24.7
370	525G35-525B65	20.4	22.3	11.6	7.1	19.9	21.3
371	525G40-525B60	15	16.2	8.3	5	14.3	15.6
372	525G45-525B55	9.1	9.9	4.5	2.4	8.5	9.1
373	525G50-525B50	4.3	4.5	1.3	0.4	4.2	4.1
374	525G55-525B45	4.6	4.6	2.9	2.6	4.8	4.8
375	525G60-525B40	9.5	10.1	6.2	4.8	9.8	10
376	525G65-525B35	16	17.2	9.9	7.7	16.1	17.2
377	525G70-525B30	22	24	13.5	9.8	22.1	23.8
378	540R50-540Y50	23.2	24.2	11	7	22.7	24.2
379	540R55-540Y45	18.1	19.5	8.5	5.3	18	19.5
380	540R60-540Y40	14.9	16.3	6.4	4.2	14.8	16.3
381	540R65-540Y35	10.6	11.6	3.9	2.3	10.1	11.4

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
382	540R70-540Y30	10.1	10.7	3.4	1.9	10.1	10.7
383	540R75-540Y25	12.2	11.8	4.7	2.9	12.4	11.9
384	540R80-540Y20	17.8	16.3	7.6	4.7	17.8	16.5
385	540R85-540Y15	25	23.2	10.9	6.5	24.8	23.3
386	540R35-540G65	55.1	61	27.9	18.6	54.4	60.5
387	540R40-540G60	50.3	55.9	25	16.5	49.6	55.4
388	540R45-540G55	45.6	50.8	22	14.4	44.9	50.5
389	540R50-540G50	41.1	45.9	19.2	12.5	40.5	45.8
390	540R55-540G45	37	41.5	16.8	10.7	36.4	41.6
391	540R60-540G40	33.2	37.4	13.8	8.9	32.9	37.5
392	540R65-540G35	29.1	32.3	10.9	6.8	28.2	32.5
393	540R35-540B65	58.1	63.2	30.2	19.7	57.3	61.9
394	540R40-540B60	52.3	57.5	27.1	17.5	51.6	56.2
395	540R45-540B55	47.3	52.4	24.4	15.4	46.9	51.4
396	540R50-540B50	42.2	47.1	21.2	13.1	41.9	46.2
397	540R55-540B45	37.4	42	18.2	11.3	36.8	41.2
398	540R60-540B40	33.2	37.2	15.2	9.3	32.6	36.7
399	540R65-540B35	28.3	32.1	12.1	7	27.6	31.6
400	540Y35-540G65	35.1	39.7	19.2	13.4	34.7	39.7
401	540Y40-540G60	29.7	33.7	15.5	10.7	29.2	33.6
402	540Y45-540G55	25.2	28.9	12	8.2	24.7	28.6
403	540Y50-540G50	20.9	23.9	9.1	5.9	20.6	23.9
404	540Y55-540G45	18.4	20.3	7.2	4.1	18.2	20.6
405	540Y60-540G40	17.4	18.1	6.1	3.1	17.2	18.3
406	540Y65-540G35	18.4	17.7	7.1	4.2	18.1	18
407	540Y40-540B60	30.8	34.6	17.5	11.6	30.4	33.7
408	540Y45-540B55	25.6	29.4	14	9.1	25.3	28.4
409	540Y50-540B50	19.7	23.4	10.4	6.3	19.8	22.5
410	540Y55-540B45	15.3	18.1	7.3	4.1	15.2	17.7
411	540Y60-540B40	12.3	14.2	4.8	2.4	12.3	13.9
412	540Y65-540B35	11.8	12.5	4.6	3.2	12	12.4
413	540Y70-540B30	15.4	14.7	7.8	5.7	15.4	14.7
414	540G35-540B65	25.8	26.6	15.7	10.5	25.5	25.5

	Color pair	ΔE^*_{ab} Normal		ΔE^*_{ab} CVG		ΔE^*_{ab} BVG	
		35	70	35	70	35	70
415	540G40-540B60	19.1	19.1	11.6	7.4	18.8	18.4
416	540G45-540B55	12.9	13	7.2	4.1	13	12
417	540G50-540B50	8.2	7.8	3.6	1.5	8.2	7.7
418	540G55-540B45	7.4	7.8	2.9	2.3	7.3	7.9
419	540G60-540B40	11.7	13.2	6.8	5.5	11.7	13.5
420	540G65-540B35	17.1	19.1	10.7	8.7	17	19.3
421	540G70-540B30	24.3	26.6	15.1	11.7	23.9	26.6
422	555R35-555Y65	58.7	60.4	33.4	26.4	56.9	59.2
423	555R40-555Y60	54.4	56	30.8	24.5	52.8	55.2
424	555R45-555Y55	44.9	46.1	25.2	19.9	43.9	45.2
425	555R50-555Y50	38.5	39.3	21.2	16.7	37.2	38.5
426	555R55-555Y45	32.1	32.7	17.4	13.4	31.2	32.1
427	555R60-555Y40	27.2	27.4	14.4	11.3	26.2	27
428	555R65-555Y35	22.5	22.8	12	9.6	22	22.5
429	555R35-555G65	80.6	85.1	46	36.4	78.6	84.2
430	555R40-555G60	84.1	89.1	48.5	38.8	82	88.2
431	555R45-555G55	80.3	84.9	46.4	36.8	78.3	84
432	555R50-555G50	75.5	79.6	43.7	34.3	73.8	78.9
433	555R55-555G45	71.7	75	41.4	32.1	70.2	74.5
434	555R60-555G40	69.3	71.9	39.9	30.5	67.7	71.3
435	555R65-555G35	66.7	68.5	38.3	28.7	65.2	68
436	555R35-555B65	73.2	79.9	42.6	35.1	71.4	78.5
437	555R40-555B60	76.4	83.4	44.7	37.1	74.5	82.1
438	555R45-555B55	75.3	82.4	44.2	36.7	73.5	81.1
439	555R50-555B50	75.2	82.6	44.2	36.7	73.4	81.2
440	555R55-555B45	69.4	76.1	40.8	33.5	67.8	75
441	555R60-555B40	64.3	70.3	37.8	30.7	62.9	69.3
442	555R65-555B35	59.5	64.7	34.9	27.8	58.3	63.9
443	555Y35-555G65	62.4	61.2	32.8	23.4	60.9	60.3
444	555Y40-555G60	65.1	64	34.7	25	63.5	63.2
445	555Y45-555G55	67.7	66.4	36.6	26.1	66.2	65.5
446	555Y50-555G50	70	68	38	26.8	68.2	67.1
447	555Y55-555G45	72.8	70	39.8	27.9	71.1	69.1

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
448	555Y60-555G40	74	70.2	40.4	27.9	72.1	69.3
449	555Y65-555G35	75.4	71.4	41.3	28.4	73.6	70.4
450	555Y35-555B65	39.8	42.7	22.5	18.5	39	42
451	555Y40-555B60	42.4	45.4	24	19.6	41.6	44.8
452	555Y45-555B55	46.2	49.4	26.3	21.4	45.4	48.7
453	555Y50-555B50	50	53.3	28.7	23.2	48.9	52.6
454	555Y55-555B45	50.2	52.5	28.9	22.7	49.3	51.8
455	555Y60-555B40	48.9	49.5	28	21.1	48	49
456	555Y65-555B35	49.5	49.1	28.3	21.1	48.6	48.6
457	555G35-555B65	42.3	40.8	23.9	16.8	40.9	39.8
458	555G40-555B60	40.5	38.9	22.7	15.8	39.2	38
459	555G45-555B55	39.6	38	21.9	15	38.2	37
460	555G50-555B50	39.4	38	21.5	14.6	38.1	36.8
461	555G55-555B45	35.7	34	18.8	12.1	34.6	32.7
462	555G60-555B40	32.9	31.1	16.9	10.5	31.8	29.8
463	555G65-555B35	33.4	31.7	17	10.3	32.4	30.4
464	595R25-595Y75	20.7	20.5	12.4	8.2	20.2	20.3
465	595R30-595Y70	13.6	13.6	8.2	5.3	13	13.2
466	595R35-595Y65	7.4	7.9	4.7	2.7	7.5	7.6
467	595R40-595Y60	2.4	2.5	1.2	0.7	2.2	2.1
468	595R45-595Y55	5.5	5.2	3.1	2.7	5.3	5.1
469	595R50-595Y50	11.7	10.9	7.3	5.2	11.5	11.5
470	595R55-595Y45	17.8	16.9	10.9	7.9	17.3	17.5
471	595R60-595Y40	22.8	22	14.2	10.1	22.4	22.3
472	595R5-595G95	33.1	31.4	14.5	8.2	32.5	31.6
473	595R10-595G90	19.6	18.9	9.3	5.2	19.5	19
474	595R15-595G85	10.1	8.8	4.8	2.7	9.9	9.7
475	595R20-595G80	3.6	3.5	1.4	0.8	3.6	3.7
476	595R25-595G75	7.1	6.6	3.9	2.6	7.1	7.1
477	595R30-595G70	13.1	12.4	7.4	5.1	13.1	13
478	595R35-595G65	19.1	18	10.8	7.3	18.9	18.8
479	595R40-595G60	24.9	23.8	14.1	9.5	24.6	24.5
480	595R10-595B90	23.6	22.6	11.2	6.4	23.6	22.8

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
481	595R15-595B85	14.2	12.9	6.8	3.9	14.7	13.6
482	595R20-595B80	7.3	6.8	3.2	1.5	7.7	7.3
483	595R25-595B75	6.1	6.1	2.6	2	5.8	6.1
484	595R30-595B70	11	10.8	5.9	4.4	10.5	10.8
485	595R35-595B65	16.3	15.9	9.1	6.6	15.9	15.8
486	595R40-595B60	21.9	21.4	12.3	8.8	21.4	21.3
487	595R45-595B55	26.7	26.2	15.1	10.7	26.1	25.8
488	595Y10-595G90	26.6	24.8	12.1	6.7	26.2	25.5
489	595Y15-595G85	17.3	16	8.2	4.5	17.1	16.7
490	595Y20-595G80	9.9	8.9	4.8	2.6	9.8	9.7
491	595Y25-595G75	3.5	3.1	1.5	0.9	3.5	3.2
492	595Y30-595G70	3.3	3.5	1.8	1.3	3.3	3.5
493	595Y35-595G65	9.1	8.9	4.8	3.1	9	8.9
494	595Y40-595G60	14.3	13.8	7.7	5	14	14
495	595Y45-595G55	19	18.6	10.1	6.6	18.8	18.3
496	595Y15-595B85	21.2	19.7	10	5.7	21.6	20.4
497	595Y20-595B80	14	12.9	6.8	3.8	14.4	13.7
498	595Y25-595B75	8.1	7.1	3.8	1.8	8.4	7.8
499	595Y30-595B70	4.1	4.1	1.3	1	3.9	3.9
500	595Y35-595B65	6.5	7	3.2	2.5	6.2	6.2
501	595Y40-595B60	11.3	11.3	5.9	4.3	10.9	10.8
502	595Y45-595B55	15.6	15.7	8.3	5.8	15.2	14.9
503	595Y50-595B50	20.8	21	11.2	7.8	20.3	20
504	595G35-595B65	17.1	15.9	7.7	4.3	16.9	16.6
505	595G40-595B60	12.4	11.5	5.6	3	12.4	11.9
506	595G45-595B55	8.2	7.5	3.8	2	8.4	8.2
507	595G50-595B50	3.7	3	1.5	0.7	3.8	3.6
508	595G55-595B45	2.5	2.7	1	0.8	2.3	2.3
509	595G60-595B40	6	6.3	2.5	1.9	5.7	5.5
510	595G65-595B35	10.3	10.4	4.4	2.9	9.9	9.6
511	595G70-595B30	15.1	14.9	6.7	4.1	14.9	14.3
512	595G75-595B25	20.1	19.7	8.8	5.3	19.9	19.1
513	615R20-615Y80	23.6	23.3	13.9	9.1	23.4	24

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
514	615R25-615Y75	16.4	16	9.8	6.6	16.2	16.7
515	615R30-615Y70	10	9.7	6.4	4.1	9.9	10.3
516	615R35-615Y65	3.2	2.8	2.3	1.2	3.2	3.6
517	615R40-615Y60	2.6	2.6	1	1.2	2	1.4
518	615R45-615Y55	8.4	8.7	4.7	3.7	7.9	7.8
519	615R50-615Y50	14.2	14.2	8.1	6.1	13.7	13.5
520	615R55-615Y45	19	19.2	11.6	8.2	18.9	19
521	615R60-615Y40	25.1	25.4	15.2	10.9	25	25.1
522	615R5-615G95	25.9	25.5	11.2	6.3	25.7	25.9
523	615R10-615G90	13.3	12.9	6.5	3.6	13.2	13.5
524	615R15-615G85	4.4	4.2	2.5	1.3	4.6	4.9
525	615R20-615G80	3.7	3.9	1.7	1.3	3.4	3.1
526	615R25-615G75	10.4	10.8	5.1	3.6	10.2	9.9
527	615R30-615G70	16.3	16.5	8.4	5.6	16.4	16.4
528	615R35-615G65	22.6	22.5	12	8	22.4	22.4
529	615R5-615B95	21.6	21.1	9	5	21.7	21.6
530	615R10-615B90	9.8	9.3	4.6	2.4	9.8	9.9
531	615R15-615B85	2	1.3	0.7	0.6	1.5	1.6
532	615R20-615B80	7.5	7.8	3.5	2.5	7.1	7
533	615R25-615B75	14.3	14.7	7.1	4.4	13.9	13.9
534	615R30-615B70	19.6	20.1	9.7	6.6	19.5	19.2
535	615R35-615B65	25.9	26.3	13.3	8.8	25.5	25.2
536	615Y10-615G90	21.7	21.3	9.5	5.4	21.4	21.8
537	615Y15-615G85	14	13.7	6.4	3.7	13.8	14
538	615Y20-615G80	7.1	6.8	3.5	2	7.2	7.4
539	615Y25-615G75	0.9	0.6	0.7	0.2	1.1	1.4
540	615Y30-615G70	4.5	4.5	2.1	1.3	4.4	4.6
541	615Y35-615G65	9.6	9.5	4.6	3.1	9.4	9.5
542	615Y40-615G60	14.4	14.4	7.2	4.5	14.1	14.2
543	615Y45-615G55	19.3	19.2	9.6	6.2	19.1	19
544	615Y5-615B95	28.2	27.1	10.8	5.9	28	27.7
545	615Y10-615B90	18.1	17.6	7.6	4.1	17.9	18
546	615Y15-615B85	10.4	9.9	4.5	2.5	10.3	10.3

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
547	615Y20-615B80	3.8	3.1	1.7	0.9	3.9	3.7
548	615Y25-615B75	3.5	3.6	1.4	0.8	2.9	2.9
549	615Y30-615B70	7.8	8.1	3.5	2.4	7.6	7.5
550	615Y35-615B65	13	13.3	6	3.9	12.7	12.5
551	615Y40-615B60	17.9	17.9	8.6	5.5	17.4	17.3
552	615Y45-615B55	22.8	22.9	11.2	7.2	22.2	22
553	615G25-615B75	15.6	15.1	6.1	3.5	15.7	15.5
554	615G30-615B70	12	11.7	4.9	2.8	11.9	12
555	615G35-615B65	8.3	7.9	3.5	1.7	8.1	8.3
556	615G40-615B60	4.7	4.5	1.9	0.8	4.7	4.8
557	615G45-615B55	1.8	1.4	0.3	0.2	1.7	1.6
558	615G50-615B50	3.4	3.5	1.1	1	3	2.7
559	615G55-615B45	7.3	7.3	2.8	1.7	6.6	6.8
560	615G60-615B40	10.9	10.9	4.2	2.6	10.5	10.4
561	615G65-615B35	13.8	14	5.5	3.3	13.4	13.2
562	615G70-615B30	18.2	18.3	7.3	4.2	17.7	17.5
563	630R20-630Y80	25.8	26	16.4	11.7	26.2	26.5
564	630R25-630Y75	18.1	18.1	11.7	8.3	18.4	18.6
565	630R30-630Y70	11.1	11.1	7.4	5.1	11.5	11.8
566	630R35-630Y65	4.5	4.2	3.2	2	4.6	5
567	630R40-630Y60	2.3	2.7	1	1.2	1.9	1.7
568	630R45-630Y55	8.9	9.2	5.2	4.3	8.4	8.3
569	630R50-630Y50	15	15.3	9	7.3	14.5	14.2
570	630R55-630Y45	21.5	21.6	12.9	10.3	20.5	20.6
571	630R5-630G95	26.5	26.3	12.4	7.4	26.6	26.8
572	630R10-630G90	12.7	12.4	6.7	4	12.8	13.2
573	630R15-630G85	2.8	2.5	1.7	1	3.1	3.3
574	630R20-630G80	5.5	6.5	3.2	2.3	5.8	5.8
575	630R25-630G75	13	13.9	7.2	4.9	13.2	13
576	630R30-630G70	19.3	20.1	10.8	7.6	19.2	19
577	630R5-630B95	20.4	19.6	8.9	5	19.9	20.2
578	630R10-630B90	6.5	5.6	3.3	1.6	6	6.5
579	630R15-630B85	3.6	4.3	1.8	1.5	3.9	3.5

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
580	630R20-630B80	12.1	13	6.3	4.2	12.3	12.1
581	630R25-630B75	19.7	20.4	10.5	7.1	19.8	19.5
582	630R30-630B70	25.7	26.6	14.1	9.5	25.6	25.4
583	630Y10-630G90	21.6	21.3	10.5	6.3	21.7	21.9
584	630Y15-630G85	13.3	13	6.8	4.2	13.5	13.6
585	630Y20-630G80	6.1	5	2.9	1.6	5.6	5.7
586	630Y25-630G75	0.9	1.8	0.5	0.4	1.3	1
587	630Y30-630G70	7	7.6	3.7	2.5	7	6.8
588	630Y35-630G65	12.3	12.5	6.7	4.3	12.3	12.4
589	630Y40-630G60	17.9	18.1	9.6	6.7	17.9	17.8
590	630Y5-630B95	27.6	26.7	11.5	6.3	26.9	27
591	630Y10-630B90	15.4	14.4	7	3.9	14.9	15.2
592	630Y15-630B85	7	6.2	3.4	1.8	6.6	6.7
593	630Y20-630B80	0.6	1.4	0.4	0.5	0.9	0.7
594	630Y25-630B75	7.6	8.3	3.7	2.5	7.8	7.4
595	630Y30-630B70	13.4	14.1	6.9	4.4	13.3	13.2
596	630Y35-630B65	18.6	19.3	9.7	6.5	18.6	18.3
597	630Y40-630B60	23.8	24.6	12.2	8.1	24	23.5
598	630G20-630B80	19.7	19.4	8.4	4.8	19.8	20
599	630G25-630B75	14.9	14.6	6.5	3.6	15	15.2
600	630G30-630B70	10.6	10	4.4	2.5	10.5	10.8
601	630G35-630B65	6.6	6.1	2.8	1.5	6.4	6.8
602	630G40-630B60	2.3	1.7	1.3	0.6	2	2.4
603	630G45-630B55	1.7	1.9	0.5	0.4	1.3	1.2
604	630G50-630B50	5.3	5.6	2	1.4	4.9	4.9
605	630G55-630B45	9.5	9.7	3.9	2.5	9.1	9
606	630G60-630B40	13.6	13.8	5.8	3.3	13.2	13
607	630G65-630B35	17.5	17.7	7.5	4.6	17.4	16.9
608	660R20-660Y80	20.1	19.2	10.1	6	19.6	19.8
609	660R25-660Y75	13.4	12.6	7.1	4.2	13.1	13.4
610	660R30-660Y70	7.5	7	4.1	2.4	7.5	7.7
611	660R35-660Y65	2.3	1.5	1.4	0.7	2	2.5
612	660R40-660Y60	3.2	3.7	1.5	1.3	3.2	2.7

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
613	660R45-660Y55	8.1	8.7	4.2	2.9	7.9	7.5
614	660R50-660Y50	12.7	13.4	6.5	4.6	12.6	12.3
615	660R55-660Y45	18.1	18.2	9.4	6.3	18	17.9
616	660R5-660G95	20.2	19.6	6.9	3.7	20.1	20.2
617	660R10-660G90	9.8	9.2	3.7	2	9.5	9.6
618	660R15-660G85	2.2	1.7	0.9	0.6	2.1	2.4
619	660R20-660G80	4.1	4.5	1.8	1.2	4.2	4
620	660R25-660G75	9.8	10.3	4.3	2.5	9.8	9.5
621	660R30-660G70	14.8	15	6.6	3.9	14.5	14.3
622	660R35-660G65	19.9	20.2	8.9	5.7	19.7	19.3
623	660R5-660B95	12.9	12.4	3.8	2	12.8	12.9
624	660R10-660B90	2.9	2.4	1	0.6	2.6	2.9
625	660R15-660B85	4.6	4.9	1.8	1	4.7	4.2
626	660R20-660B80	10.8	11.3	4.2	2.5	10.8	10.5
627	660R25-660B75	16.2	16.4	6.5	3.7	16.1	15.6
628	660R30-660B70	21.3	21.5	8.9	5.3	20.9	20.6
629	660Y5-660G95	26.2	24.6	8.2	4.4	25.4	25.5
630	660Y10-660G90	17.2	16.3	5.9	3.2	16.5	16.7
631	660Y15-660G85	10.9	10	3.8	2.1	10.5	10.8
632	660Y20-660G80	5.4	4.8	2.1	1.2	5.2	5.3
633	660Y25-660G75	1.1	0.2	0.3	0.4	0.6	0.8
634	660Y30-660G70	3.5	3.8	1.4	0.8	3.4	3.3
635	660Y35-660G65	8.2	8.5	3.3	1.9	8.1	7.8
636	660Y40-660G60	12.1	11.9	4.8	3	12	11.9
637	660Y45-660G55	16.2	16	6.9	4.1	16	15.8
638	660Y5-660B95	18.9	17.5	5.1	2.8	18.3	18.3
639	660Y10-660B90	10.3	9.5	3.2	1.7	9.6	10
640	660Y15-660B85	4.3	3.5	1.2	0.6	3.8	4.2
641	660Y20-660B80	1.5	2.1	0.5	0.2	1.6	1.2
642	660Y25-660B75	5.8	6	2.2	1.1	5.8	5.3
643	660Y30-660B70	9.9	10.3	3.7	2.2	9.8	9.6
644	660Y35-660B65	14.1	14.5	5.5	2.9	14	13.6
645	660Y40-660B60	16.7	18.1	7	3.8	17.8	17.5

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
646	660G20-660B80	13.2	11.9	3.5	2.1	12.9	12.7
647	660G25-660B75	10.2	9.3	2.8	1.7	9.7	9.7
648	660G30-660B70	6.5	5.9	1.9	0.8	6.2	6.3
649	660G35-660B65	3.3	2.3	0.9	0.6	2.9	2.9
650	660G40-660B60	1.6	0.3	0.1	0.4	0.2	0.3
651	660G45-660B55	2.8	3	0.9	0.4	2.6	2.6
652	660G50-660B50	6.2	6.3	2.2	0.9	6	5.9
653	660G55-660B45	8.4	8.6	2.3	1.2	8.3	8.1
654	660G60-660B40	11.3	11.2	3.4	1.7	10.8	10.9
655	700R40-700Y60	1	1.4	0.3	0.2	1.4	1.4
656	700R45-700Y55	3.4	3.1	0.7	0.3	3.1	2.9
657	700R50-700Y50	6.1	5.3	1.2	0.5	5.1	5.1
658	700R55-700Y45	7.7	6.9	1.6	0.8	6.8	7.1
659	700R60-700Y40	9.9	9.3	2.2	0.9	9.4	9.4
660	700R65-700Y35	11.2	10.8	2.5	1.1	10.7	10.5
661	700R50-700G50	10.8	10.3	2.3	0.8	10.2	10.2
662	700R55-700G45	12.8	11.9	2.1	1.2	11.9	11.4
663	700R60-700G40	14.2	13.3	2.9	1.4	13.2	12.9
664	700R65-700G35	14.9	14.5	3.2	2	14	13.7
665	700R70-700G30	16.4	15.7	3.1	2.3	15.8	15.4
666	700R75-700G25	17.6	16.7	3.3	2.3	16.6	16.2
667	700R40-700B60	8.6	8.7	1.5	1.9	7.9	8
668	700R45-700B55	10	10.1	2	1.9	9.4	9.3
669	700R50-700B50	11.8	11	2.5	1.8	11.2	10.7
670	700R55-700B45	13.7	12.8	2.7	2	12.8	12.3
671	700R60-700B40	15	14.2	2.9	2.2	14.1	13.8
672	700R65-700B35	15.4	14.6	3.2	2.2	14.4	14.1
673	700Y65-700G35	8.5	8.7	1.7	1.8	7.9	7.5
674	700Y70-700G30	9.2	9.3	1.8	1.9	8.8	8.5
675	700Y75-700G25	11	10.6	1.8	1.9	10.3	10.3
676	700Y80-700G20	12.2	11.5	2.4	2	11.5	11.5
677	700Y85-700G15	12.8	12.3	2.4	2.1	12.1	12.4
678	700Y90-700G10	13.9	13.1	2.6	2	13.1	12.9

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
679	700Y60-700B40	8.5	8.3	1.4	2	7.5	7.6
680	700Y65-700B35	9	8.8	1.7	1.9	8.4	8
681	700Y70-700B30	9.7	9.8	1.8	2	9	9
682	700Y75-700B25	11.3	11.1	1.8	2	10.4	10.7
683	700Y80-700B20	12.3	12.2	2.5	2.1	11.6	11.5
684	700Y85-700B15	13.1	12.3	2.4	2.1	12.6	12.7
685	410R-410Y	16.3	19.2	7.1	4.2	16.2	18.4
686	410R-410G	16.2	19.1	9.7	6.9	15.8	18.7
687	410R-410B	3.9	6.4	2.7	6.8	4.3	4.7
688	410Y-410G	32.5	38.2	16.8	11.1	32	37.1
689	410Y-410B	12.8	12.8	4.5	3	12	13.8
690	410G-410B	19.9	25.5	12.4	13.5	20.1	23.3
691	420R-420Y	18.8	22.1	11.7	8.3	18.2	21.3
692	420R-420G	24.3	28.3	17.7	14.8	24	27.4
693	420R-420B	2.3	4.2	1.8	13.8	2.1	1.7
694	420Y-420G	43.1	50.3	29.4	23	42.1	48.8
695	420Y-420B	16.7	17.9	10	5.7	16.1	19.8
696	420G-420B	26.5	32.4	19.4	28.5	26	29
697	435R-435Y	21.3	25	14.6	11.6	20.9	24.1
698	435R-435G	29.1	33.2	20.9	19.1	28.1	32.4
699	435R-435B	1.2	2.5	0.9	20	1.2	0.7
700	435Y-435G	50.4	58.2	35.5	30.7	49	56.4
701	435Y-435B	20.5	22.6	13.7	8.6	20	24
702	435G-435B	30	35.6	21.8	38.9	29	32.4
703	455R-455Y	21.1	25.3	14.5	11.7	20.7	24.4
704	455R-455G	26.6	30.9	19.3	17.5	25.7	30
705	455R-455B	6.7	6.4	4.8	20.6	6.8	8.8
706	455Y-455G	47.7	56.1	33.8	29.1	46.4	54.4
707	455Y-455B	27.8	31.7	19.3	9.1	27.4	33.2
708	455G-455B	20	24.4	14.6	37.9	19	21.2
709	475R-475Y	16.1	18.3	7.7	4.9	15.9	17.5
710	475R-475G	26.3	26.2	17.7	14.7	25.5	25.2
711	475R-475B	15.5	16.8	6.2	7.6	15.6	16.5

	Color pair	ΔE*$_{ab}$ Normal		ΔE*$_{ab}$ CVG		ΔE*$_{ab}$ BVG	
		35	70	35	70	35	70
712	475Y-475G	39.3	41	25	19.4	38.1	39.3
713	475Y-475B	18.7	17.9	11.4	3.1	18.5	18.4
714	475G-475B	23.5	26.6	14.4	21.9	22.5	24.3
715	495R-495Y	19	19.8	8.2	4.9	18.5	19.1
716	495R-495G	37.8	39.9	24.1	19.5	37.1	39.4
717	495R-495B	37.1	40	22.4	5.8	36.5	39.9
718	495Y-495G	33.7	33.7	21.3	17.4	32.9	33
719	495Y-495B	26.5	27.3	17.3	9.2	26.3	27.9
720	495G-495B	13.2	13.3	7.5	24.9	12.5	12
721	525R-525Y	23.4	24.7	12	7.5	22.9	24.1
722	525R-525G	36.3	40.4	22.4	16.1	35.9	39.5
723	525R-525B	40.6	43.2	23.9	5.6	40.1	44
724	525Y-525G	15.5	17.3	10.5	8.6	15.3	17
725	525Y-525B	17.8	18.9	11.9	13	17.8	20.3
726	525G-525B	7.1	5.3	2.2	21.5	6.6	6.4
727	540R-540Y	28.5	30.7	16.3	12	28	30.2
728	540R-540G	51.9	59.1	28.6	21.2	51	58.5
729	540R-540B	53	58.1	30.4	7.7	52.5	59.1
730	540Y-540G	27	31.4	13.9	9.9	26.6	31.1
731	540Y-540B	25.2	28.1	14.5	19	25.2	29.4
732	540G-540B	11.2	9.7	4.8	27.5	10.9	10.3
733	555R-555Y	24.9	22.9	12.1	7.9	24.1	21.9
734	555R-555G	56.1	54.3	32.1	23.1	54.8	53
735	555R-555B	18	19.4	10.8	27.6	18.1	19.3
736	555Y-555G	78.1	73.9	42.2	29.1	76.1	71.4
737	555Y-555B	34.1	31.6	17.3	34.1	33.9	31.3
738	555G-555B	44.6	43.3	25.4	18.5	42.8	40.9
739	595R-595Y	13.7	13.5	9	7.2	13.6	14
740	595R-595G	42.8	41.6	27	20.2	42.4	42.3
741	595R-595B	39.1	39.9	25.1	29.7	39.1	39
742	595Y-595G	29.3	28.3	18	13	28.9	28.4
743	595Y-595B	25.4	26.5	16.1	22.5	25.5	25.1
744	595G-595B	5	3.1	2.3	9.7	4.6	4.6

	Color pair	ΔE*ab Normal		ΔE*ab CVG		ΔE*ab BVG	
		35	70	35	70	35	70
745	615R-615Y	16.4	16.4	10.9	8.6	16.2	16.7
746	615R-615G	45.7	45.5	28.2	20.9	45.2	45.6
747	615R-615B	48.7	50.5	30	28.8	48.6	48.9
748	615Y-615G	29.3	29.2	17.4	12.3	29	29
749	615Y-615B	32.3	34.1	19.2	20.3	32.4	32.2
750	615G-615B	3.2	5.2	1.8	8.2	3.8	3.6
751	630R-630Y	17.6	17.7	11.8	9.8	17.5	18
752	630R-630G	52	52.1	33.2	25.8	51.7	52.2
753	630R-630B	58.5	60.1	37	35.8	58.4	58.6
754	630Y-630G	34.4	34.4	21.5	16	34.2	34.2
755	630Y-630B	40.9	42.4	25.3	26.1	40.9	40.6
756	630G-630B	6.5	8	3.8	10.3	6.8	6.5
757	660R-660Y	15.4	15.6	9.6	7.1	15.4	15.5
758	660R-660G	40.9	41.1	22.8	15.9	40.6	40.8
759	660R-660B	47.8	48.9	25.9	20.5	47.7	47.7
760	660Y-660G	25.5	25.5	13.2	8.8	25.3	25.3
761	660Y-660B	32.4	33.4	16.4	13.5	32.4	32.2
762	660G-660B	7	7.9	3.2	4.9	7.1	6.9
763	700R-700Y	7	6.6	1.7	0.8	7.2	7.1
764	700R-700G	16.9	16.4	3.7	2	16.7	16.1
765	700R-700B	18.9	17.9	4.1	2.6	18.1	17.5
766	700Y-700G	10.1	9.9	2	1.2	9.6	9
767	700Y-700B	12	11.3	2.3	2.2	11	10.4
768	700G-700B	2	1.5	0.5	1.8	1.4	1.4

Appendix D

Table D-1 Luminance, x, y, CCT and SPD of 4 lighting conditions

Wavelength (nm)	W-L	FR-L	CV-L	BV-L
Luminance (cd/m2)	187.48	187.80	187.58	186.40
x	0.3224	0.3229	0.2009	0.2181
y	0.3338	0.2847	0.2013	0.1869
CCT (K)	6012	6009	------	------
380	0.03	0.03	0.00	0.03
390	0.06	0.08	0.02	0.08
400	0.02	0.86	0.02	0.96
410	0.05	10.77	0.02	11.59
420	1.82	67.63	0.10	69.61
430	13.56	66.47	0.97	67.40
440	42.26	19.19	6.06	19.68
450	90.99	4.54	22.06	4.75
460	82.19	1.24	54.19	1.30
470	52.12	0.40	93.87	0.41
480	36.43	0.38	85.81	0.34
490	37.10	1.43	41.94	0.89
500	44.62	5.15	18.03	2.92
510	51.56	11.27	7.19	8.68
520	54.70	16.14	2.96	17.87
530	54.78	18.21	1.25	18.68
540	52.67	18.50	0.55	11.23
550	49.03	18.16	0.30	6.25
560	44.20	17.57	0.39	3.16
570	40.63	16.64	1.54	1.56
580	40.57	15.37	5.52	0.79
590	42.42	13.88	16.32	0.42
600	43.77	12.51	28.39	0.32
610	44.39	11.84	6.58	0.48
620	46.36	13.85	1.27	1.16

Wavelength (nm)	W-L	FR-L	CV-L	BV-L
630	49.74	23.82	0.40	3.28
640	51.91	15.84	0.37	9.12
650	50.72	5.44	0.80	22.25
660	45.41	3.36	1.99	38.48
670	36.59	2.44	4.97	7.33
680	27.83	1.85	12.26	1.11
690	21.10	1.42	29.13	0.23
700	16.60	1.08	62.90	0.06
710	13.40	0.82	67.74	0.03
720	10.81	0.63	13.94	0.03
730	8.67	0.49	2.45	0.03
740	7.09	0.39	0.51	0.02
750	5.89	0.31	0.16	0.02
760	4.84	0.25	0.10	0.04
770	3.89	0.24	0.07	0.01
780	3.09	0.18	0.07	0.00

Table D-2 Color difference (ΔE^*_{94}) of 200 colored pairs

Pairs	Color 1	Color 2	ΔE^*_{94}				
			SPEX	W-L	FR-L	CV-L	BV-L
1	10B	2.5B	12.4	6.8	8.5	7.6	6.2
2	10B	5B	8.3	4.3	5.7	5.1	4.0
3	10B	7.5B	3.2	3.0	3.9	3.7	2.7
4	10B	7.5BG	18.5	1.2	1.4	1.4	1.2
5	10B	10BG	14.8	8.5	9.4	10.9	6.7
6	10BG	2.5BG	9.9	1.4	1.7	2.5	1.1
7	10BG	5BG	6.9	8.0	10.2	10.1	6.8
8	10BG	7.5BG	3.9	5.6	7.4	7.6	4.5
9	10BG	7.5G	15.8	4.3	5.7	6.1	3.1
10	10BG	10G	13.1	2.5	3.0	3.2	1.0
11	10G	2.5G	9.7	3.1	4.0	3.7	2.8

Pairs	Color 1	Color 2	ΔE*$_{94}$				
			SPEX	W-L	FR-L	CV-L	BV-L
12	10G	5G	4.6	1.7	2.3	1.3	2.3
13	10G	7.5G	2.9	7.2	9.7	8.8	7.1
14	10G	7.5GY	23.3	6.0	8.0	7.3	5.6
15	10G	10GY	16.1	4.1	5.2	4.4	3.2
16	10GY	2.5GY	15.3	5.2	7.7	7.5	6.6
17	10GY	5GY	13.6	3.9	6.0	5.0	5.8
18	10GY	7.5GY	7.6	2.3	3.8	3.7	3.4
19	10GY	7.5Y	21.7	8.0	11.6	10.9	9.6
20	10GY	10Y	18.7	6.2	8.7	7.9	6.8
21	10P	2.5P	11.0	7.7	5.9	6.0	3.5
22	10P	5P	8.0	6.0	4.8	4.7	2.8
23	10P	7.5P	4.1	3.6	3.3	3.7	1.9
24	10P	7.5PB	18.4	1.8	1.0	5.0	0.9
25	10P	10PB	14.2	9.8	6.6	8.0	4.3
26	10PB	2.5PB	15.9	2.6	2.7	2.5	2.1
27	10PB	5PB	10.8	10.1	8.7	8.7	5.8
28	10PB	7.5PB	4.7	8.5	7.5	7.4	5.1
29	10PB	7.5B	23.2	6.2	6.0	6.3	4.2
30	10PB	10B	19.8	4.4	3.6	7.0	2.8
31	10R	2.5R	10.5	4.1	4.6	4.1	3.4
32	10R	5R	7.7	1.5	1.8	1.5	1.3
33	10R	7.5R	4.3	9.9	9.4	9.0	6.5
34	10R	7.5RP	16.2	7.6	7.9	7.9	5.6
35	10R	10RP	12.6	5.8	5.5	8.3	4.1
36	10RP	2.5RP	11.9	6.1	7.5	7.0	6.0
37	10RP	5RP	7.0	3.6	4.7	4.4	3.6
38	10RP	7.5RP	4.2	2.1	2.9	2.9	2.3
39	10RP	7.5P	18.6	9.6	10.9	11.0	8.2
40	10RP	10P	14.9	7.8	8.4	10.9	6.6
41	10Y	2.5Y	7.1	10.3	5.4	7.8	6.0
42	10Y	5Y	4.2	7.6	3.9	5.8	3.9

Pairs	Color 1	Color 2	ΔE*$_{94}$				
			SPEX	W-L	FR-L	CV-L	BV-L
43	10Y	7.5Y	2.9	4.7	2.3	3.8	2.3
44	10Y	7.5YR	13.7	2.2	1.0	2.1	1.2
45	10Y	10YR	11.3	12.2	7.5	9.0	7.9
46	10YR	2.5YR	9.3	1.9	1.4	1.2	0.7
47	10YR	5YR	6.2	12.0	6.2	8.9	6.3
48	10YR	7.5YR	2.4	9.4	4.7	7.0	4.2
49	10YR	7.5R	16.2	6.5	3.2	4.9	2.7
50	10YR	10R	12.9	4.1	2.0	3.2	1.8
51	2.5B	2.5BG	12.5	4.2	2.8	2.5	1.6
52	2.5B	5BG	9.6	2.5	1.5	1.5	1.0
53	2.5B	7.5BG	6.6	11.6	5.9	7.9	4.7
54	2.5B	10BG	2.8	8.8	4.5	6.1	3.3
55	2.5B	10G	15.7	6.4	3.5	4.5	2.5
56	2.5BG	2.5G	12.5	6.2	5.0	5.0	2.9
57	2.5BG	5G	7.7	4.4	3.8	4.3	2.2
58	2.5BG	7.5G	5.9	2.0	2.3	5.0	1.5
59	2.5BG	10G	3.2	10.7	6.5	8.0	3.8
60	2.5BG	10GY	19.0	8.4	5.6	5.9	3.5
61	2.5G	2.5GY	21.0	8.6	9.4	6.7	10.6
62	2.5G	5GY	20.2	6.4	6.9	4.6	7.7
63	2.5G	7.5GY	14.2	3.7	3.7	2.3	4.1
64	2.5G	10GY	6.6	2.3	2.7	1.9	2.7
65	2.5G	10Y	24.3	10.1	11.1	7.0	12.5
66	2.5GY	2.5Y	10.5	2.8	1.7	2.0	2.2
67	2.5GY	5Y	7.7	11.2	10.5	8.4	12.0
68	2.5GY	7.5Y	6.5	9.1	8.1	6.4	9.3
69	2.5GY	10Y	3.5	6.4	5.1	4.1	5.9
70	2.5GY	10YR	15.0	4.9	4.0	3.4	4.4
71	2.5P	2.5PB	19.2	5.9	3.4	4.1	3.9
72	2.5P	5PB	14.1	3.1	1.8	2.2	1.8
73	2.5P	7.5PB	8.1	12.0	9.4	8.5	10.7

Pairs	Color 1	Color 2	ΔE*$_{94}$				
			SPEX	W-L	FR-L	CV-L	BV-L
74	2.5P	10PB	3.5	9.4	6.6	6.3	7.4
75	2.5P	10B	23.0	7.9	5.6	5.6	6.0
76	2.5PB	2.5B	16.8	8.3	4.6	6.2	4.9
77	2.5PB	5B	12.7	5.5	3.0	4.3	3.0
78	2.5PB	7.5B	7.6	2.5	1.3	2.1	1.2
79	2.5PB	10B	4.4	11.7	7.6	8.3	8.4
80	2.5PB	10BG	19.2	10.3	6.7	7.6	7.0
81	2.5R	2.5RP	13.8	7.6	10.5	4.5	11.4
82	2.5R	5RP	9.0	5.7	7.6	3.2	8.6
83	2.5R	7.5RP	6.2	4.0	4.4	2.2	5.1
84	2.5R	10RP	2.3	1.7	2.2	0.6	2.4
85	2.5R	10P	16.8	9.5	11.9	5.8	12.9
86	2.5RP	2.5P	14.1	2.3	3.1	2.1	3.5
87	2.5RP	5P	11.2	9.7	13.2	6.0	14.3
88	2.5RP	7.5P	7.2	7.8	10.3	5.0	11.6
89	2.5RP	10P	3.3	6.0	7.0	4.2	8.2
90	2.5RP	10PB	17.3	4.0	5.1	2.6	5.7
91	2.5Y	2.5YR	12.1	4.9	6.3	4.4	7.2
92	2.5Y	5YR	9.4	2.7	3.5	2.3	4.0
93	2.5Y	7.5YR	6.5	10.1	12.9	7.0	14.8
94	2.5Y	10YR	4.5	8.3	9.6	6.3	11.6
95	2.5Y	10R	15.5	6.5	8.2	4.7	9.3
96	2.5YR	2.5R	13.9	6.4	7.3	5.0	8.5
97	2.5YR	5R	11.2	4.2	4.6	3.0	5.4
98	2.5YR	7.5R	7.8	1.6	1.6	0.9	1.6
99	2.5YR	10R	3.8	9.7	10.7	6.8	12.7
100	2.5YR	10RP	15.9	8.0	9.2	5.3	10.5
101	5B	2.5B	4.1	7.2	8.1	6.4	9.6
102	5B	2.5BG	16.3	4.6	5.9	4.2	6.9
103	5B	5BG	13.5	3.6	4.2	3.2	5.1
104	5B	7.5BG	10.5	2.0	1.8	1.5	1.7

Pairs	Color 1	Color 2	ΔE^*_{94}				
			SPEX	W-L	FR-L	CV-L	BV-L
105	5B	10BG	6.6	10.8	12.8	9.2	13.7
106	5BG	2.5BG	3.2	2.0	3.0	1.6	3.1
107	5BG	2.5G	15.7	9.2	11.2	7.8	12.6
108	5BG	5G	10.9	6.7	9.0	5.6	10.0
109	5BG	7.5G	9.1	5.6	7.3	4.7	8.1
110	5BG	10G	6.4	4.0	4.5	2.9	4.6
111	5G	2.5G	5.1	3.7	6.2	2.9	6.7
112	5G	2.5GY	25.3	1.8	3.4	1.4	3.7
113	5G	5GY	25.0	8.4	12.2	6.9	13.5
114	5G	7.5GY	19.1	7.3	10.5	6.0	11.7
115	5G	10GY	11.6	5.6	7.5	4.2	8.2
116	5GY	2.5GY	4.3	6.0	8.5	4.0	9.3
117	5GY	2.5Y	14.2	4.0	5.6	2.7	6.4
118	5GY	5Y	11.4	2.3	2.5	1.7	2.8
119	5GY	7.5Y	10.1	9.5	12.9	7.0	14.2
120	5GY	10Y	7.3	7.9	10.0	5.3	10.8
121	5P	2.5P	3.0	11.1	8.8	16.0	5.8
122	5P	2.5PB	21.8	9.9	8.9	16.9	7.2
123	5P	5PB	16.8	6.8	5.2	12.5	3.8
124	5P	7.5PB	10.9	3.6	4.2	3.6	4.2
125	5P	10PB	6.4	13.3	10.7	18.6	6.7
126	5PB	2.5PB	5.5	2.8	2.5	2.9	2.8
127	5PB	2.5B	21.9	13.5	10.7	18.0	5.7
128	5PB	5B	17.9	12.7	11.6	19.0	9.7
129	5PB	7.5B	12.7	9.6	7.8	14.6	6.2
130	5PB	10B	9.4	6.5	6.9	6.1	7.0
131	5R	2.5R	3.0	3.7	3.9	3.6	4.5
132	5R	2.5RP	16.5	1.0	1.5	1.0	1.8
133	5R	5RP	11.8	13.4	13.0	19.4	11.2
134	5R	7.5RP	9.1	10.3	9.0	15.1	7.7
135	5R	10RP	5.2	7.4	8.4	6.8	8.7

Pairs	Color 1	Color 2	ΔE*$_{94}$				
			SPEX	W-L	FR-L	CV-L	BV-L
136	5RP	2.5RP	5.0	5.2	6.6	5.4	8.1
137	5RP	2.5P	18.7	2.7	4.5	2.9	5.4
138	5RP	5P	15.9	1.7	2.9	2.0	3.6
139	5RP	7.5P	12.0	11.7	11.5	16.2	10.8
140	5RP	10P	8.2	8.9	11.2	8.4	12.2
141	5Y	2.5Y	3.0	6.5	5.9	4.9	7.3
142	5Y	2.5YR	14.9	4.8	4.3	4.0	4.4
143	5Y	5YR	12.3	3.7	3.6	4.9	3.5
144	5Y	7.5YR	9.3	2.1	2.1	3.3	2.1
145	5Y	10YR	6.9	9.1	8.0	9.0	10.7
146	5YR	2.5YR	3.2	3.2	5.0	3.9	7.5
147	5YR	2.5R	16.7	9.3	10.0	3.9	12.4
148	5YR	5R	14.1	7.6	8.4	3.4	9.3
149	5YR	7.5R	10.8	6.4	7.0	3.4	8.7
150	5YR	10R	7.0	5.0	5.8	2.6	7.0
151	7.5B	2.5B	9.0	5.4	5.6	4.5	5.7
152	7.5B	5B	5.0	3.2	3.5	5.7	3.4
153	7.5B	5BG	18.4	10.2	9.7	8.0	8.6
154	7.5B	7.5BG	15.4	9.1	8.7	8.6	7.8
155	7.5B	10BG	11.6	7.6	7.1	7.1	5.9
156	7.5BG	2.5BG	6.0	8.5	7.1	13.4	7.2
157	7.5BG	5BG	2.9	6.6	4.9	14.0	3.8
158	7.5BG	5G	13.7	3.4	1.9	9.7	2.0
159	7.5BG	7.5G	11.9	12.2	10.1	17.0	9.0
160	7.5BG	10G	9.1	10.6	8.6	15.7	7.2
161	7.5G	2.5G	6.8	6.8	8.2	3.9	12.2
162	7.5G	5G	1.7	5.4	5.9	3.4	9.0
163	7.5G	5GY	26.6	4.0	3.6	4.6	5.4
164	7.5G	7.5GY	20.7	2.7	2.7	3.9	3.9
165	7.5G	10GY	13.3	8.3	10.1	4.9	16.9
166	7.5GY	2.5GY	8.6	1.8	1.7	0.9	3.0

Pairs	Color 1	Color 2	ΔE*94				
			SPEX	W-L	FR-L	CV-L	BV-L
167	7.5GY	5GY	6.0	8.5	9.8	4.4	15.3
168	7.5GY	5Y	16.2	7.1	7.5	4.2	12.1
169	7.5GY	7.5Y	14.9	5.7	5.1	5.6	8.0
170	7.5GY	10Y	12.0	4.2	3.7	4.9	6.1
171	7.5P	2.5P	7.0	3.0	3.1	0.8	4.8
172	7.5P	5P	4.0	1.2	1.6	1.2	2.5
173	7.5P	5PB	20.4	8.4	9.0	3.8	13.6
174	7.5P	7.5PB	14.7	6.9	6.2	4.7	9.9
175	7.5P	10PB	10.4	5.3	4.5	3.9	8.0
176	7.5PB	2.5PB	11.3	4.4	4.4	1.7	6.6
177	7.5PB	5PB	6.2	2.6	2.7	0.9	3.7
178	7.5PB	5B	23.9	1.5	1.5	1.6	2.2
179	7.5PB	7.5B	18.7	8.4	7.7	6.3	11.7
180	7.5PB	10B	15.4	6.9	6.1	5.6	9.7
181	7.5R	2.5R	6.6	6.7	9.5	9.0	10.6
182	7.5R	5R	3.7	5.3	7.7	6.5	9.8
183	7.5R	5RP	15.1	3.7	5.5	5.2	7.1
184	7.5R	7.5RP	12.5	1.8	2.1	1.6	3.3
185	7.5R	10RP	8.7	7.7	10.6	9.3	11.0
186	7.5RP	2.5RP	7.8	1.7	2.6	1.7	2.7
187	7.5RP	5RP	2.9	8.3	12.1	10.6	14.4
188	7.5RP	5P	18.5	6.9	10.3	8.2	13.5
189	7.5RP	7.5P	14.8	5.4	8.1	6.9	10.5
190	7.5RP	10P	11.0	3.4	4.5	3.3	6.4
191	7.5Y	2.5Y	4.3	3.9	6.8	4.4	8.6
192	7.5Y	5Y	1.5	2.2	4.3	2.7	5.4
193	7.5Y	5YR	13.7	8.9	14.5	11.0	21.3
194	7.5Y	7.5YR	10.7	7.5	12.3	9.7	17.7
195	7.5Y	10YR	8.3	5.5	8.7	6.0	12.9
196	7.5YR	2.5YR	7.1	5.3	8.1	4.3	10.6
197	7.5YR	5YR	3.9	3.6	5.6	2.6	7.2

Pairs	Color 1	Color 2	ΔE^*_{94}				
			SPEX	W-L	FR-L	CV-L	BV-L
198	7.5YR	5R	17.5	1.7	1.8	0.7	1.9
199	7.5YR	7.5R	14.3	8.7	13.6	9.4	20.3
200	7.5YR	10R	10.8	6.9	10.1	5.9	15.3

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