# การหาความสว่างเทียบเท่าของสิ่งเร้าขนาดเล็กในผู้สูงอายุโดยใช้แว่นจำลองต้อกระจก

นางสาว ภัทริน วงษ์สมพิพัฒน์



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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ปีการศึกษา 2553

DERTERMINATION OF EQUIVALENT LIGHTNESS OF SMALL STIMULUS
IN THE ELDERLY USING CATARACT EXPERIENCING GOGGLES

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Imaging Technology
Department of Imaging and Printing Technology
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| Thesis Advisor | Assistant Professor Pichayada Katemake, Ph.D. |
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ภัทริน วงษ์สมพิพัฒน์: การหาความสว่างเทียบเท่าของสิ่งเร้าขนาดเล็กในผู้สูงอายุโดยใช้แว่นจำลองต้อกระจก. (DETERMINATION OF EQUIVALENT LIGHTNESS OF SMALL STIMULUS IN THE ELDERLY USING CATARACT EXPERIENCING GOGGLES) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ.ดร. พิชญดา เกตุเมฆ, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม: Prof. Mitsuo Ikeda, 61 หน้า.

งานวิจัยนี้ได้ศึกษาเพื่อหาค่าความสว่างเทียบเท่า (equivalent lightness ; L*eq) ในผู้สูงอายุด้วยแว่นจำลองต้อกระจกและเสนอแนวทางการปรับปรุงค่าความสว่างเทียบเท่าในผู้สูงอายุ โดยการทดลองแบ่งเป็น 2 ส่วน คือ การทดลองภายใต้สภาวะการมองปกติ (normal viewing condition) และการทดลองภายใต้สภาวะการมองสภาพแวดล้อมและสิ่งเร้าแยกกันอิสระ (environment-stimulus independent condition) ในการทดลองภายใต้สภาวะการมองปกติ ได้ทำการหาค่าความสว่างเทียบเท่าโดยเทียบความจ้าของสิ่งเร้ามีสีกับความจ้าของแถบสีเทา (heterochromatic brightness matching) ภายใต้ระดับความสว่าง 9 ระดับตั้งแต่ 0.08 – 800lx.ภายในห้องผู้สังเกต โดยทดลองทั้งหมด 4 สี ผลที่ได้คือ เมื่อมองสิ่งเร้ามีสีผ่านแว่นจำลองต้อกระจก ค่าความสว่างเทียบที่ได้จากสิ่งเร้ามีสีทั้งหมด 4 สีนั้นมีค่าน้อย ซึ่งมีค่าความสว่างประมาณ 10 หน่วย จากนั้นได้ทดลองศึกษาการปรากฏสีด้วยวิธีการบอกคำเรียกสีพื้นฐาน (elementary color naming) โดยให้ผู้สังเกตบอกปริมาณความเป็นสี (Chromaticness) ความขาว (Whiteness) และความดำ (Blackness) ในรูปร้อยละและบอกสีสันของสิ่งเร้ามีสีทั้ง 4 สีที่วางอยู่ในห้องผู้สังเกต ผลที่ได้คือ เมื่อระดับความสว่างภายในห้องผู้สังเกตมีค่าต่ำ ค่าความอิ่มตัวสีที่ได้มีค่าลดลง ซึ่งเป็นสาเหตุให้ค่าความสว่างเทียบเท่าที่ได้มีค่าลดลง และการทดลองภายใต้สภาวะการมองสภาพแวดล้อมและสิ่งเร้าแยกกันอิสระนั้น เป็นการเสนอแนวทางการปรับปรุงค่าความสว่างเทียบเท่าในผู้สูงอายุให้สูงขึ้น โดยวางสิ่งเร้ามีสีในห้องที่แยกกันจากห้องผู้สังเกตที่มีระดับความสว่างคงที่ที่ 200 lx. ขณะเดียวกันปรับระดับความสว่างภายในห้องผู้สังเกตเช่นเดียวกันกับการทดลองภายใต้สภาวะการมองปกติ ซึ่งการทดลองวิธีนี้จะทำให้ลดผลกระทบที่มาจากแสงในสภาวะแวดล้อม ผลที่ได้แสดงให้เห็นว่าเมื่อมองสิ่งเร้ามีสีผ่านแว่นจำลองต้อกระจก ค่าความสว่างเทียบเท่าที่ได้นั้นมีค่าสูงขึ้นทุกๆระดับความสว่างภายในห้องผู้สังเกต ซึ่งต่างจากการทดลองภายใต้สภาวะการมองปกติ จากการทดลองทั้งสองส่วนทำให้พบว่าค่าความสว่างเทียบเท่าในผู้สูงอายุนั้นประกอบด้วยค่าความสว่างของวัตถุ (L*achr), ค่าความสว่างที่มาจากสีของวัตถุ (L*chr) และค่าความสว่างที่มาจากสภาวะแวดล้อม (L*env)



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| ภาควิชา วิทยาศาสตร์ทางภาพถ่าย | ลายมือชื่อนิสิต.............................. |
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## # 5272472023 : MAJOR IMAGING TECHNOLOGY
KEYWORDS : BRIGHTNESS/ LIGHTNESS/ EQUIVALENT LIGHTNESS/ COLOR APPEARANCE/ ELDERLY PEOPLE/ CATARACT EXPERIENCING GOGGLES

PATARIN WONGSOMPIPATANA : DETERMINATION OF EQUIVALENT LIGHTNESS OF SMALL STIMULUS IN THE ELDERLY USING CATARACT EXPERIENCING GOGGLES. ADVISOR : ASST. PROF. PICHAYADA KATEMAKE. CO-ADVISOR : PROF. MITSUO IKEDA, Ph.D. 61 pp.

The research aims to obtain and to improve the equivalent lightness perceived by elderly people by using the cataract experiencing goggles. Two viewing conditions were employed, the normal viewing and the environment-stimulus independent condition. In the normal viewing condition the heterochromatic brightness matching was carried out for four colored stimuli under nine illuminance levels from 0.08 lx through 800 lx. The results showed the equivalent lightness was lower with the goggles by the amount about 10 L* unit at any illuminance level. The color appearance experiment was also carried out by the elementary color naming method, where the chromaticness, whiteness, and blackness were estimated for colored stimuli. The chromaticness decreased for lower illuminance causing the equivalent lightness to decrease. The environment-stimulus independent condition was proposed to keep the equivalent lightness of elderly people high. A colored stimulus was placed in a separated room from the subject room and its illuminance was kept constant as 200 lx, while that of the subject room was varied as in the normal viewing experiment. By this way the effect of the environment light was reduced. The result showed that the equivalent lightness was high even with goggles for all the room illuminance unlike the normal viewing condition. It was found from the two experiments that the equivalent lightness of elderly people was composed of L*achr, L*chr, and L*env.

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Student's Signature Patarin Wongsompipatana
Advisor's Signature Pichayada K
Co-advisor's Signature M. Ikeda

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# CHAPTER I
# INTRODUCTION

Population distribution for ages is rapidly changing in any country and so in Thailand as seen in Fig. 1.1 for 1965, 2005 and 2050, which is taken from the UN World Population Prospects, 2004 revision. The abscissa gives the percentage of the total population and along the ordinate the ages in five years old steps. The ordinate is divided to three sections, children, working people and elderly people. As we can see in the figure the proportion of the elderly people to the working people increases very rapidly year after year. An obvious result from this change is the increase of the

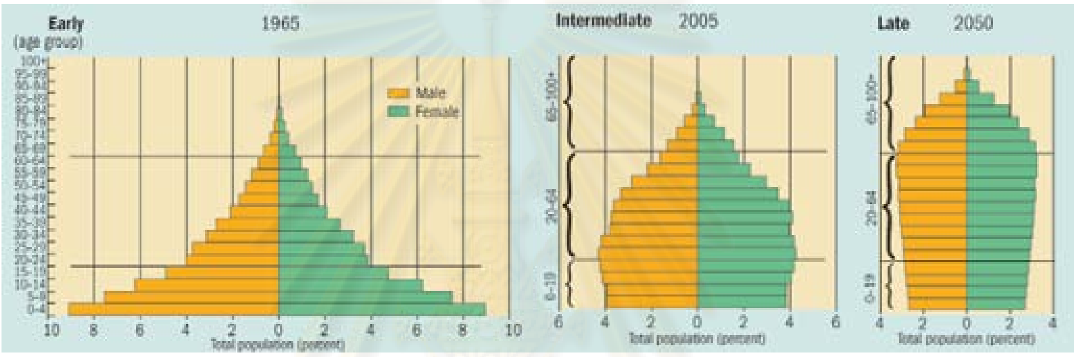



Fig. 1.1 Shift of population distribution in time in Thailand.

burden of the working people to support the elderly people, that is the working people is obliged to pay more tax in the near future than the present time. One solution to solve this problem is to modify the infrastructure of the society in many ways to suit elderly people. What is the problem in the elderly people? There are many, but one of the most serious problems is the change in the visual function. It deteriorates as age, mostly because of the cataract. The visual perception of the cataract eyes is composed of three elements, color, brightness and haze. The color element is related to the reduced transmittance of light at short wavelengths of crystalline lens, the brightness element to the reduced transmittance at entire region of wavelength, and the haze element to the opacity of the crystalline lens [1].

An important visual perception that is affected by the cataract is the brightness. By the brightness we can identify objects and lights and scientists and engineers made every effort to quantify it. The luminous efficiency function $V(\lambda)$ introduced by CIE in 1924 [2] was the first step in the effort and many photometric units were developed to express the brightness based on the function. The luminance coming to the eyes from surfaces of objects or from light sources expresses their brightness. The lightness is another expression of the brightness of surfaces of objects. From the time of the development of these photometric units, however, a discrepancy between those units and the brightness perception has been pointed out by Kohlrausch already in 1935 [3]. A systematic measurement to show the discrepancy quantitatively was done by Sanders and Wyszecki [4] for lights and by Wyszecki [5] for colored objects, and made it clear that colored lights and colored objects are brighter than an achromatic light or an achromatic object when the luminance was made equal. This phenomenon is now called the Helmholtz-Kohlrausch effect.

To express the brightness of objects more properly the equivalent lightness L*eq was introduced, which is the lightness of a gray scale that matches the object in brightness.

Ikeda et al. [6] and Ikeda and Ashizawa [7, 8] measured the equivalent lightness for various colors and under various illuminance levels and proposed that the equivalent lightness L*eq is composed of two lightness, that is

$$L^*eq = L^* + L^*chr \qquad (1.1)$$

where L* is the lightness itself and L*chr the lightness coming from the color of an object.

By using the cataract experiencing goggles to simulate the elderly vision Ikeda and Obama [9] found that colors desaturate because the environment light is scattered into the eyes by the haze filter of the goggles. There are lots of the environment light around us and the light is scattered on the retina because of the haze filter. The environment light is normally white and desaturates the color of retina image. The desaturation should cause L*chr smaller because the contribution of color to L*chr is smaller. The color objects should appear less bright than normal eyes.

In this experiment we first measure the equivalent lightness perceived by the elderly people by using the heterochromatic brightness matching method with the cataract experiencing goggles under various illuminance levels covering mesopic and photopic vision and then investigate the color appearance to see how much the color changes in the elderly people by using the elementary color naming method with the cataract experiencing goggles. This experiment may be called the normal viewing experiment. In the second step we will propose a way to improve the equivalent lightness of colored objects in elderly people by introducing the environment-stimulus independent condition that reduces the effect of environment light. In this experiment we use two rooms, one for the subject and the other for the stimulus. We may call the experiment the two rooms experiment. We will obtain the equivalent lightness and the color appearance of objects in elderly people under various illuminance levels in this experiment also.

# CHAPTER II
# LITERATURE REVIEW

A systematic investigation on the brightness-luminance discrepancy for object colors was carried out by Wyszecki [5] in 1967. He used 43 colored ceramic tiles as stimuli and made the brightness matching with a set of 10 gray tiles. The luminance of the matched gray tile was always larger than the luminance of those colored tiles and he showed the results by the ratio of the luminance of the matched gray tile and of the colored tile, which is called B/L ratio. The B/L was larger than 1.0 for all the colored tiles. The contour curves of constant B/L were drawn on the CIE xy chromaticity diagram as shown in Fig. 2.1. It is clearly shown that the more saturated colored tiles have larger B/L value.

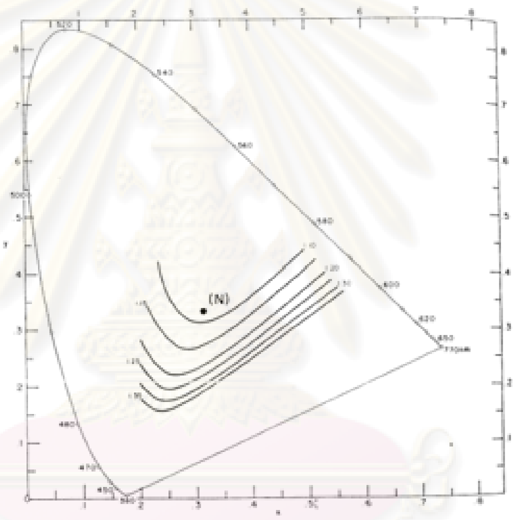



Fig. 2.1 Contour curves of B/L of color tiles.

In treating the brightness of objects it is more useful to specify it by the equivalent lightness L*eq rather than the luminance. It is the lightness of a gray scale that matches a stimulus object in brightness. Ikeda et al. [6] measured the equivalent lightness of colored chips of the size 20’, 1°, and 6° under illuminance 0.01 lx to 1000 lx and showed that the equivalent lightness L*eq can be expressed as

$$L^*eq = L^*achr + L^*chr \qquad (2.1)$$

where L*achr is the achromatic lightness and L*chr the chromatic lightness. When the illuminance is very low L*achr becomes the scotopic lightness and when the illuminance is high it becomes the photopic lightness. In between the scotopic vision and the photopic vision there is the intermediate vision called the mesopic vision. L*achr shifts from the scotopic to photopic lightness smoothly in that region but the authors concluded the shift can be expressed by a straight line. They concluded also that the border from the scotopic vision to the mesopic vision locates at the illuminance 0.02 lx and the border from the mesopic to the photopic at the illuminance 2 lx. They employed colored stimuli of three sizes and L*eq was obtainable for the largest stimulus for all the three regions of scotopic, mesopic, and photopic vision, but obtainable with the smallest stimulus only for the photopic region. It was clearly shown that L*chr depends on the color of colored patch.

The dependence of L*chr on the color was further investigated by Ikeda and Ashizawa [7] by employing colored stimuli of different Munsell Chroma but of a same Munsell Hue and a same Munsell Value. Examples of the results are shown in Fig. 2.2 for the stimuli 5R4/2, 5R4/6, 5R4/10, and 5R4/14. The abscissa gives the illuminance E lx in

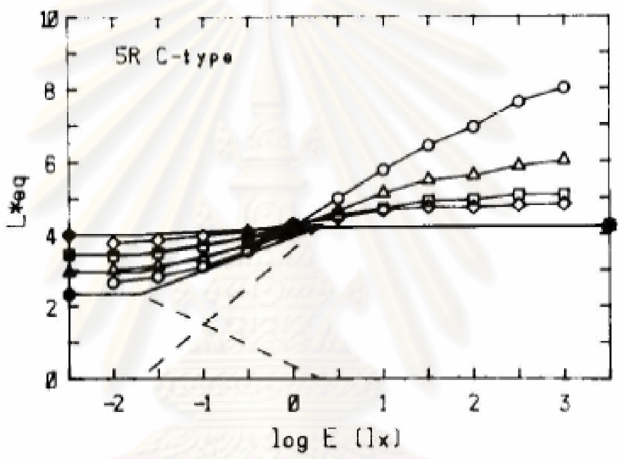



Fig. 2.2 The equivalent lightness of red stimuli plotted for the room illuminance. The four curves correspond to different Chroma. Straight lines show the achromatic lightness.

log unit under which the brightness matching was conducted and the ordinate the equivalent lightness L*eq. Straight solid lines are L*achr. The horizontal lines at low illuminance show L*achr of the scotopic vision and the horizontal line at high illuminance shows L*achr of the photopic vision. Oblique lines show L*achr of the mesopic vision. All the equivalent lightness locate above the achromatic lightness at any region, but it is most high with the stimulus 5R4/14. A stimulus of a high Chroma or a high saturation appears very bright compared to its achromatic lightness. The effect of hue to the equivalent lightness was also analyzed and it was smallest with the yellow hue among four hues.

Ikeda et al. [10] derived a hue coefficient formula to show the effect of hue to the equivalent lightness, which is shown by a solid curve in Fig. 2.3. The coefficient is large for hues 5R, 5P, 10B and so on, but it is smallest for 5Y, or yellow. The yellow

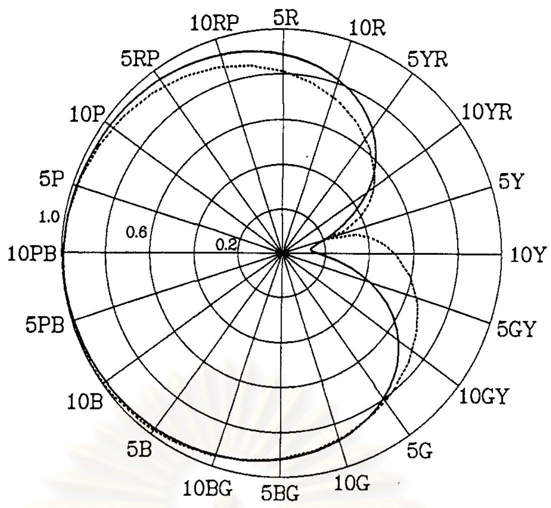



Fig. 2.3 Hue coefficient of the contribution to the brightness.

color does not contribute to the brightness much.

So far for the equivalent lightness of the normal vision and we review now literatures about the vision of the elderly people. Soon or later elderly people get cataract in their eyes and it became important in many countries to investigate about the visual perception by the cataract eyes. Obama et al. [1] developed the cataract experiencing goggles so that young people can experience the elderly vision. The goggles are in principle composed of three filters, a color filter, a neutral density filter, and a haze filter. The first two reduced the light transmitted but the last haze filter scatters incoming light. We call the goggles the Panasonic goggles if it is necessary to distinguish it from other goggles.

By using the cataract experiencing goggles Ikeda and Obama [9] studied the color appearance of colored objects and showed that the color desaturates with the goggles as shown on the Munsell color notation graph in Fig. 2.4. Open circles indicate the colored objects seen by one eye and the arrows indicate the shift of the color appearance with the goggles in the other eye. All the arrows of the colors, whether under the illumination 10 lx or 1000 lx and whether the subject MI or TK, point toward the center of the graph implying the desaturation with the goggles. The authors concluded that the desaturation was caused by the scattered light by the haze filter. There is a lot of environment light surrounding us which is normally white and the light is scattered by the haze filter of the goggles into the eyes. The white light over lays on the retinal image of the colored stimulus and the color desaturates. Ikeda et al. [11] investigated the effect of the stimulus size on the color desaturation. Color stimuli of the size 0.7, 1.5, 2.2, 5.9, 10.3, and 24.1° of arc of visual angle were employed and their color appearance was measured by the elementary color naming method. It was shown that the color desaturation was large for the small three sizes. A colored stimulus of a small size such as 2° may be used in investigation of the equivalent lightness of the elderly people.

If this desaturation takes place in the elderly eyes the equivalent lightness L*eq should become smaller because L*chr in Eq. (2.1) is smaller due to the less contribution from the color. This is a serious change in the brightness perception in the elderly people but there has been no investigation in the past about this.

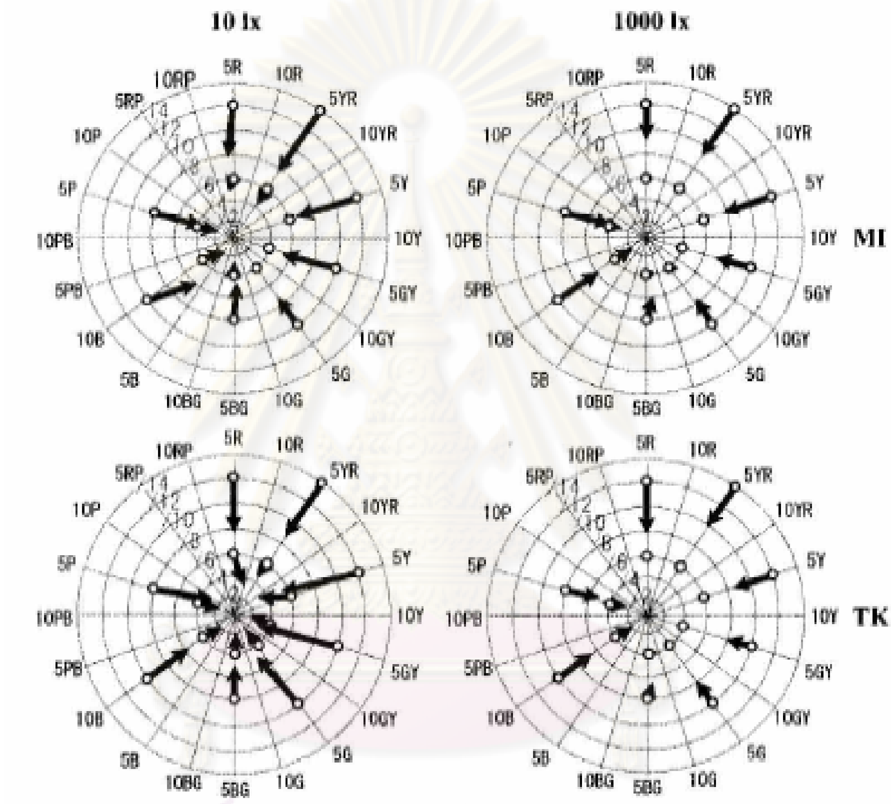


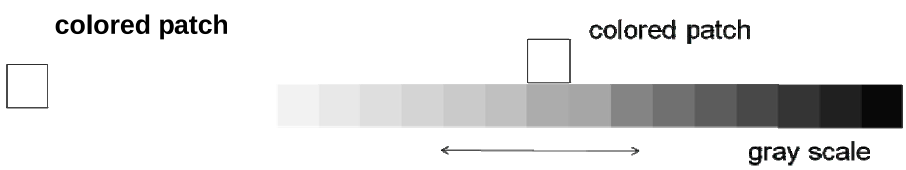

Fig. 2.4 Color appearance shift from the normal eyes to the eyes with the goggles.

# CHAPTER III
# PRINCIPLE AND METHODOLOGY OF EXPERIMENT

We are interested in determining the equivalent lightness of the elderly people and naturally the persons who participate to the experiment as subjects would be elderly people. But it is difficult to do precise psychophysical measurement for elderly people by asking them to come to the laboratory and to spend many days for the experiment. It is not practical. So we use young students and ask them to wear the cataract experiencing goggles to simulate elderly vision. The Panasonic goggles will be used, of which properties are well documented [1, 9].

It was stated that the equivalent lightness is influenced by the color saturation. In the first step of the experiment we investigate the color saturation by measuring the color appearance of colored objects and in the second step we measure the equivalent lightness. We employ the elementary color naming method for measuring the color appearance. A colored patch of a small size is presented in front of a subject as shown in Fig. 3.1a and he/she looks at the color patch and judges its color appearance in terms of color elements, namely, chromaticness, whiteness and blackness, in percentage. And then he/she judges the chromaticness in terms of unique hues, namely red, yellow, green and blue, again in percentage but by using only one or two of them. The opponent hues, that is the red-versus-green and the yellow-versus-blue can not be used at the same time. For example, a bright yellowish green patch may be judged as 60 % for chromaticness, 32 % for whiteness and 8 % for blackness to make 100 % altogether. Finally, he/she may judge the chromaticness composing of 35 % of yellow and 65 % of green. The yellow and the blue are not opponent colors. The color saturation that we are interested in can be known by the ratio of the chromaticness to the whiteness. It should be understood that the elementary color naming is the absolute judgment without any reference color unlike the brightness matching.






(a) (b)

Fig.3.1 Arrangement for the elementary color naming (a), and for the heterochromatic brightness matching (b).

In the second step we measure the equivalent lightness by using the heterochromatic brightness matching method. A colored patch is compared with a gray scale side by side as shown in Fig. 3.1b and a subject moves the gray scale back and forth and find out a patch in the gray scale that matches with the colored patch in brightness. The lightness of the matched gray scale is now the equivalent lightness of the colored patch. This matching is done for two patches of different colors and the method is called the heterochromatic brightness matching. In normal situation the gray scale is made of steps of achromatic patches and there might not be a patch that matches the colored patch exactly in brightness. In this case an interpolation between two gray patches can be made. In some other time the brightness of a colored patch may appear still brighter than the brightest gray patch and an extrapolation can be made in this case.

Whether for the color naming or for the heterochromatic brightness matching the judgment is made both with the normal eyes, that is, without the goggles, and with the goggles so that we can compare results between young eyes and elderly eyes. We have to notice here, however, that in obtaining the equivalent lightness in this way the subject wares the goggles when he/she looks not only at the colored patch but also at the gray scale. In other words the brightness for the gray scale is the brightness experienced by an elderly person as illustrated in Fig. 3.2a. We are interested to express the brightness of a colored patch experienced by the elderly people by the brightness of a gray scale experienced by the young people. So the equivalent lightness determined in the above way should be transferred to the equivalent lightness based on the perception of the young people. Therefore, we do another experiment where the brightness matching between two gray scales, one of which is observed with the goggles and the other is observed without the goggles, is made as illustrated in Fig. 3.2b. This experiment will be called the transfer experiment in the

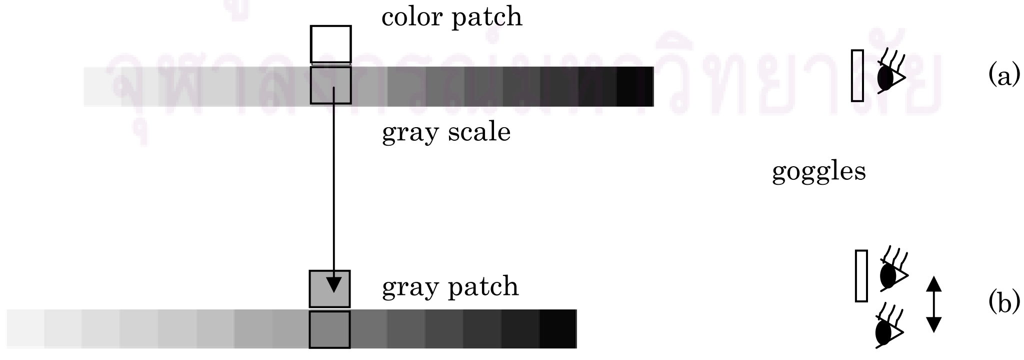
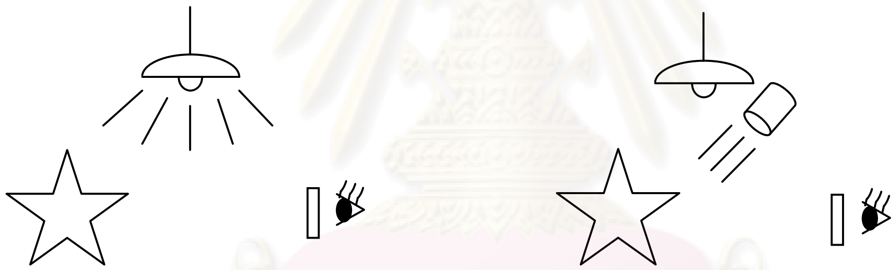



Fig. 3.2 Arrangement for the transfer experiment.

present paper. It is of course possible in theory to do the heterochromatic brightness matching between a colored patch observed with the goggles and a gray scale observed without the goggles. But this is extremely difficult for subjects to do as the brightness of patches of different colors should be made by memory of the brightness, one for a colored patch and the other for an achromatic patch, with a time interval to wear or to take out the goggles. Such matching between both achromatic patches can be reasonably done even with the time interval.

It was anticipated that the equivalent lightness is smaller in elderly people causing their brightness perception for any colored surfaces lower because of the color desaturation caused by the foggy crystalline lens and the environment light that is scattered into the eyes as illustrated in Fig. 3.3a. We can expect then that lowering of the equivalent lightness would be avoided if we can reduce the environment light without reducing the illumination on the object that the elderly person is looking at as in Fig. 3.3b. This situation can be realized by employing two rooms, one for the person and the other for the object, and by illuminating the rooms independently.



(a) (b)

Fig. 3.3 Illustration of normal viewing situation (a) and environment-stimulus independent situation (b).

This experiment will be called the environment-stimulus independent experiment. In the present paper we will build an experimental booth which is composed of two rooms, a subject room and a stimulus room, connected by a window between them. A subject looks at stimuli placed in the stimulus room through the window while he/she is staying in the subject room. We can investigate the effect of the environment light on the color appearance and on the equivalent lightness by controlling both illuminations for the subject room and the stimulus room. The environment-stimulus independent experiment can be called the two rooms experiment, while the experiment under normal illuminating condition may be called the normal viewing experiment or the one room experiment. Fig. 3.4 shows the entire experiment of the present paper in a block diagram.

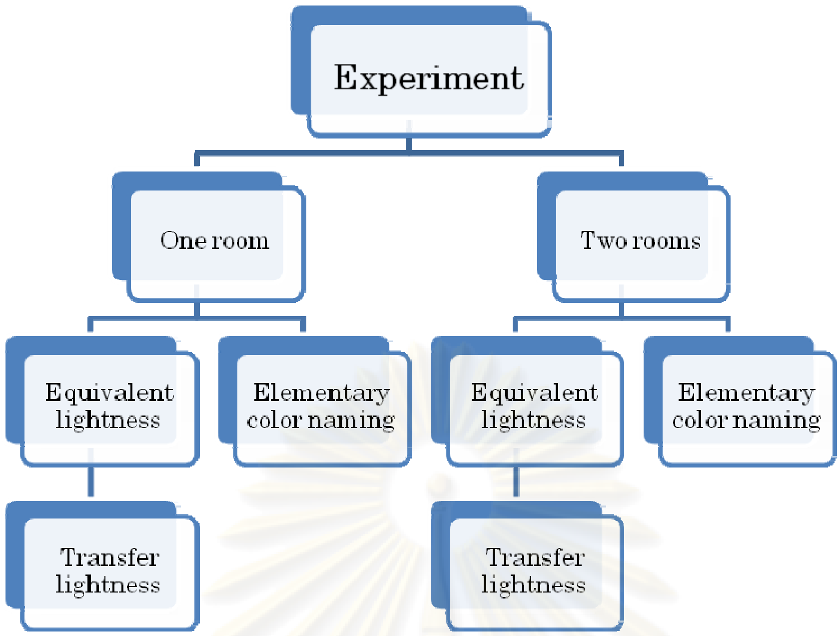



Fig. 3.4 A block diagram to show the entire experiment of the present research.

# CHAPTER IV
# EXPERIMENTAL APPARATUS AND EXPERIMENTAL CONDITION

## 4.1 Goggles

The cataract experiencing goggles are made in principle of three filters, a neutral density filter, a color filter, and a haze filter [1]. In reality the first two filters were replaced by one color filter and the newest version of its spectral transmittance curve is shown in Fig. 4.1 as given by Dr. Obama. The haze value of the haze filter is about 18 %. The haze value is defined as the percentage of the scattered light to the entire transmitted light. The determination of these filters was based on 48 cataract patients who started to feel inconvenience in their daily life in seeing and who operated for one eye to replace the crystalline lens with an intraocular lens IOL.

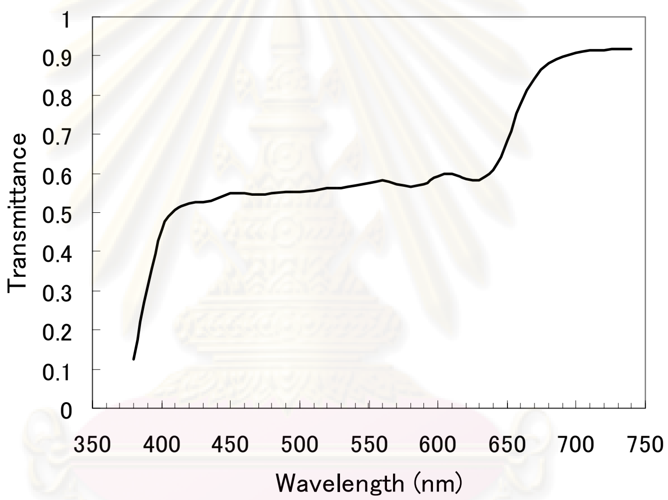
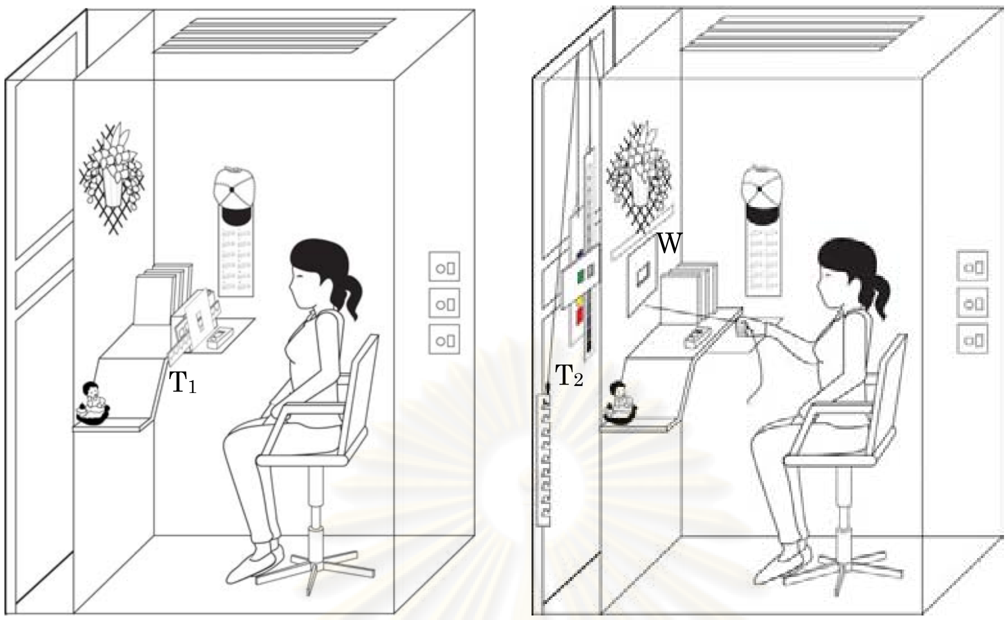



Fig. 4.1 Spectral transmittance curve of the color filter used in the goggles.

## 4.2 Experimental booth

A room of 100 cm wide, 175 cm deep, and 240 cm high was built and it was divided to two rooms in the depth to make a subject room of 150 cm deep and a stimulus room of 25 cm deep, which is shown in Fig. 4.2. In between the two rooms a small window W of the size 4.2 cm high and 12 cm wide was opened at a height 130 cm through which a subject could just observe a stimulus and a gray scale placed in the stimulus room in the environment-stimulus independent experiment (b). The window was closed in the normal viewing experiment (a). The inside walls were pasted by a white wall paper with a slight texture of the Munsell Value N8.2. The subject room was illuminated by five fluorescent lamps of 3-bands type of 20 W each attached on the ceiling. The stimulus room was also illuminated by a fluorescent lamp of 3-bands type of 20 W attached on the dividing wall. Both illuminations were controllable in




(a) (b)

Fig. 4.2 A scheme of the experimental booth, a, normal viewing condition; b, environment-stimulus independent condition.

intensity. There was a shelf attached on the front wall at a height 100 cm on which an illuminometer was put to measure the room illuminance. The subject room was decorated with dolls, artificial flowers, books, pictures and so on to simulate a normal room. A subject sat in the subject room at the distance 90 cm from the front wall and his/her eyes were 130 cm high.

In the normal viewing experiment, stimuli and a gray scale were placed on a tilted plate which was put on the shelf as shown by $T_1$ in Fig. 4.2. The subject moved the gray scale horizontally by his/her hand. He/she also chose a colored stimulus by him/herself following the experimenter's requirement. In the environment-stimulus independent experiment, stimuli and a gray scale were placed vertically in the stimulus room at the distance 25 cm from the dividing wall as shown by $T_2$. The subject pulled or released a string that hung the gray scale to adjust its position. The experimenter used another string to select a stimulus.

#### 4.3 Stimuli and gray scales

Four colored patches were selected as stimuli, 5R4/14, 5Y8/14, 5G5/10, and 10B5/10. They were cut in the size 4.5 x 4.5 $cm^2$ and pasted in the order on a paper board for the normal viewing experiment and on plywood for the environment-stimulus independent experiment. The gray scale was made of 15 gray patches ranging from

N2.5 to N9.5 with N0.5 steps. They were also pasted on a board. The size of each patch was 3 x 3 $cm^2$ for the normal viewing experiment and 4.5 x 4.5 $cm^2$ for the environment-stimulus independent experiment. In the normal viewing experiment a subject looked at the colored patch and the gray scale at the distance 40 cm. We wanted to have the stimulus size of $2^\circ$ arc of the visual angle to have a large desaturation effect [11] and consequently a square window of the size 1.4 x 1.4 $cm^2$ was placed on both the colored stimulus and the gray scale in the normal viewing experiment. In the environment-stimulus independent experiment the window size was 4 x 4 $cm^2$ to give the same visual angle of $2^\circ$ arc as the viewing distance was 115 cm.

Figure 4.3a shows a set of the stimulus and the gray scale placed in the subject room in the normal viewing experiment. The small upper window is for the colored stimulus


(a) (b)

Fig. 4.3 Subject's view for stimulus and gray scale (a), and a subject looking at the stimulus with goggles (b). Normal viewing experiment.

and any stimulus of four colors can be shown by sliding the stimulus board side way. The lower window is for the gray scale and its position in the window can be read out through a large window below. Fig. 4.3b shows the instance when a subject is adjusting the gray scale by her hand. She wears the goggles. An illuminometer to measure the room illuminance is seen in front of the stimulus-grayscale set. In the case of color appearance experiment only the stimulus is shown without the gray scale.

Figure 4.4 shows the set of the stimulus and the gray scale in the case of the environment-stimulus independent experiment. The photograph was taken through an enlarged window on the dividing wall. The stimulus and the gray scale were placed side by side, the test stimulus on the left and the gray scale on the right. A small window on the right is the window to see the position of the gray scale. A horizontal rectangular frame with a dotted line shows the size of the observing window opened on the dividing wall. The size was made as small as possible just to see the stimulus, the gray scale and the number of the gray scale by both eyes and it was 12 x 4 $cm^2$. This was to minimize the environment light coming from the stimulus room itself.

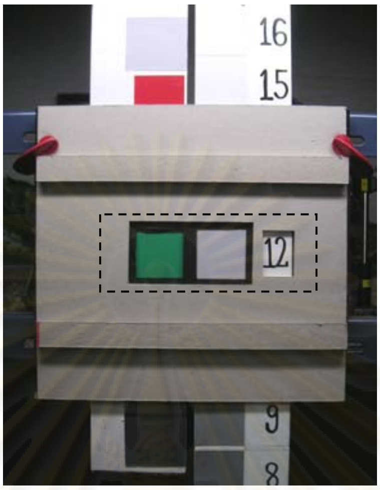



Fig. 4.4 The stimulus and the gray scale in the stimulus room. A dotted rectangle indicates the window size through which a subject is looking at them.

In the transfer experiment a sliding mask was put on the stimulus and the gray scale so that only one of them can be seen to the subject. This made the difficult measurement a little bit easier.

### 4.4 Illuminance levels

Nine levels of illuminance were prepared for the subject room. They were 0.08, 0.25, 0.8, 2.5, 8, 25, 80, 250, and 800 lx covering the mesopic to photopic vision. They were taken to have a same interval of 0.5 in log unit. The level for the scotopic vision was not employed because the measurement can not be made for that level with the small patch size of 2 degrees square [6].

In the environment-stimulus independent experiment the stimulus room was kept constant at 200 lx of the vertical plane illuminance on the stimulus surface.

In the transfer experiment the illuminance levels of the subject room were reduced to five, 0.08, 0.8, 8, 80, and 800 lx. Only four gray patches were transferred from the goggles eyes to the normal eyes, N3.5, N5.5, N7.5, and N9.5.

### 4.4 Subjects

Five subjects participated in all the experiments, PW (24 years old, female), CJ (25, male), PR (25, male), ET (36, male), and MI (77, male). They are all normal in the color vision as tested by the 100 hue test. The experiments were done binocularly. Both eyes of the subject MI were operated for the cataract and installed with IOL. He has a good visual acuity.

### 4.5 Procedure

Prior to the main experiment each subject except an experienced subject MI was instructed about the heterochromatic brightness matching and the color naming, and experienced both experiments for some stimuli.

The instruction for the brightness matching was "Please move the gray scale back and forth and find a patch of which brightness is same as that of the colored stimulus. If there is no such gray patch that matches exactly with the stimulus in brightness, please estimate a value in between two neighboring patches such as 11.5. If you have no brighter gray patch available because a colored stimulus appears very bright, you may extrapolate the gray scale responding such as 16.8. Please report the number of the gray scale when you decide. There are four colored stimuli and the experimenter will tell you which color should be prepared. He will also tell you whether you observe patches with or without goggles."

The instruction for the transfer experiment goes like "Please slide the mask on the stimulus so that you can see only the lower window where a gray patch is presented and observe it with goggles and remember its brightness. Then slide the mask so that you can see only the upper window. Take the goggles out and find a gray patch that matches with the previous patch in brightness by your memory. You can observe the stimulus and the gray scale as many as you like to." Rest of the instruction is same as for the previous instruction.

The instruction for the color appearance was "Please look at the colored stimulus and judge its color appearance in terms of chromaticness, whiteness, and blackness in percentage to make the total 100. You can judge from any element of the three. Then judge the chromaticness in terms of unique hues, red, yellow, green, and blue in percentage. You can use only one or two of the hues, but you can't respond with red and green together, nor yellow and blue together."

Some tasks in the experiments instructed in the above instructions are carried out by the experimenter.

The experiment was always started from 800 lx of the subject room. No particular adapting time was prepared as subjects entered the subject room from another room of which illuminance was comparable to the subject room. Further more it took a few minutes before a subject could judge any. When the 800 lx level was over the next 250 lx level was investigated. No adaptation time was required as the illuminance level changes only -0.5 lx in log unit. When the lowest level of 0.08 lx was investigated one experimental session was over. When the increasing series of the subject room illuminance was employed it was always started continuously after the decreasing series to avoid a long adapting time. No special adaptation time was set when a subject wore the goggles because the illuminance change at the eyes from the normal eyes to the eyes with goggles was only -0.24 in log unit.

Total of ten sessions were conducted for the equivalent lightness experiment and five sessions for the color naming experiment.

The experimental conditions are summarized in Table 4.1.

Table 4.1 Experimental conditions

| | | |
|---|---|---|
| Stimulus | 4 colors | 5R4/14 5Y8/14 5G5/10 10B5/10 |
| Stimulus size | | 2° |
| Illuminance level | Subject room | 0.08 0.25 0.8 2.5 8 25 80 250 800 lx |
| Illuminance level | Stimulus room | 200 lx |
| Subjects | 5 persons | PW CJ PR ET MI |

# CHAPTER V
# EXPERIMENT - NORMAL VIEWING

## 5.1 Apparatus and procedure

This is the experiment of which principle was illustrated in Fig. 3.2a. The window on the dividing wall was closed and only the subject room shown in Fig. 4.2 was used. A subject sat down on a chair so that the viewing distance to the stimulus became 40 cm. A pole of 40 cm long was prepared so that the subject could estimate his/her eye position. The room illuminance was adjusted by the subject at the highest level of 800 lx in most cases. The adjusting time eventually worked as the adaptation time.

When the illuminance was adjusted at a certain level the measurement of the equivalent lightness was carried out. The subject did the heterochromatic brightness matching between the colored stimuli and the gray scale with the goggles in one case and without the goggles in another case for one colored stimulus. “With” or “without”, and “which color” were selected by an experimenter randomly. When four colored stimuli were finished the next illuminance level was adjusted and the experiment was continued until all the illuminance levels were treated, when one session was over. Ten such sessions were done by each subject at different time and on different days. One session took between 30 minutes and 2 hours depending on subjects.

## 5.2 Results of the equivalent lightness with and without goggles

Examples of the results are shown in Fig. 5.1 taken from the subjects PW and MI for the red stimulus of 5R4/14. The abscissa gives the room illuminance lx in log unit. There are indicated the regions of the mesopic and the photopic vision. The scotopic region is outside to the left in the graph. The ordinate gives the equivalent lightness

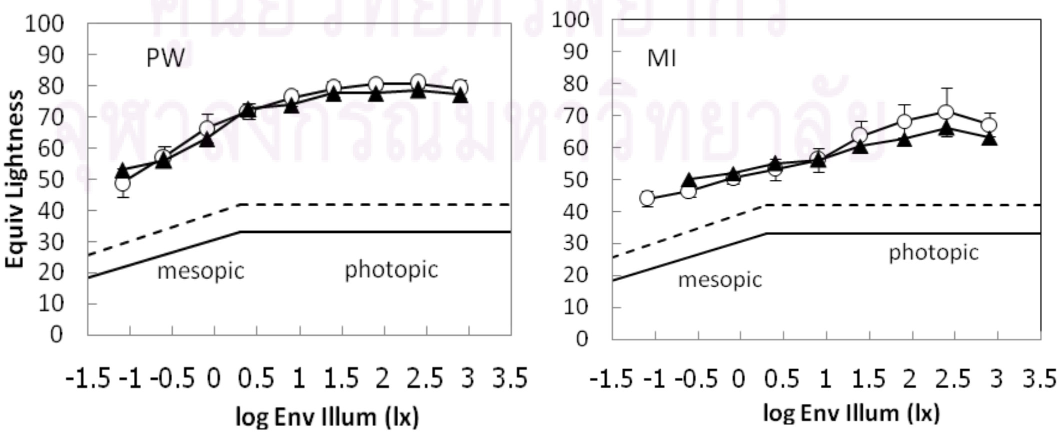



Fig. 5.1 Equivalent lightness of the subjects PW and MI for the red stimulus. Open circles, without goggles; filled triangles, with goggles.

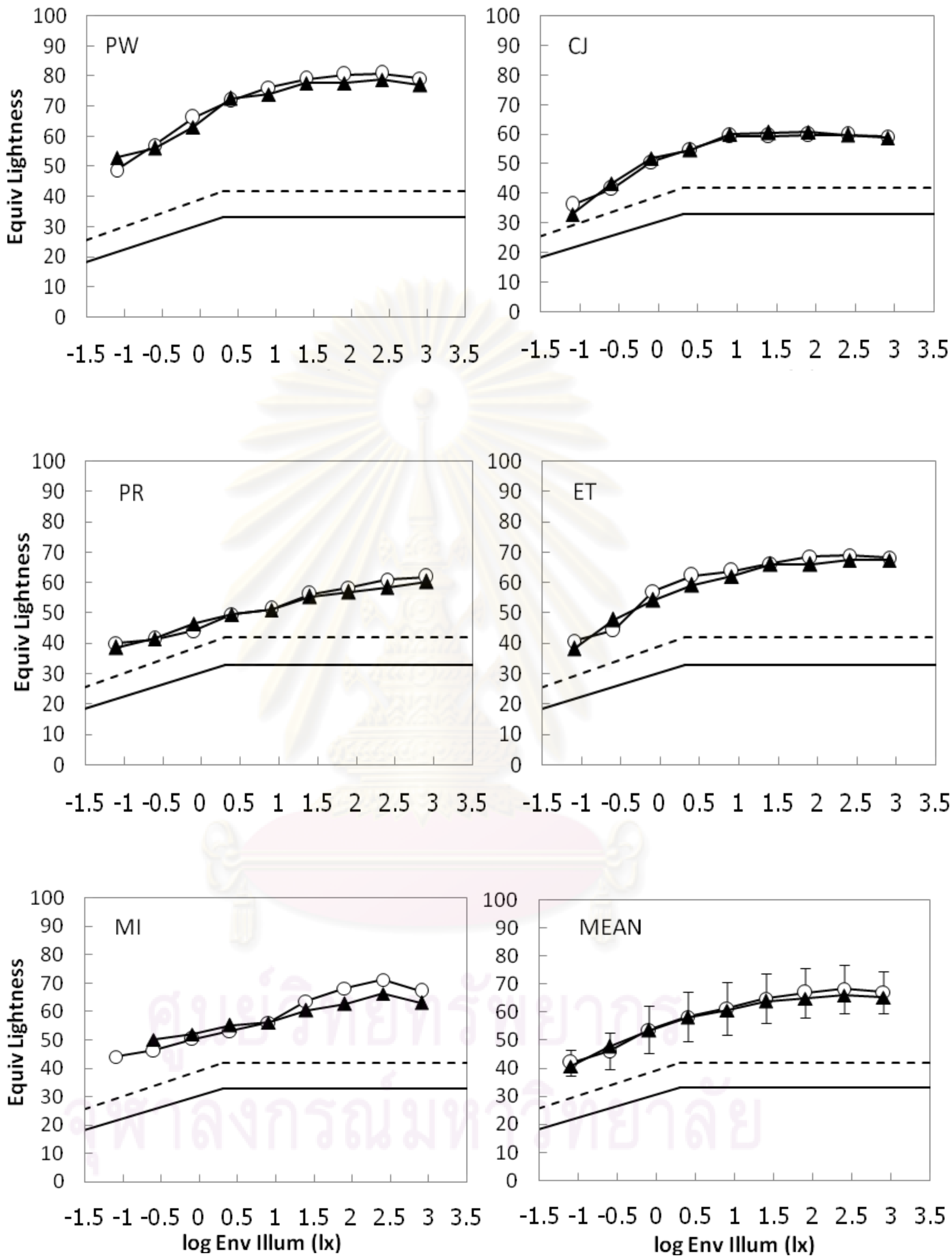
L*eq. Open circles show L*eq obtained with the normal eyes or without goggles and filled triangles show L*eq with goggles. The subject MI could not obtain L*eq with goggles at 0.08 lx because he could not discriminate the stimulus from surrounding any more. Standard deviations of ten determinations are shown by short vertical bars but only for the normal eyes. They are not large implying good accuracy of the equivalent lightness. A dotted line and a solid line show the nominal lightness or the achromatic lightness L*achr according to Ikeda and Ashizawa [7].

The equivalent lightness increases monotonically for increasing room illuminance with some saturation trend at very high illuminance, which is in accordance with previous reports [6, 7]. The data show much larger equivalent lightness than the nominal lightness and inappropriateness of using the nominal lightness defined by the CIE to express the brightness of objects. The equivalent lightness with goggles shown by filled triangles came very close to the equivalent lightness without goggles.

Data from all the five subjects are shown in Fig 5.2a for red stimulus, 5.2b for yellow, 5.2c for green, and 5.2d for blue stimulus. Graphs at the bottom right show the average of five subjects and standard deviation among five subjects. Although detailed shape of curves differ among individuals and colors one property is common. That is, they monotonically increase for higher illuminance levels. There is individual difference as to the height of curves. For example in the red stimulus the subject PW shows her curve at a high position whiles the subject PR very low. In other words PW has a large L*chr and PR has a small L*chr. It was shown by Ikeda and Ashizawa [7] that there are subjects of C-type and those of L-type, the former having a large value of L*chr and the latter small value of L*chr. If we use their expression the subject PW is a person of the C-type who evaluates color very highly to the brightness, and the subject PR is a person of the L-type whose brightness perception is mainly determined by the achromatic lightness L*achr. This difference between the two subjects is also seen for the green and blue stimulus.

The equivalent lightness of yellow locates very high as shown in Fig. 5.2b. This is understandable because the nominal lightness of this stimulus is already 80 and should locate high. But we should notice that the elevation of L*eq from L*achr is not high. That is, the contribution of color to the brightness is not large. It must be remembered that both red and yellow stimuli have the same Munsell Chroma, 14, yet the L*chr is quite different. The result is in accordance with that of Ikeda and Ashizawa [7] and Ikeda et al. [10].

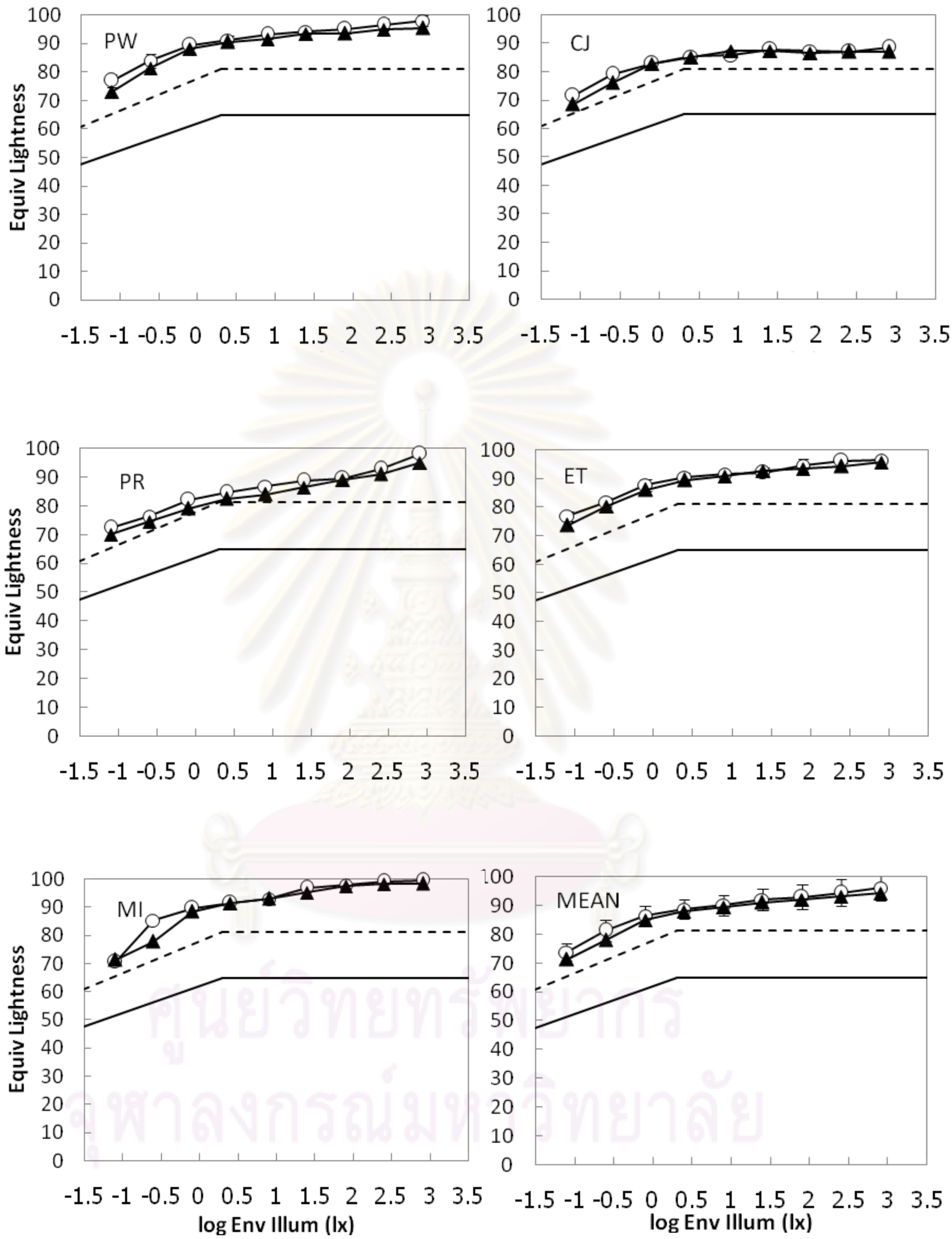
One other thing that we notice in Fig. 5.2 is the difference between the normal eyes and goggles eyes. There is found almost no difference for the red and yellow stimulus,





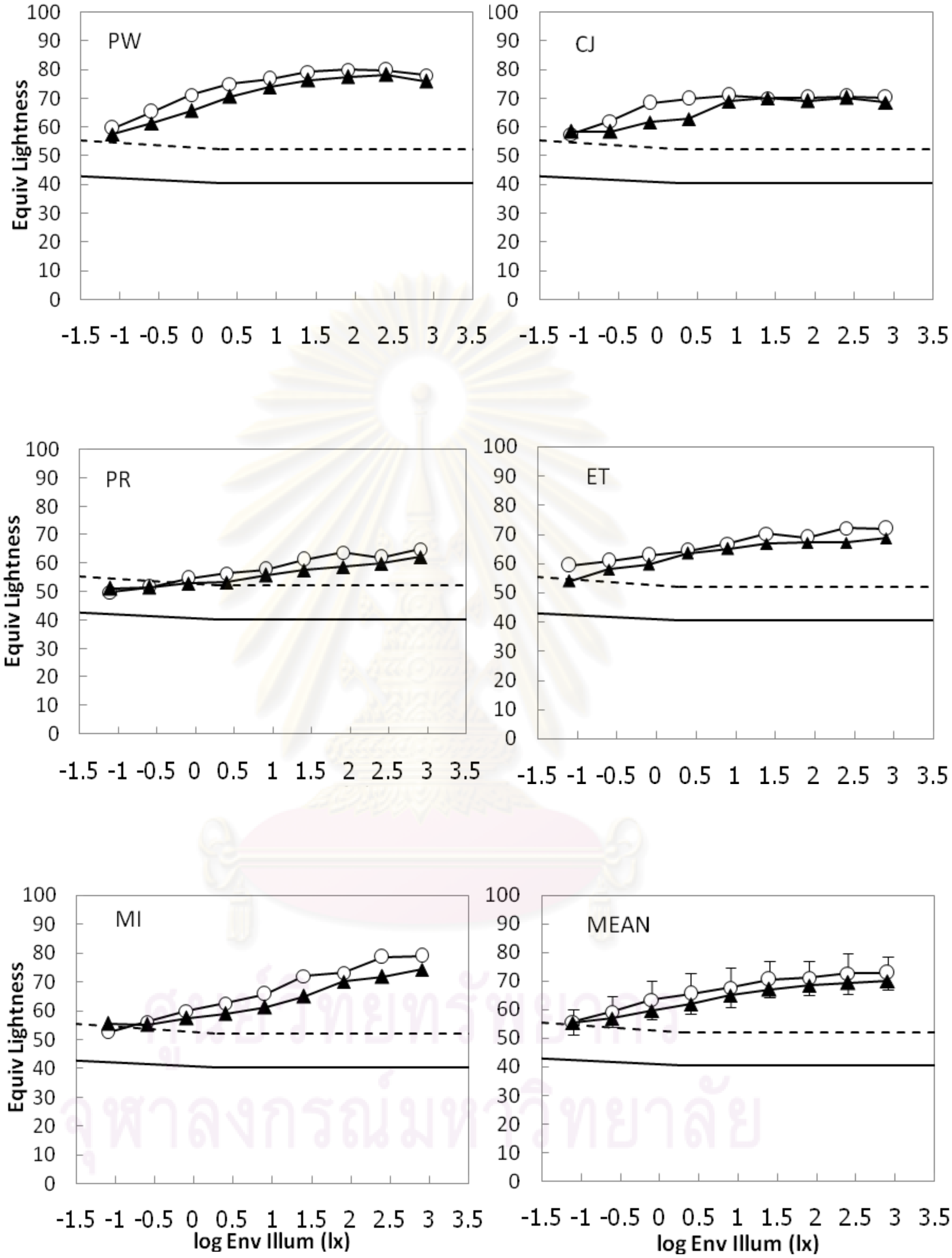

(a)

Fig. 5.2 Equivalent lightness measured without (○) and with goggles (▲) from five subjects and the mean for four colored stimuli, a, red; b, yellow; c, green; d, blue.



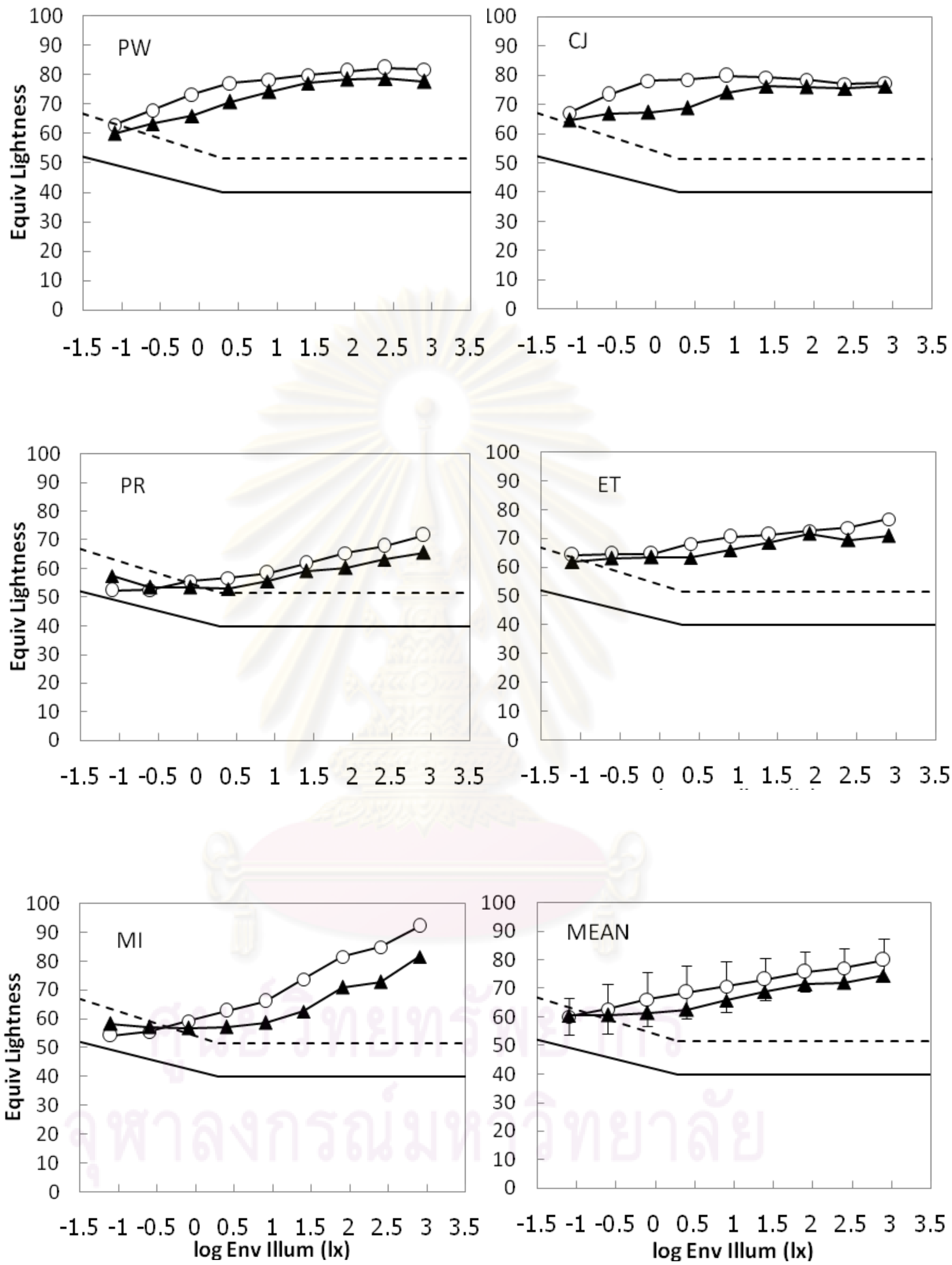

(b)

Fig. 5.2b Yellow stimulus




(c)

Fig. 5.2c Green stimulus




(d)

Fig. 5.2d Blue stimulus

but the equivalent lightness with the goggles is systematically lower for the green and blue stimulus in all the subjects.

Short vertical bars attached to the curve obtained without goggles in the graphs of the mean indicate the standard deviation among four subjects. It is large with the red stimulus whilst small with the yellow stimulus.

In Fig. 5.3 mean curves are shown for the four stimuli. The properties of the curves were already pointed above. Curves increase monotonically for higher illuminance, The elevation from the achromatic lightness differs among colors, large for red and small for yellow, and two curves of the normal eyes and of the goggles eyes are very close with each other although there is a slight difference with green and blue stimuli.

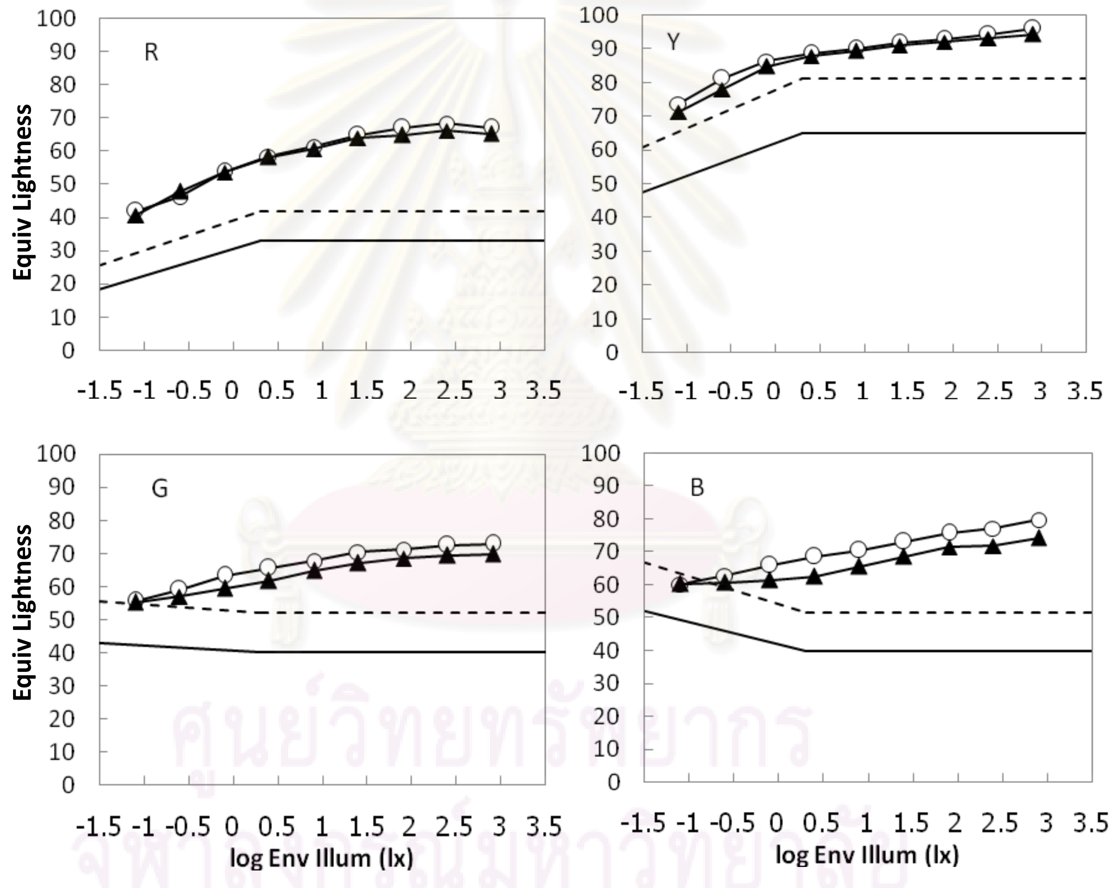



Fig. 5.3 Mean equivalent lightness of five subjects without (○) and with (▲) goggles.

The agreement of two curves without and with the goggles may pose us with a problem. We may simply suppose that L*eq with goggles is smaller than L*eq without goggles because the color desaturates with goggles and L*chr becomes smaller. But the finding here is inconsistent with this prediction. Why? We already explored this problem in Chapter 3 and pointed out a still new experiment, the transfer experiment. We should transfer the equivalent lightness seen with goggles to the equivalent lightness seen without goggles, or in other words the equivalent lightness seen by elderly people to that seen by young people, which will be done in the next section.

**5.3 Transfer experiment and the final results**

This experiment is to transfer a gray scale seen with goggles to a gray scale seen without goggles as shown in Fig. 3.2b. Only four achromatic patches, N3.5, N5.5, N7.5, and N9.5 were employed for the goggles eyes and five illuminance levels for the subject room, 0.08, 0.8, 8, 80, and 800 lx. The experiment was repeated for five times. Results are shown for the subjects PW and MI in Fig. 5.4 with different symbols for

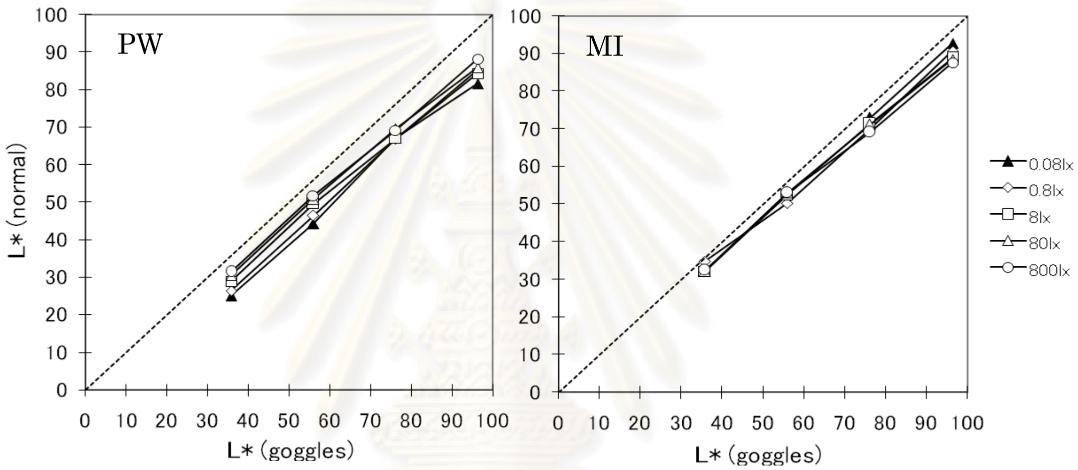
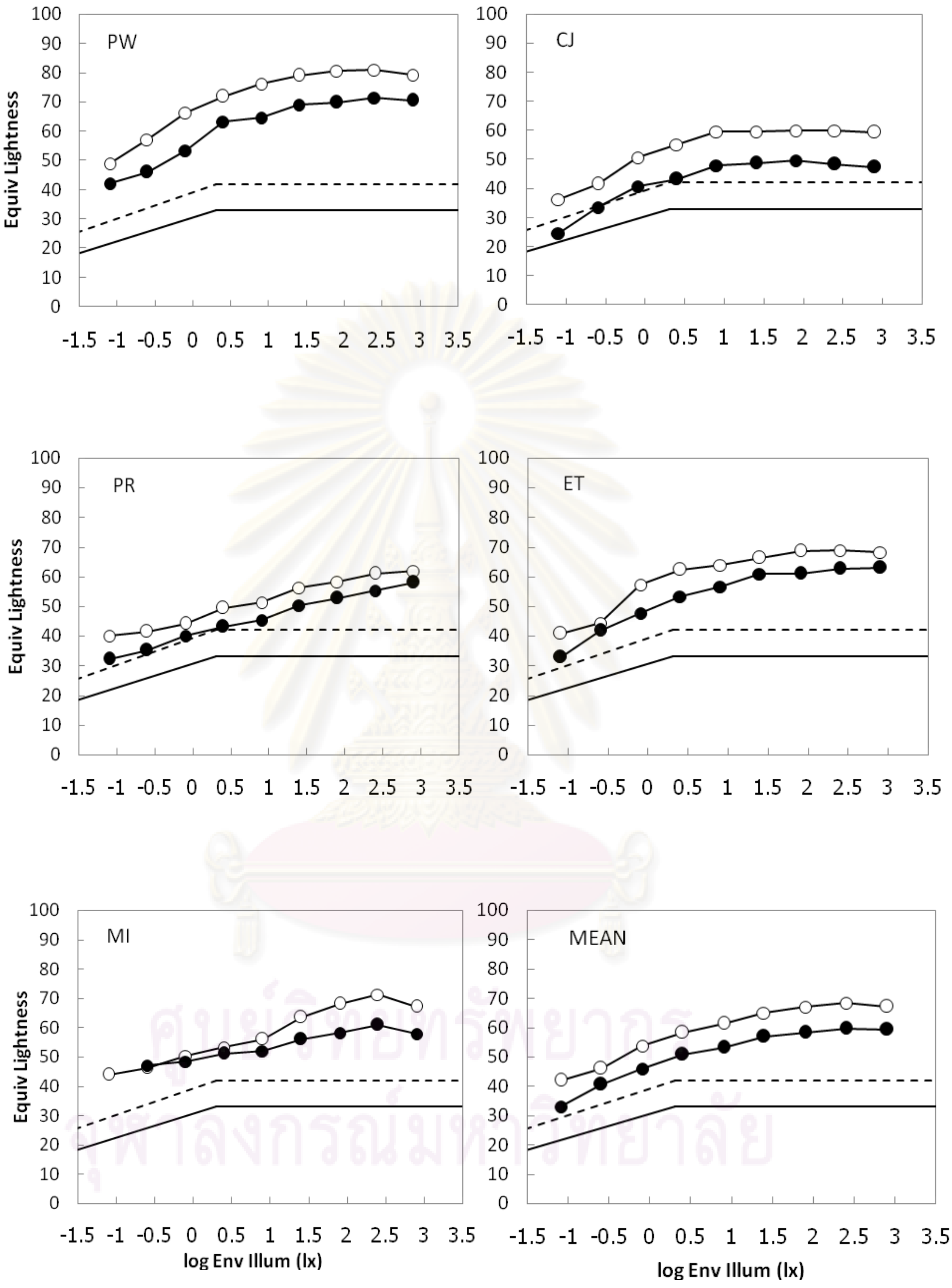



Fig. 5.4 Results of the transfer experiment taken from the subjects PW and MI for five illuminance levels.

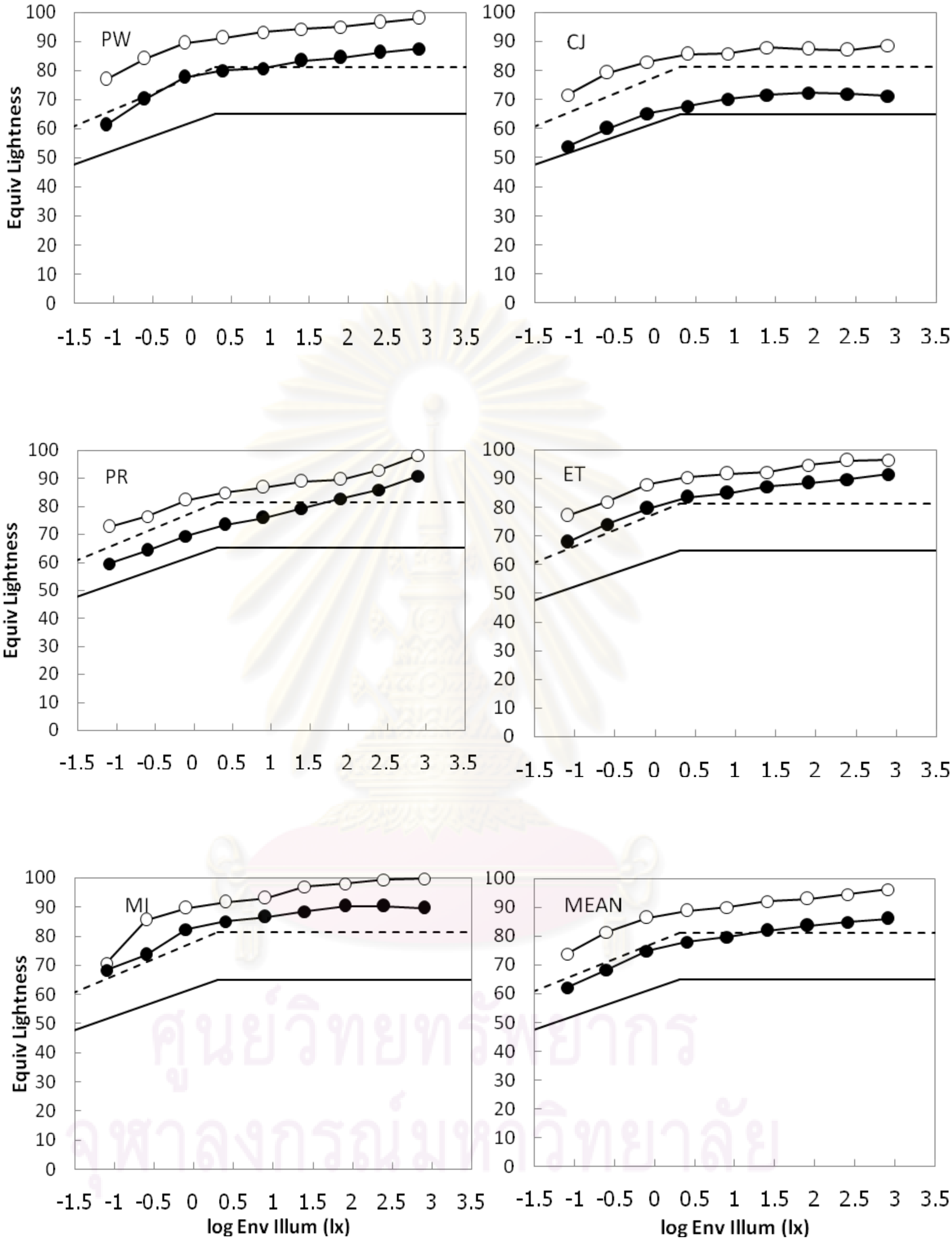
illuminance. Along the abscissa the lightness of gray patch seen with the goggles is taken and along the ordinate the lightness of gray scale that is matched with the gray patches seen with the normal eyes. It is seen that all gray patches appeared slightly darker when they are looked through the goggles. As it appears that each curve can be approximated by a straight line an equation to relate L*(goggles) to L*(normal) was derived for each illuminance and it was used to transfer the equivalent lightness shown by filled triangles in Fig. 5.2 to the final equivalent lightness expressed by young people. Equations for other illuminance levels for which the transfer measurement was not done were interpolated based on the two neighboring equations. The L*(goggles) to L*(normal) curves were obtained for all five subjects.

The final equivalent lightness with goggles expressed by the normal eyes is shown in Fig. 5.5 for five subjects and for the mean. Fig. 5.6 shows the mean results that are



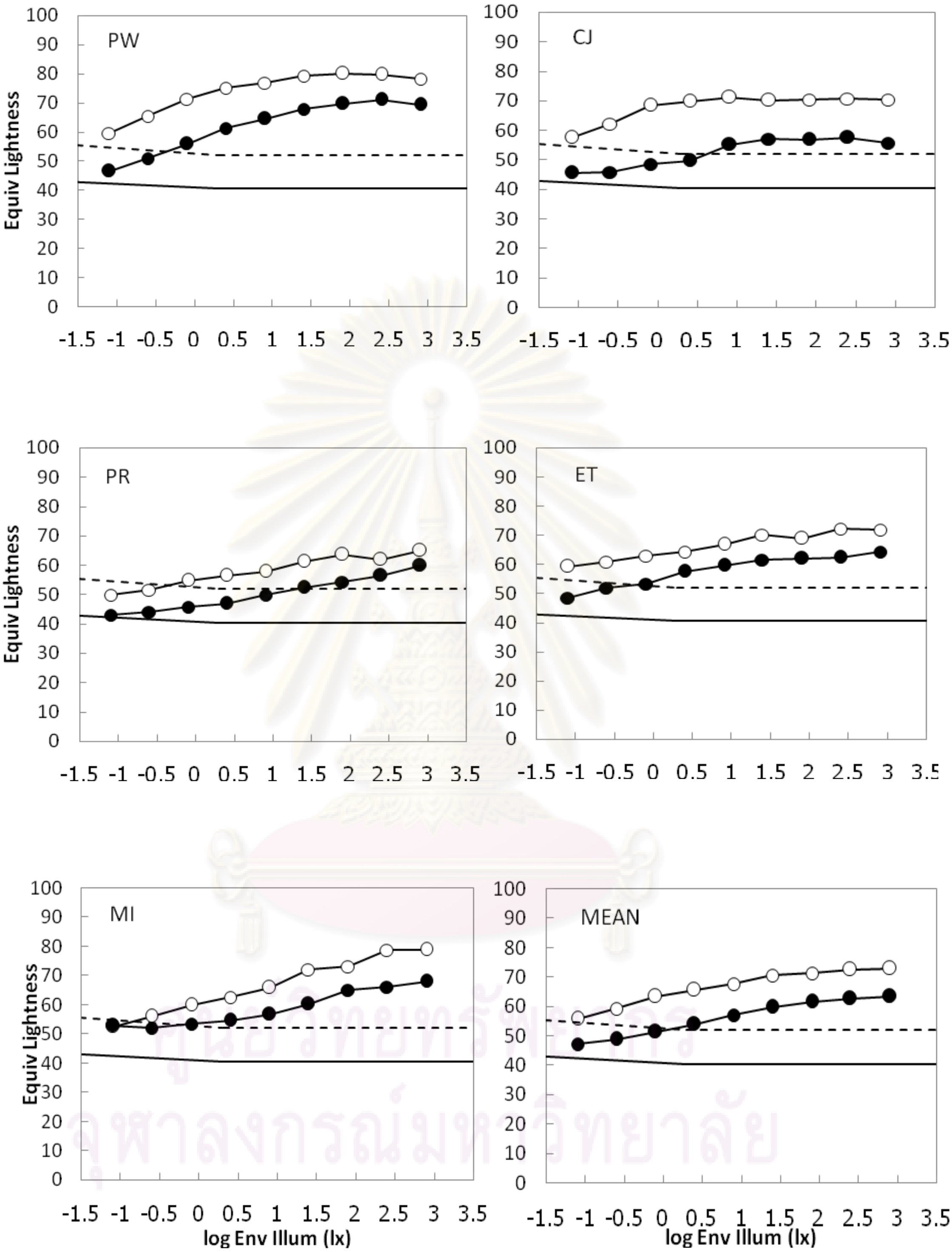

(a)

Fig. 5.5 Equivalent lightness measured without (○) and with goggles (●) expressed by the normal eye perception from five subjects and the mean for four colored stimuli, a, red; b, yellow; c, green; d, blue.



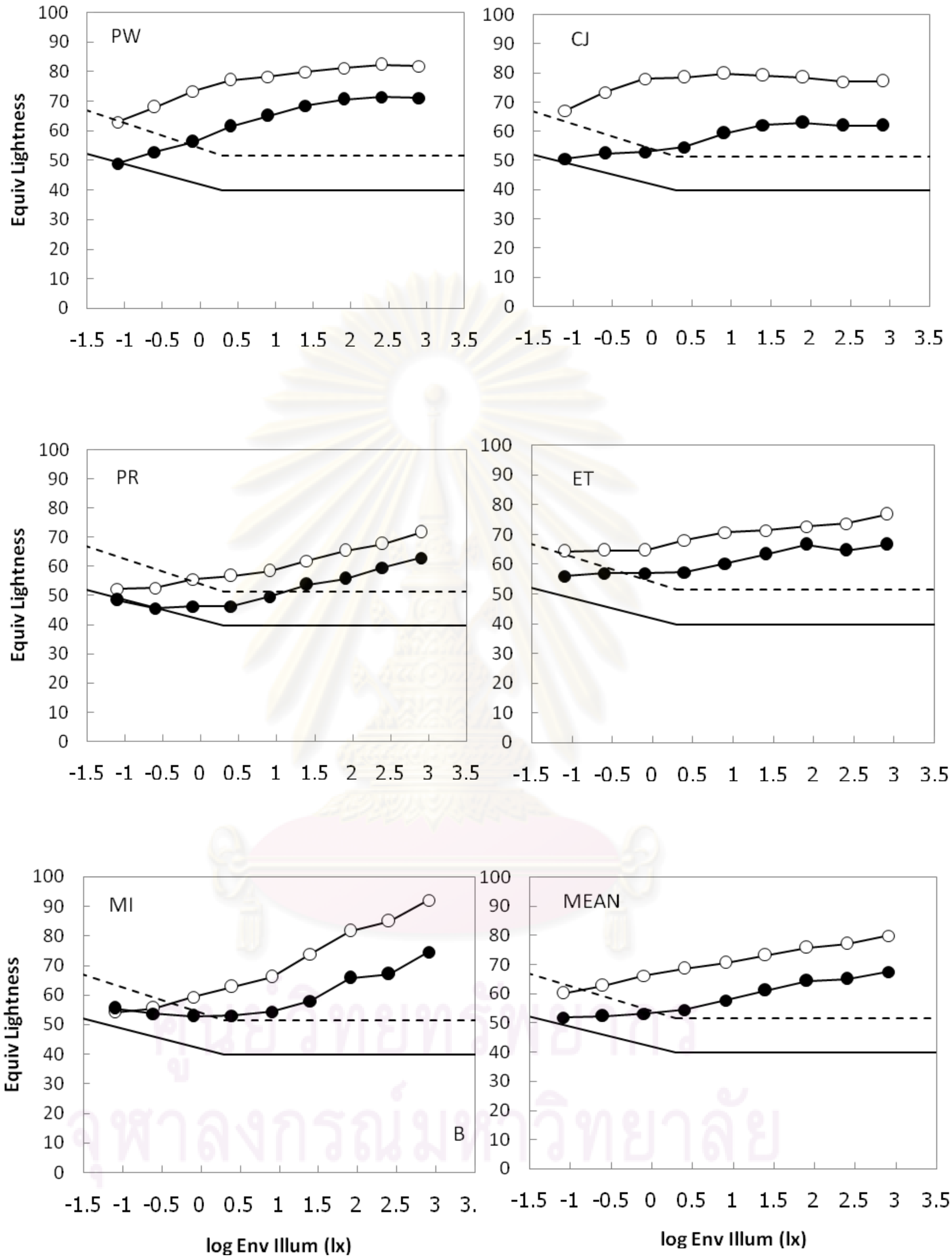

(b)

Fig. 5.5b Yellow stimulus




(c)

Fig. 5.5c Green stimulus




(d)

Fig. 5.5d Blue stimulus

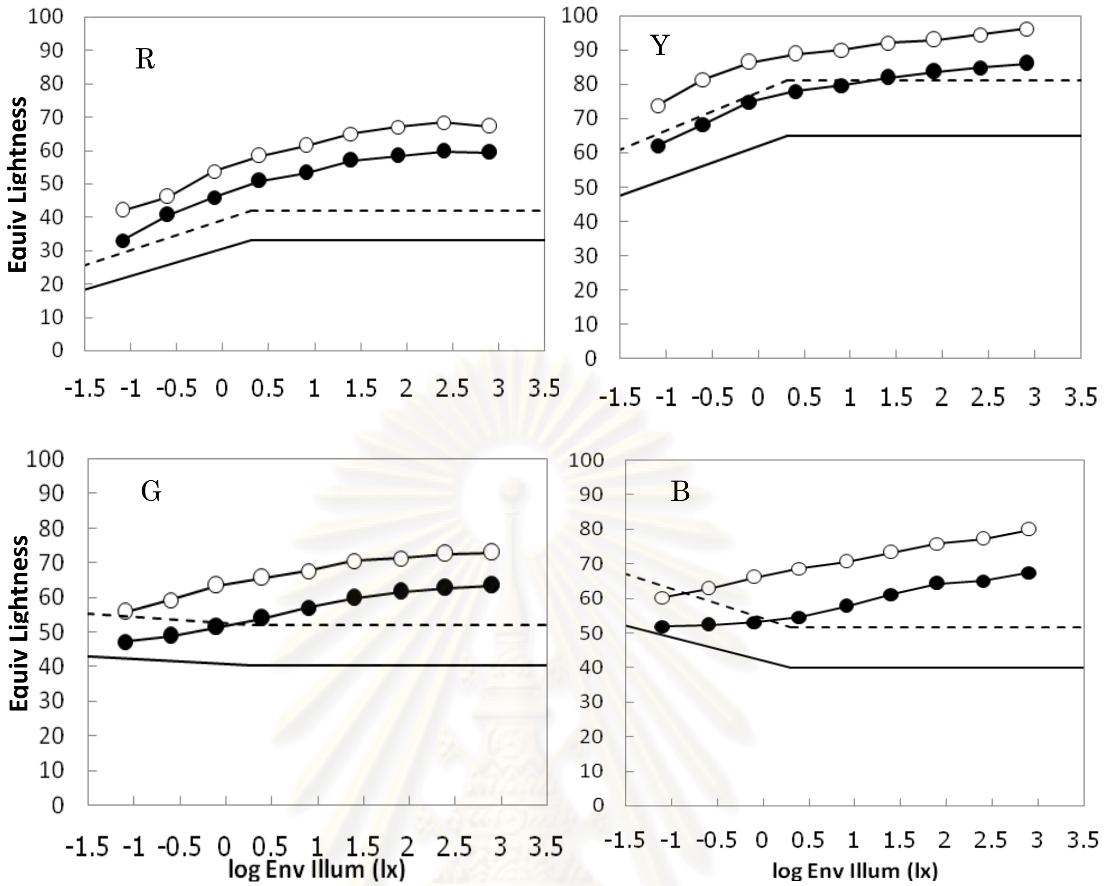



Fig. 5.6 Mean equivalent lightness of five subjects without (○) and with goggles (●) expressed by the normal eyes.

same as curves shown at the bottom right in Fig. 5.5. The abscissa and the ordinate are same as Fig. 5.2 and curves with open circles were already shown there as the equivalent lightness determined by the normal eyes. The equivalent lightness with goggles or we may say that of the elderly people is always lower than that of the normal eyes by the amount of about 8 in red, 10 in yellow, 10 in green, and 13 in blue stimulus in L* unit if we take difference in the photopic region. Objects appear darker for the elderly people than young people.



### 5.4 Color naming experiment and results

In this color appearance experiment only a colored stimulus was presented in front of a subject. He/she judged its chromaticness, whiteness, and blackness in percentage by the elementary color naming method. The amounts of unique hues were also judged for the chromaticness in percentage. Each subject repeated the judgment for five times. Examples of results are shown in Fig. 5.7 from the subjects PW and MI and for the redstimulus. The abscissa gives the room illuminance in lx and the ordinate the percentage of amount of elements, chromaticness by circles and whiteness by squares.

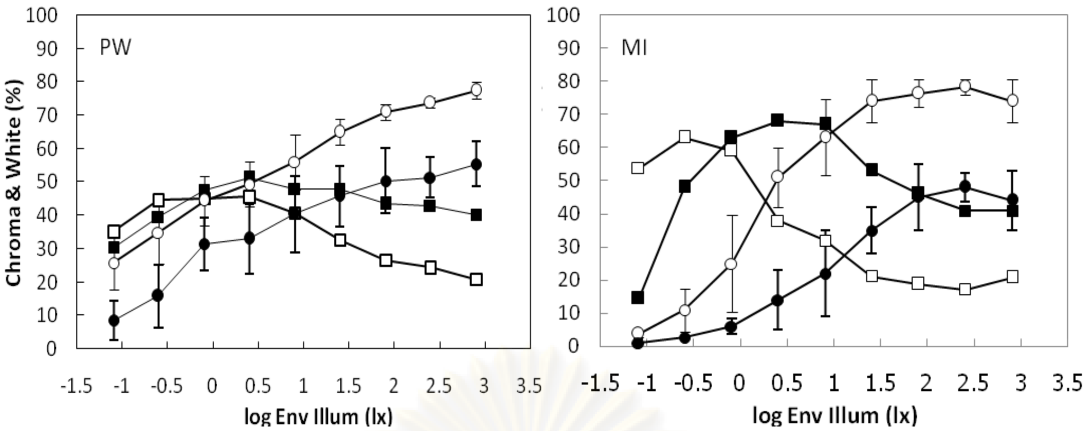
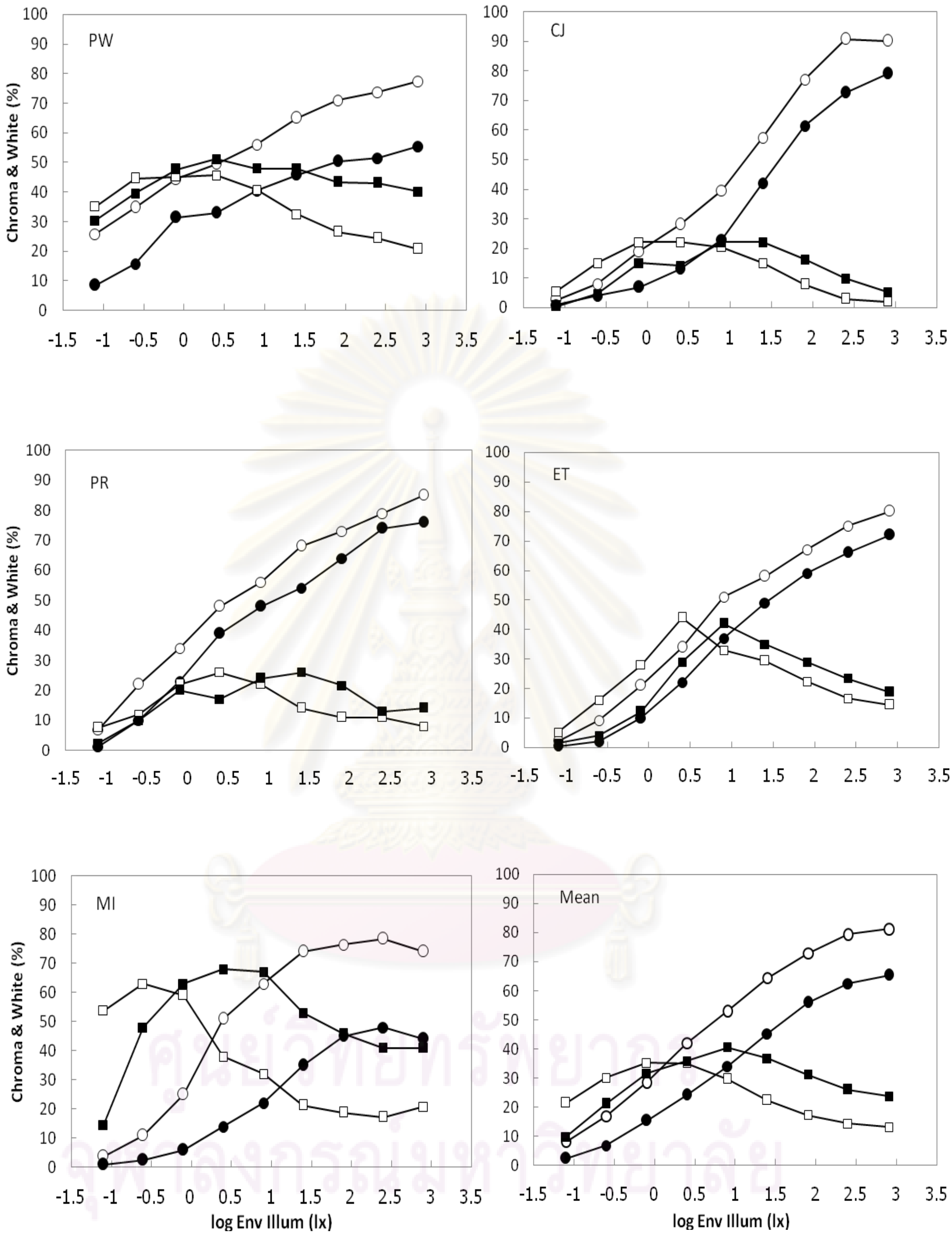


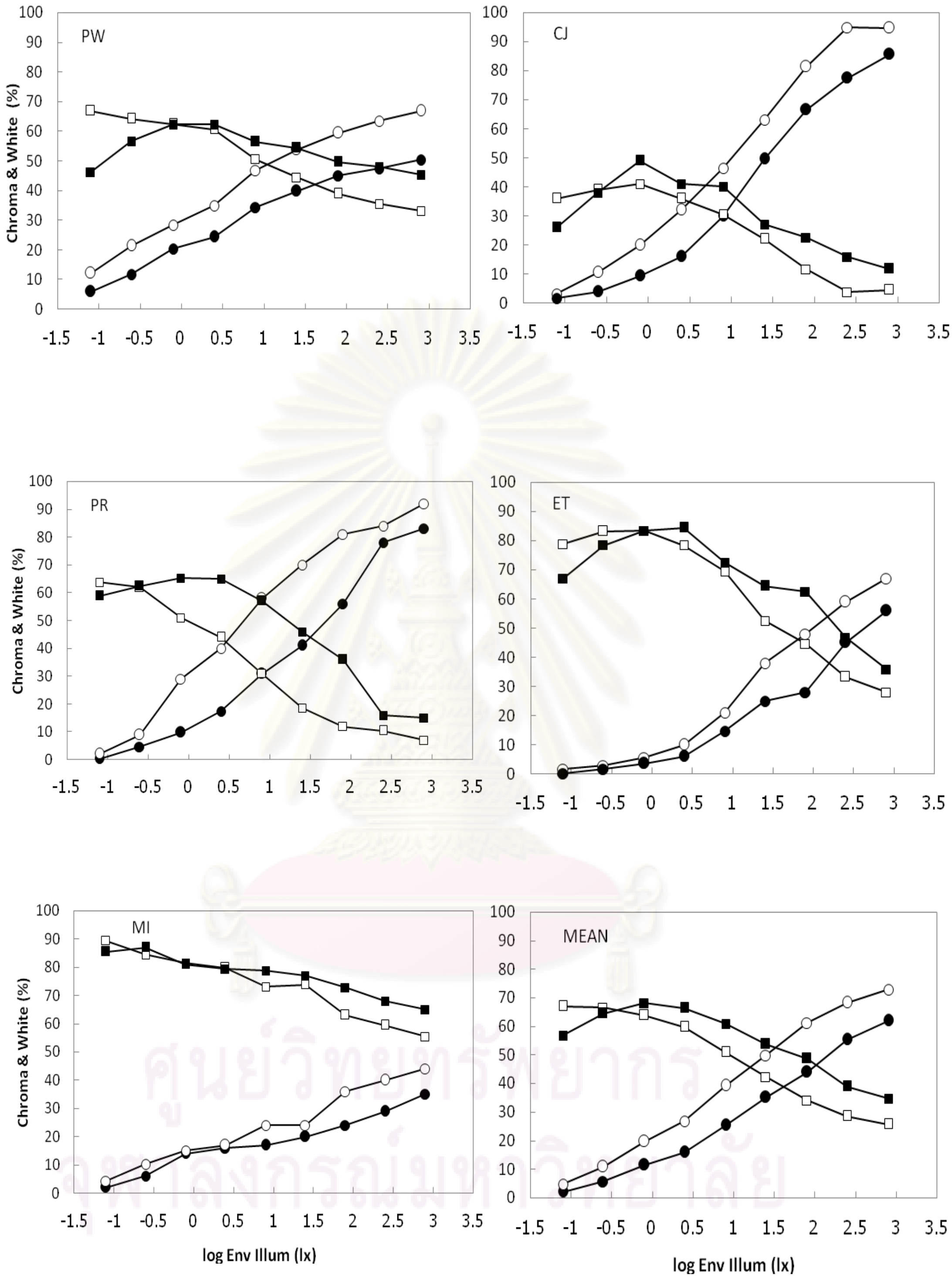

Fig. 5.7 Results of the color appearance experiment taken from the subject PW and MI for the red stimulus. Only chromaticness and whiteness are shown.

The results without the goggles are shown by open symbols and those with the goggles by filled symbols. Short bars indicate the standard deviation for the case of chromaticness. The standard deviation is relatively large at low illuminance indicating difficulty of determining the amount of chromaticness. It became smaller at high illuminance. The chromaticness with the normal eyes increases monotonically with some saturation trend at high illuminance and the whiteness increases firstly and decreases with a peak. The chromaticness curve obtained with the goggles is much lower than that without goggles in both subjects indicating the desaturation of color with the goggles in accordance with the report given by Ikeda and Obama [9]. The whiteness curve with goggles shifts toward right showing the peak at a higher illuminance than that without goggles. The monotonic increase of the chromaticness with and without the goggles indicate a monotonic increase of L*chr and agrees with the result of the equivalent lightness shown in Fig. 5.2a. Such increase of chromaticness was found for other colors as seen in Fig. 5.8, where results are shown for all the subject and the mean results of the five subjects. The blackness is not shown here but it can be estimated from the whiteness and the blackness by subtracting them from 100.



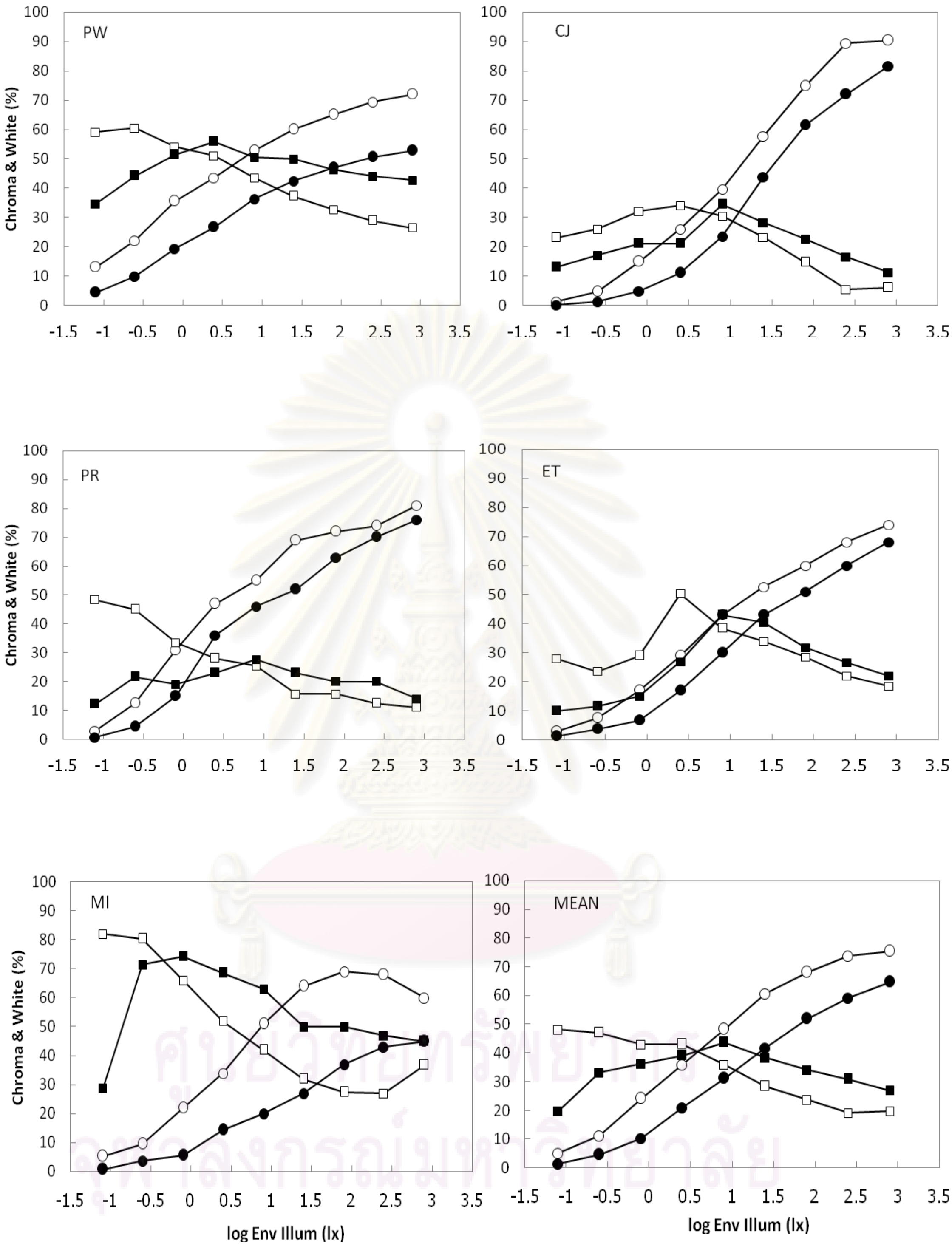

(a)

Fig. 5.8 Results of the color appearance experiment for all subjects. The mean of the five subjects is shown at the bottom right. a, red; b, yellow; c, green; d, blue.



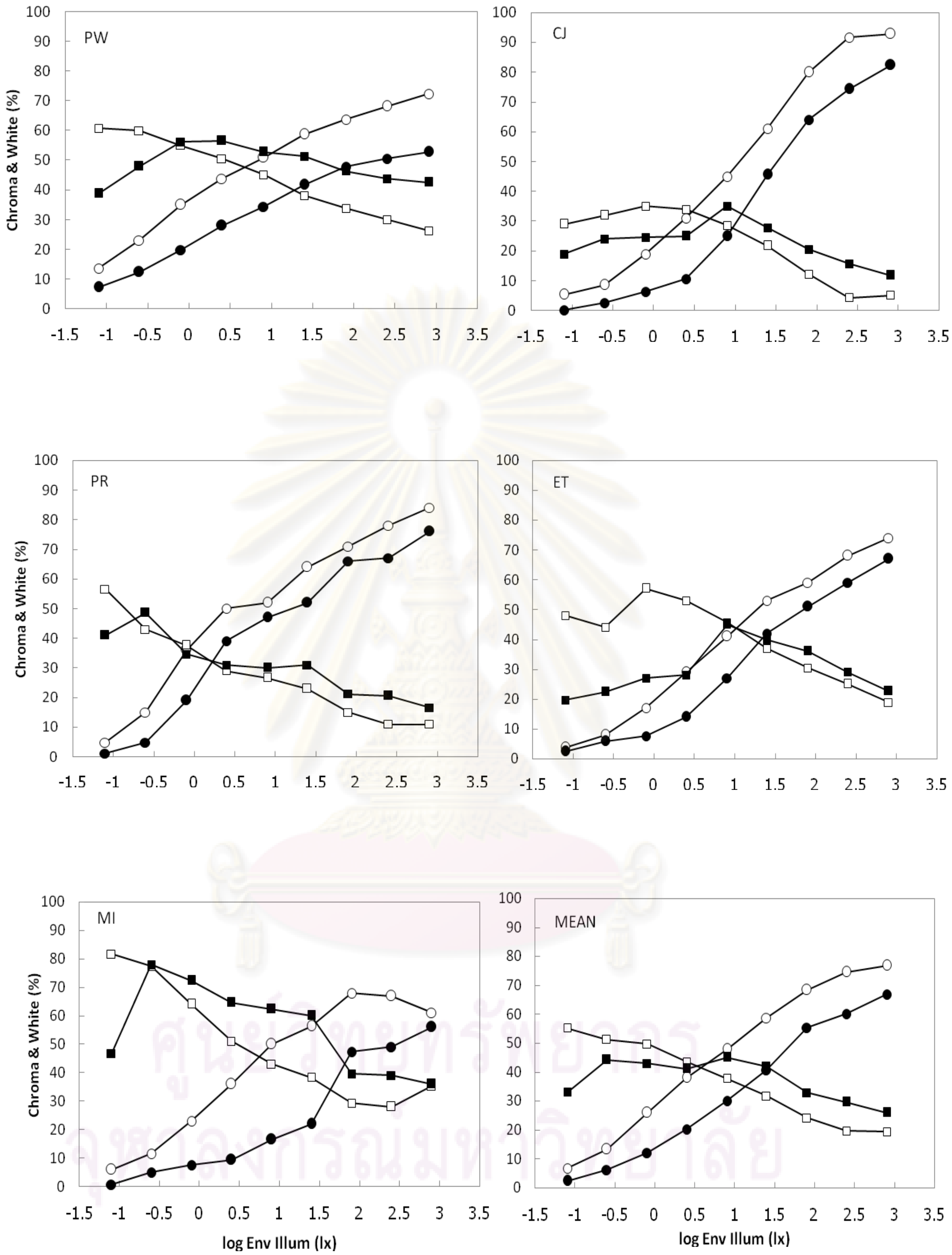

(b)

Fig. 5.8b Yellow stimulus




(c)

Fig. 5.8c Green stimulus




(d)

Fig. 5.8d Blue stimulus

The mean curves in Fig. 5.8 are summarized in Fig. 5.9.

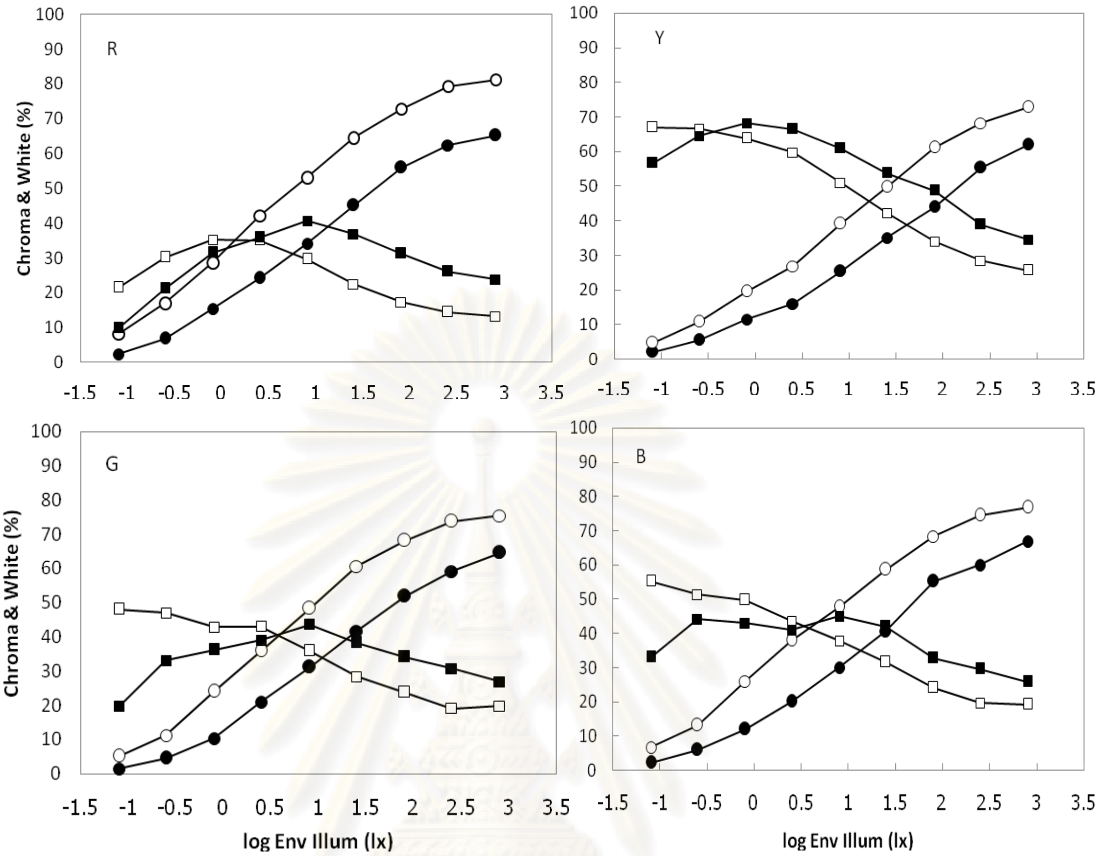



Fig. 5.9 Mean results of five subjects of the color appearance for chromaticness and whiteness.

The amounts of hues were also judged in the color appearance experiment. All the subjects judged only red hue for the red stimulus, only yellow for the yellow stimulus, only green for the green stimulus, and only blue for the blue stimulus. That is, the appearance of the colored stimuli was all unique hues, respectively. Thus the results are not shown here.

### 5.5 Discussion on the equivalent lightness in the normal viewing condition

The goggles are composed of a color filter and a haze filter. As we see the spectral transmittance curve of the color filter shown in Fig. 4.1 all the lights in the visual region are transmitted less than 60 %. This reduction of the transmittance reduces the equivalent lightness by the amounts, 9, 16, 12, and 12 in red, yellow, green, and blue stimulus, respectively for the photopic region. If we discount this reduction amount of L* from the equivalent lightness obtained by the normal eyes we get curves indicated by open diamonds in Fig. 5.10. Curves of open circles and filled circles appeared already in Fig. 5.6 to represent the equivalent lightness of young people and that of

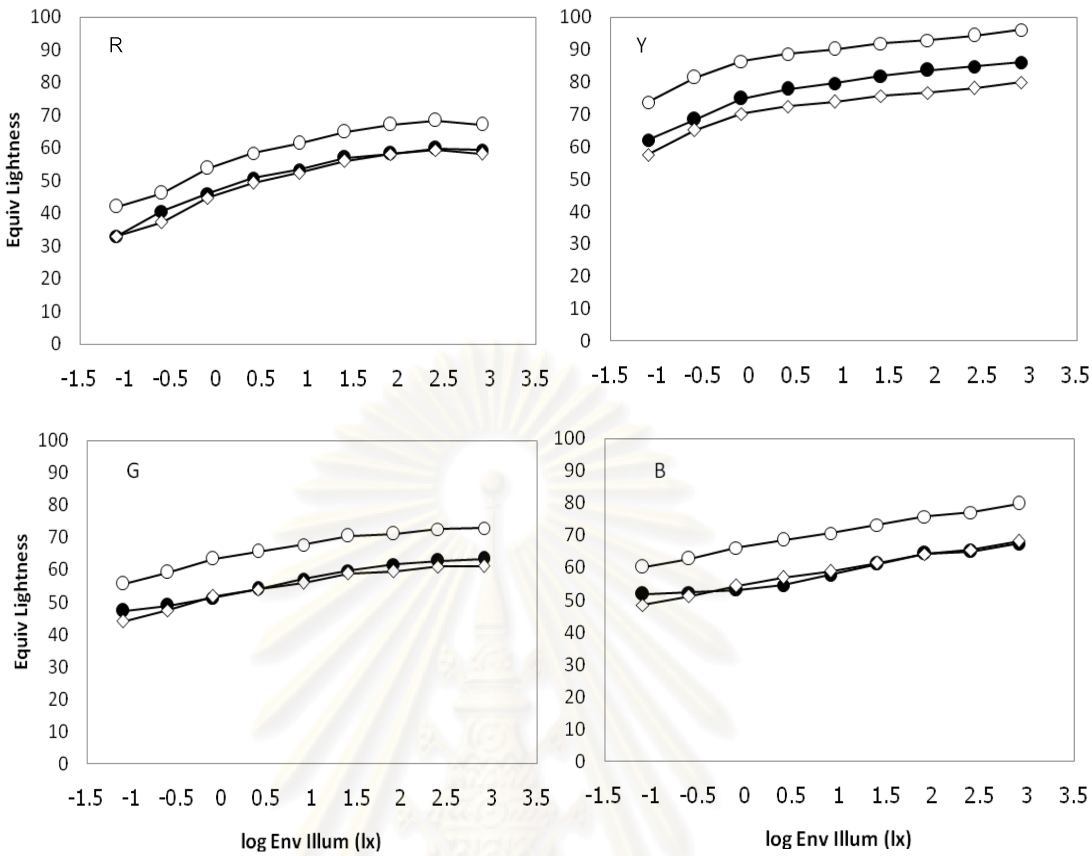



Fig. 5.10 Mean equivalent lightness by the normal eyes (○), with goggles but expressed by the normal eyes (●), and the calculated lightness based on the filter reduction (◇).

elderly people, respectively. It is surprising to see that the results shown by open diamonds agree with those of the lightness of elderly people expressed by young perception shown by filled circles. As far as the data indicate there seems to be no effect of the haze filter. We anticipated L*eq to decrease more than a mere reducing effect of the color filter because L*chr decreases by the color desaturation with the haze filter, but the decrease appears only because of the color filter. Does not the haze filter give any effect on the equivalent lightness? Answer can be found in the results of the color appearance shown already in Fig. 5.9. Here, we see the chromaticness with the goggles decreases compared to that with the normal eyes, which means the color desaturation and consequently the decrease of L*chr. But we see also at the same time the whiteness with the goggles increases compared to that with the normal eyes, which means the increase of brightness. One causes decrease of the equivalent lightness, and the other causes increase of the equivalent lightness. It appears, therefore, that the effect of the haze filter does not exist. If we calculate the chromaticness difference between with and without goggles for all the colors for the photopic range it turns out to be -17 for red, -13 for yellow, -15 for green, and -15 for blue. On the other hand the whiteness difference is 10 for red, 10 for yellow, 7 for green, and 7 for blue, respectively. The sum of chromatic difference and whiteness difference becomes -7 for red, -3 for yellow, -8 for green, and -8 for blue. The fact that there is no difference between two curves of open diamonds and filled circles in red, green, and blue stimuli, the values -7 or -8 in the above calculation would give no difference between the two curves. Then the value -3 in yellow stimulus means the final equivalent lightness shown by filled circles should be slightly elevated from the calculated lightness based on the filter transmittance, which agrees with the result in Fig. 5.10.

It is necessary to modify Eq. (1.1) to express the equivalent lightness to the following equation for elderly vision.

$$L^*eq = L^* + L^*chr + L^*env \qquad (5.1)$$

L* is the nominal lightness defined by the CIE and it was expressed sometime as L*achr in this paper and L*chr is the lightness coming from the color of objects and large in general for saturated color. L*env is a new term derived by the present experiment and it is the lightness caused by the scattered light in the eye that comes from the environment light. In the elderly people L*chr is decreased because of the desaturation of the color of objects but L*env is increased because of the environment light that is scattered in their eyes. Both L*chr and L*env are caused by the foggy crystalline lens and by the environment light.

# CHAPTER VI

# EXPERIMENT - ENVIRONMENT-STIMULUS INDEPENDENT

## 6.1 Apparatus and procedure

It was shown in the previous chapter that the environmental light that comes from our surroundings causes to change the equivalent lightness. Here in this chapter a new technique to reduce the cause of the environment light is introduced. It is called the environment-stimulus independent technique and uses two rooms, one for the subject room and the other for the stimulus room. We use both rooms of the experimental booth that was shown in Fig. 4.2 in Chapter 4 by opening a small window on the dividing wall so that a subject can see a stimulus and a gray scale placed in the stimulus room as shown in Fig. 4.4.

The illuminance levels for the subject room were same as for the normal viewing experiment, namely 0.08, 0.25, 0.8, 2.5, 8, 25, 80, 250, and 800 lx. But the illumination to the stimulus and the grayscale was kept constant throughout the experiment at 200 lx on the vertical plane on the surface of stimulus. By this arrangement we can investigate the effect of the room illumination without changing the illumination condition for the stimulus appearance.

Experimental procedures to obtain the equivalent lightness, transfer equations, and the color appearance were similar to those for the normal viewing experiment with some minor change due to the separation of a booth to two rooms. Subjects made measurements while they were looking inside the window opened to the stimulus room. Their central parts of the eyes were always adapted to the illuminance of 200 lx regardless the subject room illuminance. There was no need to pay attention to the adaptation every time when the room illuminance was changed.

## 6.2 Results of the equivalent lightness with and without goggles

Results are similarly shown as for the previous chapter. Figure 6.1 shows examples of the results obtained from the subjects PW and MI for the case of red stimulus with the standard deviation for the results of the normal eyes. A short line drawn on the abscissa shows the illuminance for the stimulus room. Above this line the subject room was brighter than the stimulus room and below this line the subject room was darker than the stimulus room. Both equivalent lightness without and with the goggles show high values and they stay high regardless the room illuminance. There is seen a slight tendency of decreasing for higher illuminance probably implying the increase of the effect of environment light.

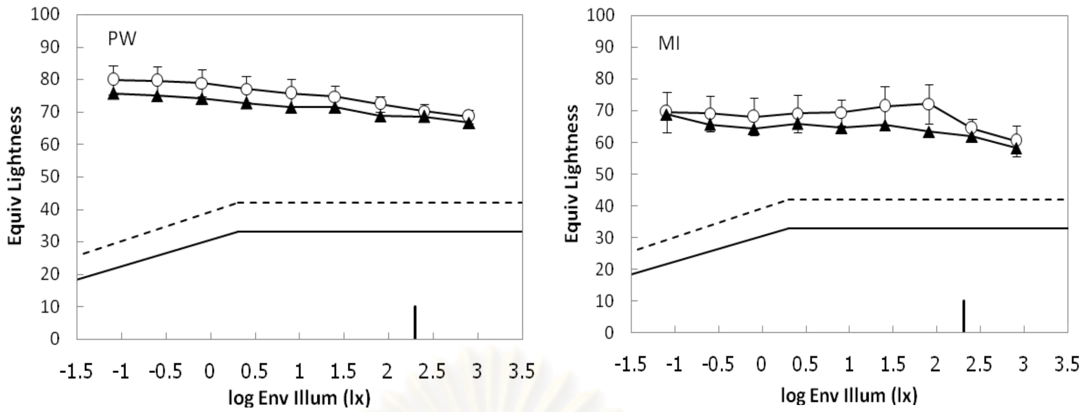
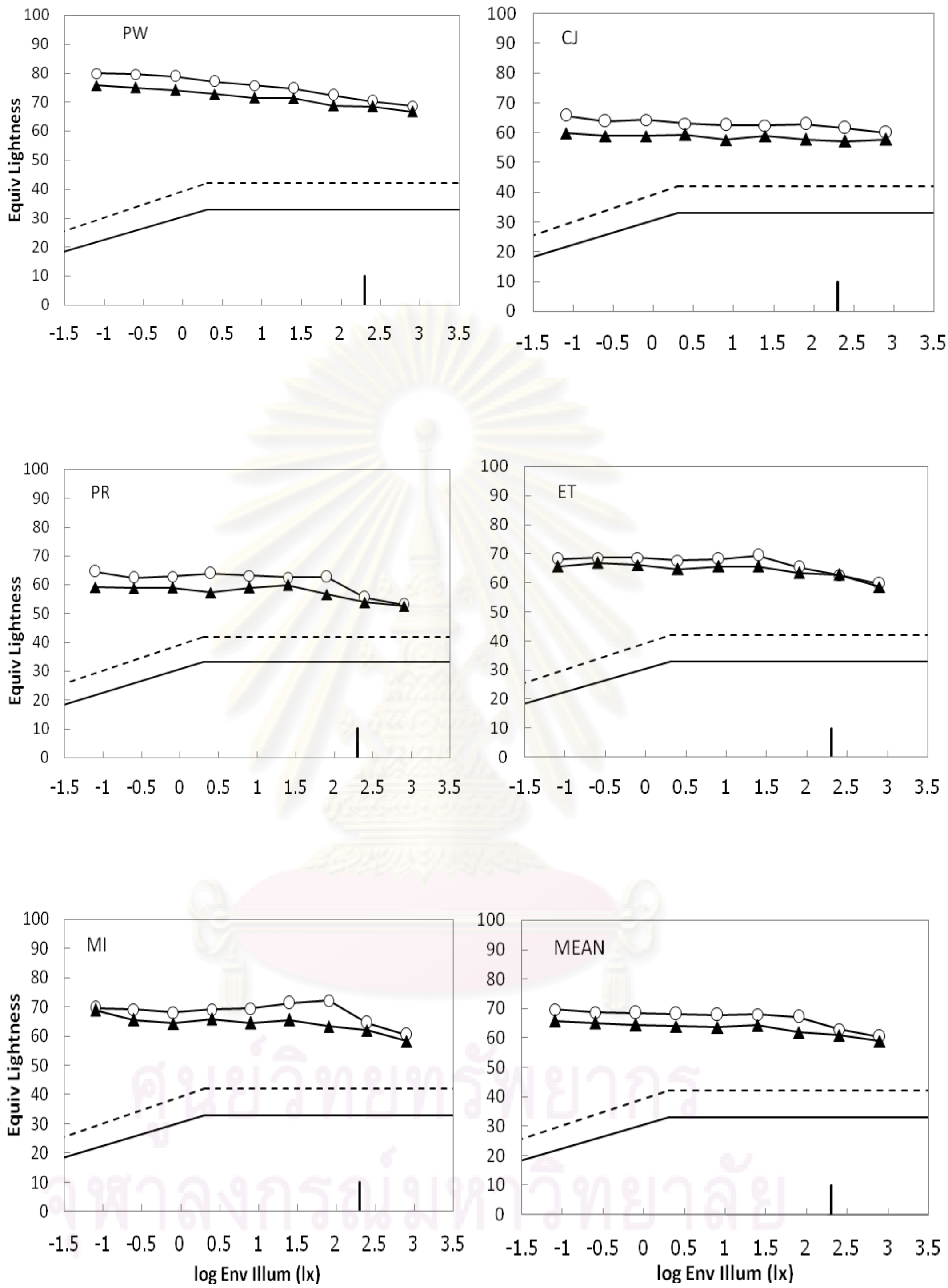



Fig. 6.1 The equivalent lightness without the goggles (○) and with the goggles (▲) from the subject PW and MI for the red stimulus.

Figure 6.2 shows the results of all five subjects and their mean. There is individual difference in the increase of the equivalent lightness from L*achr. For example in the red case (a) the subject PW shows a high elevation of L*eq from L*achr, but the subject CJ or PR does not. Such tendency is also found in other stimuli. The subject PW is clearly a C-type subject. The subject MI judged the blue stimulus very bright with his naked eyes as seen in (d). According to his subjective report the stimulus appeared the light source color for the room illuminance lower than that of the stimulus room. He judged it very bright. Fig. 6.3 shows the mean results of five subjects for four colors. All curves tend to decrease for higher room illuminance, and particularly so with green and blue stimuli at the highest two illuminances which are higher than the stimulus room illuminance.

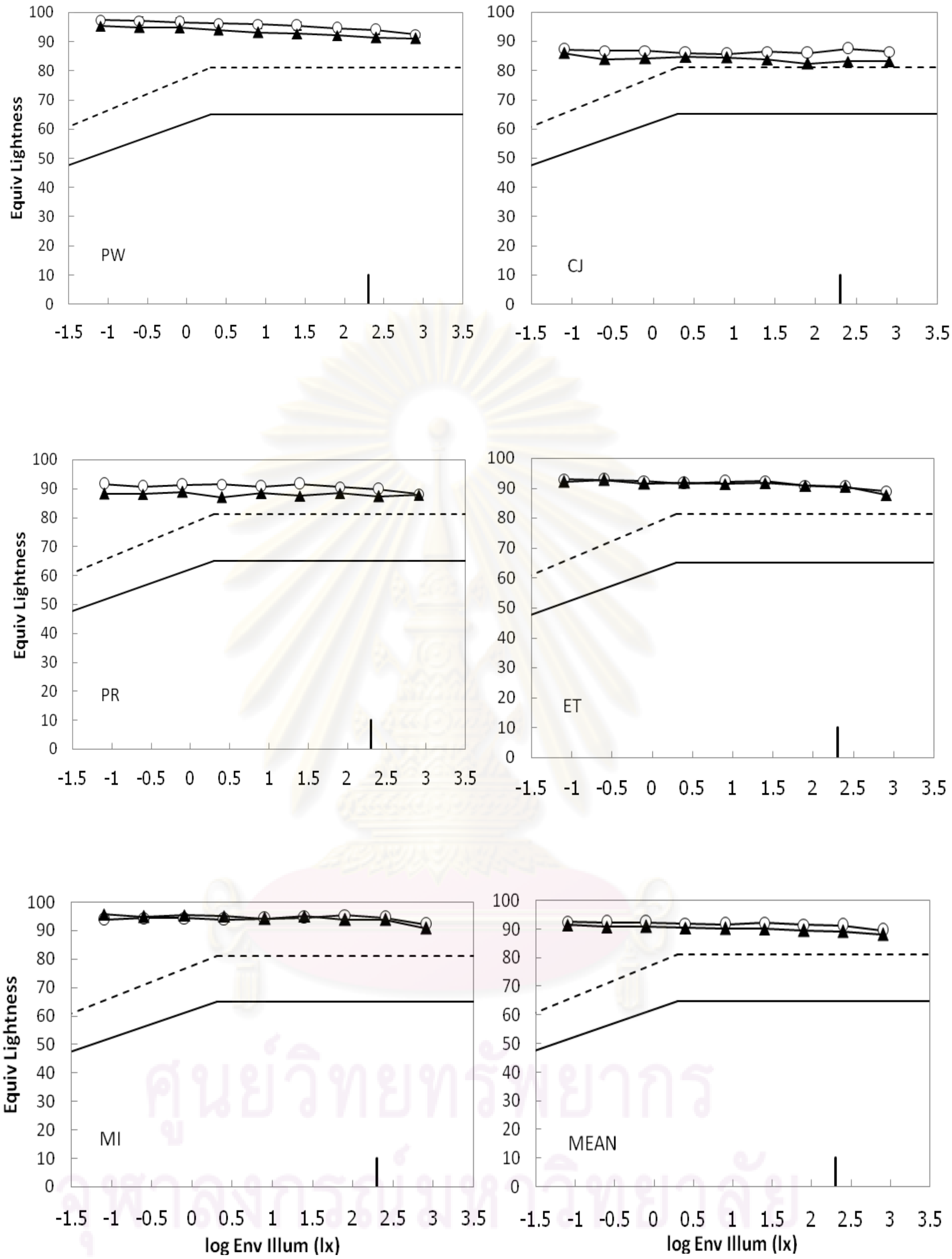
**6.3 Transfer experiment and the final results of the equivalent lightness**

The transfer experiment to change the brightness impression of four gray patches seen with goggles to the brightness impression of gray scale seen without goggles was carried out for subjects and results from the subjects PW and MI are shown for red stimulus in Fig. 6.4. The room illuminance of 250 lx was employed in these two subjects in stead of 0.08 lx. Slight difference was found here from the results obtained in the normal viewing condition of Chapter 5. There, L* (normal) was always smaller than L* (goggles), but here L* (normal) is greater than L* (goggles) for patches of N3.5 and N5.5 under 250 and 800 lx, particularly in the subject MI. According to his report the gray patches appeared brighter because of white scattered light over the gray patches when the subject room light was high.



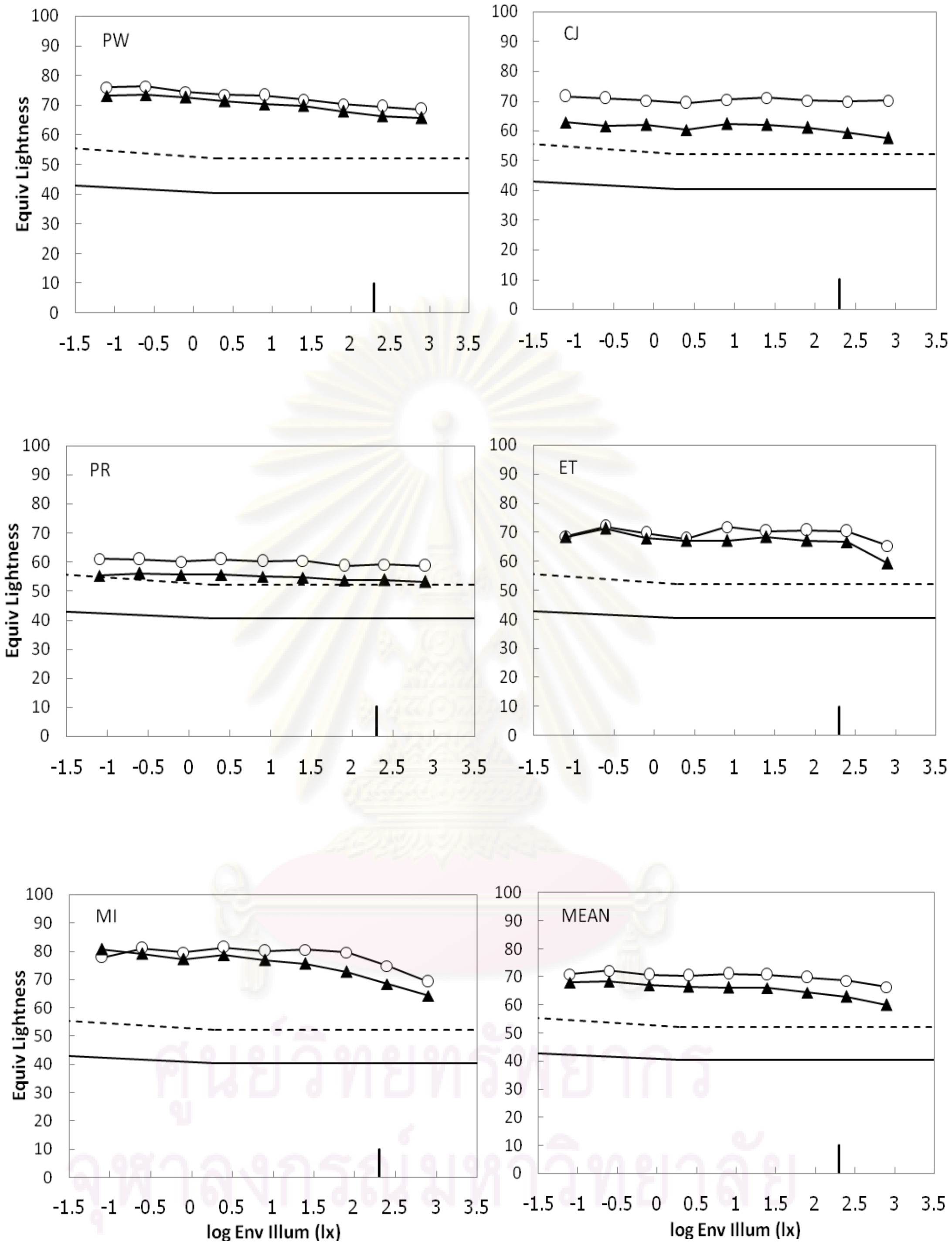

(a)

Fig. 6.2 The equivalent lightness without the goggles (○) and with the goggles (▲) for all subjects and their mean for red (a), yellow (b), green (c), and blue stimulus (d).



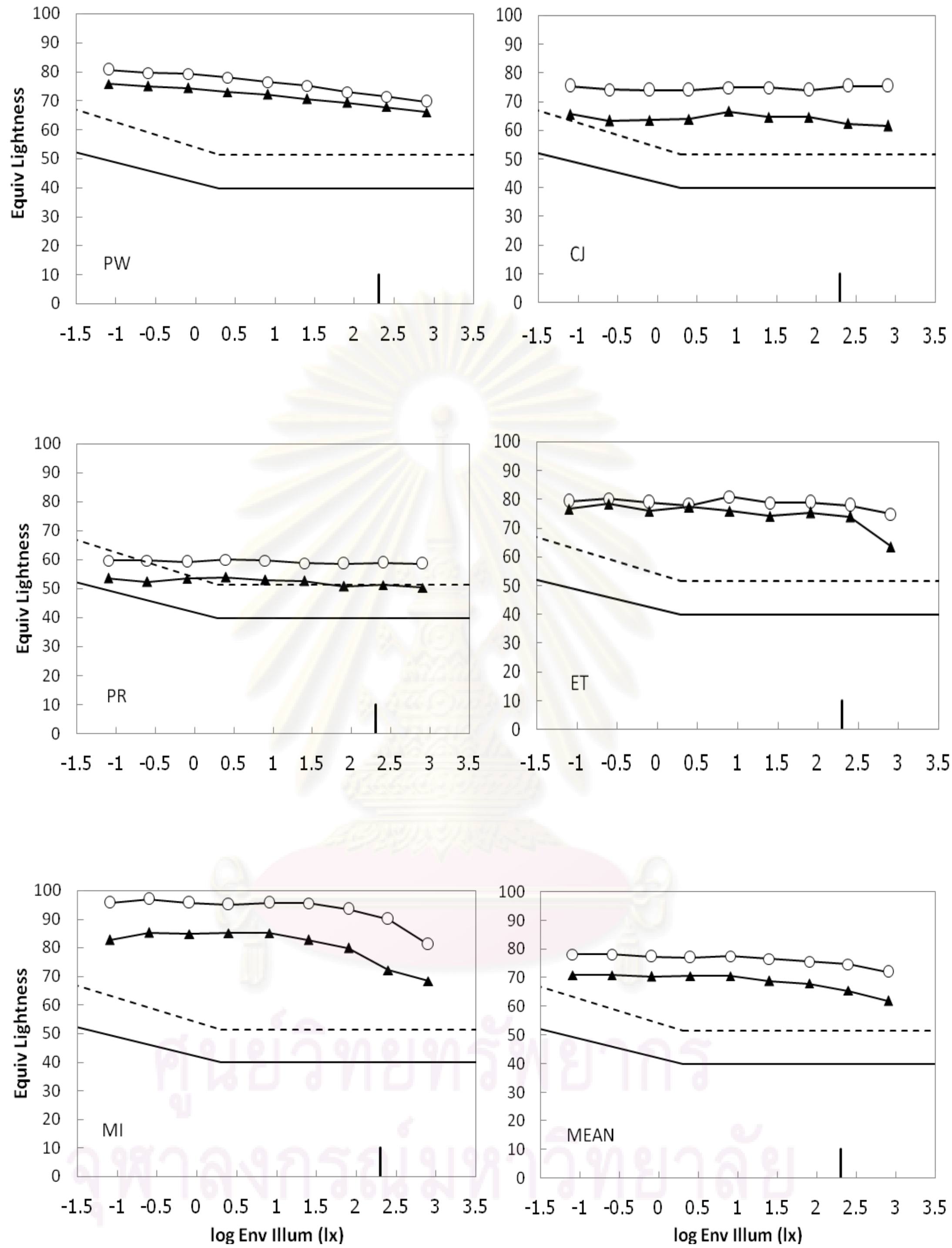

(b)

Fig. 6.2b Yellow stimulus




(c)

Fig. 6.2c Green stimulus




(d)

Fig. 6.2d Blue stimulus

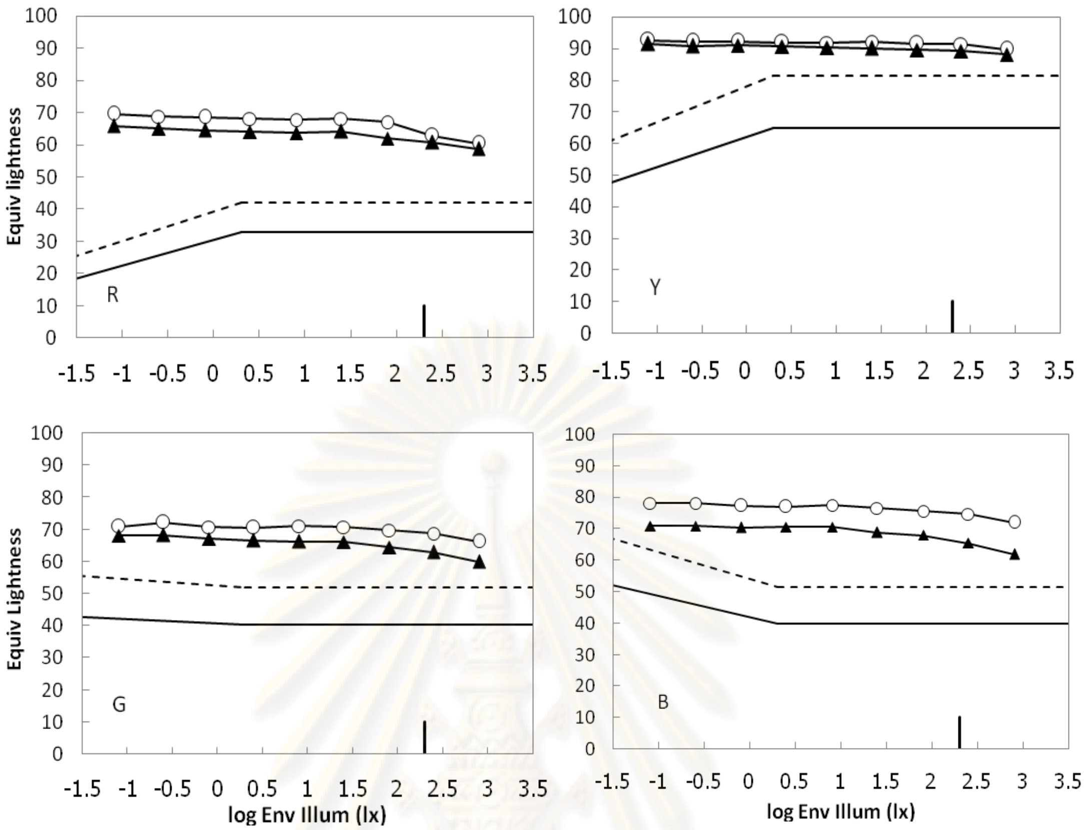



Fig. 6.3 Mean equivalent lightness without (○) and with (▲) goggles.

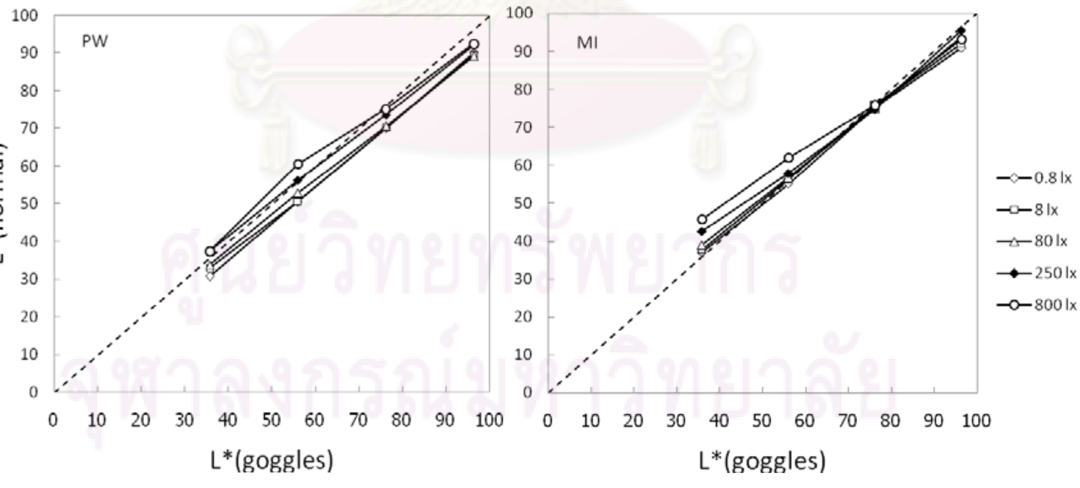
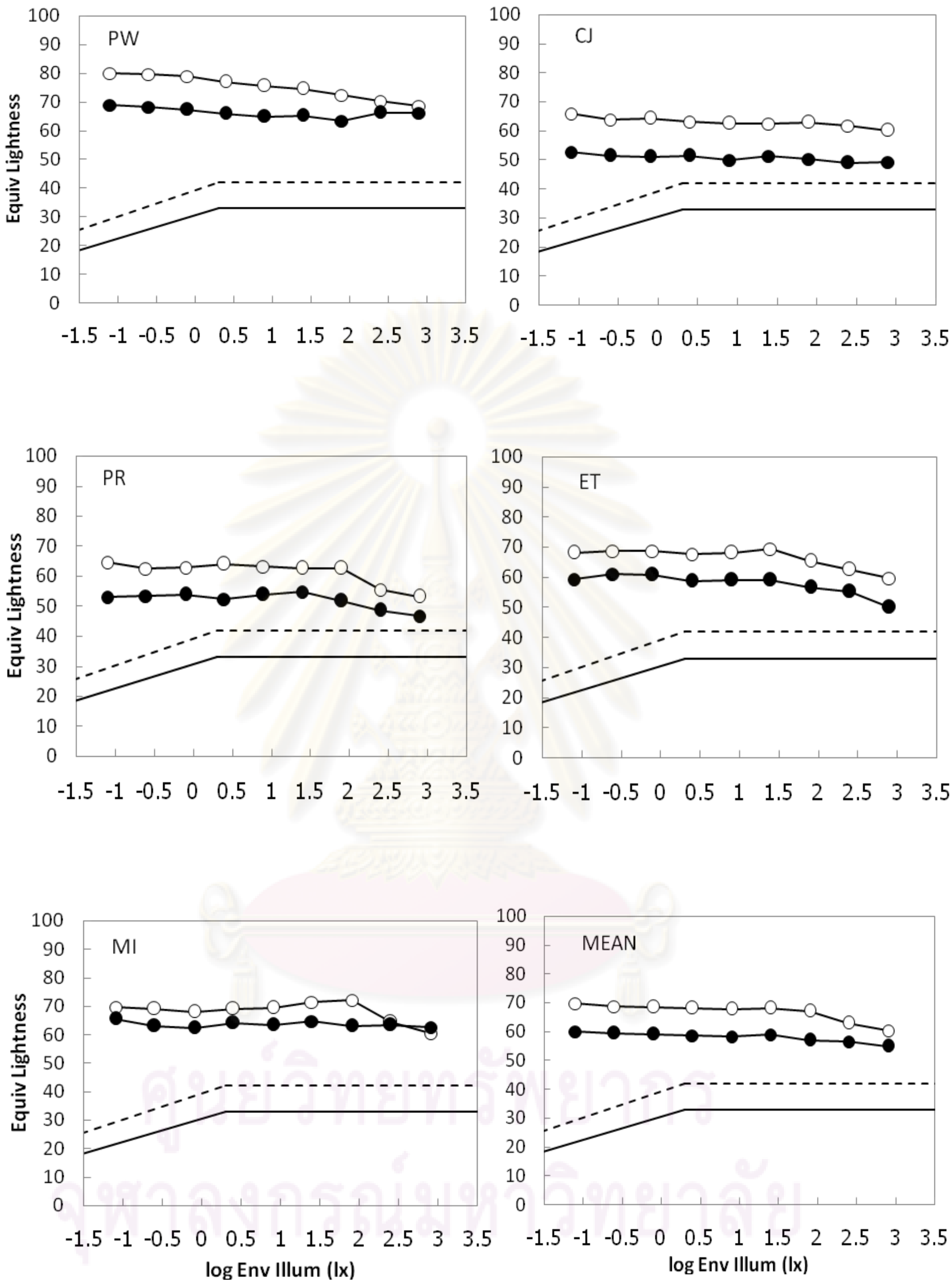


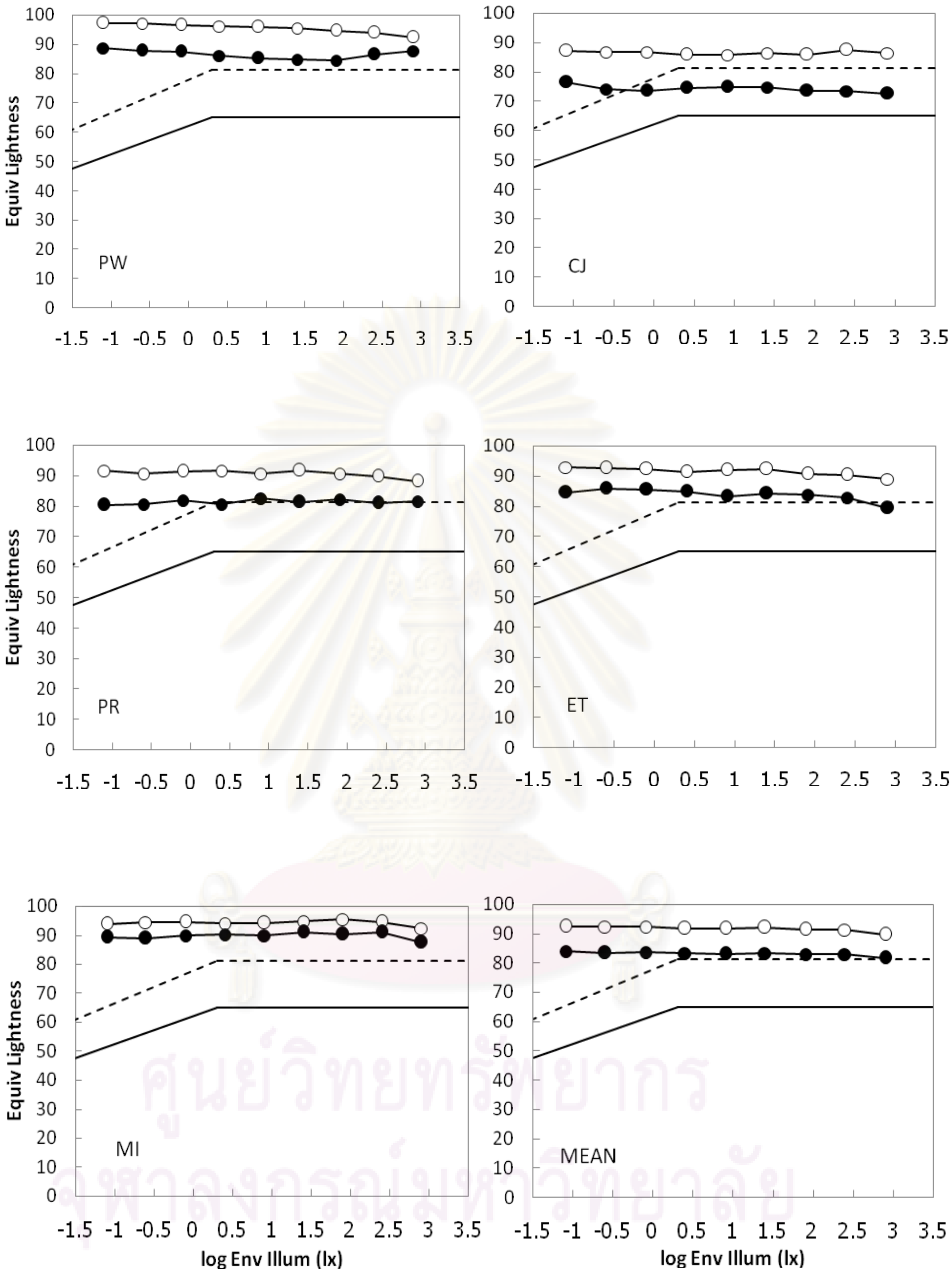

Fig. 6.4 Results of the transfer experiment taken from the subjects PW and MI for five illuminance levels.

By using the transfer curves obtained from each subject the equivalent lightness in Fig. 6.2 was transferred to the equivalent lightness expressed by the normal eyes. The results are shown in Fig. 6.5 for all the subjects, and their mean in Fig. 6.6 for the four colored stimuli. We see in Fig. 6.6 the equivalent lightness with goggles is lower than



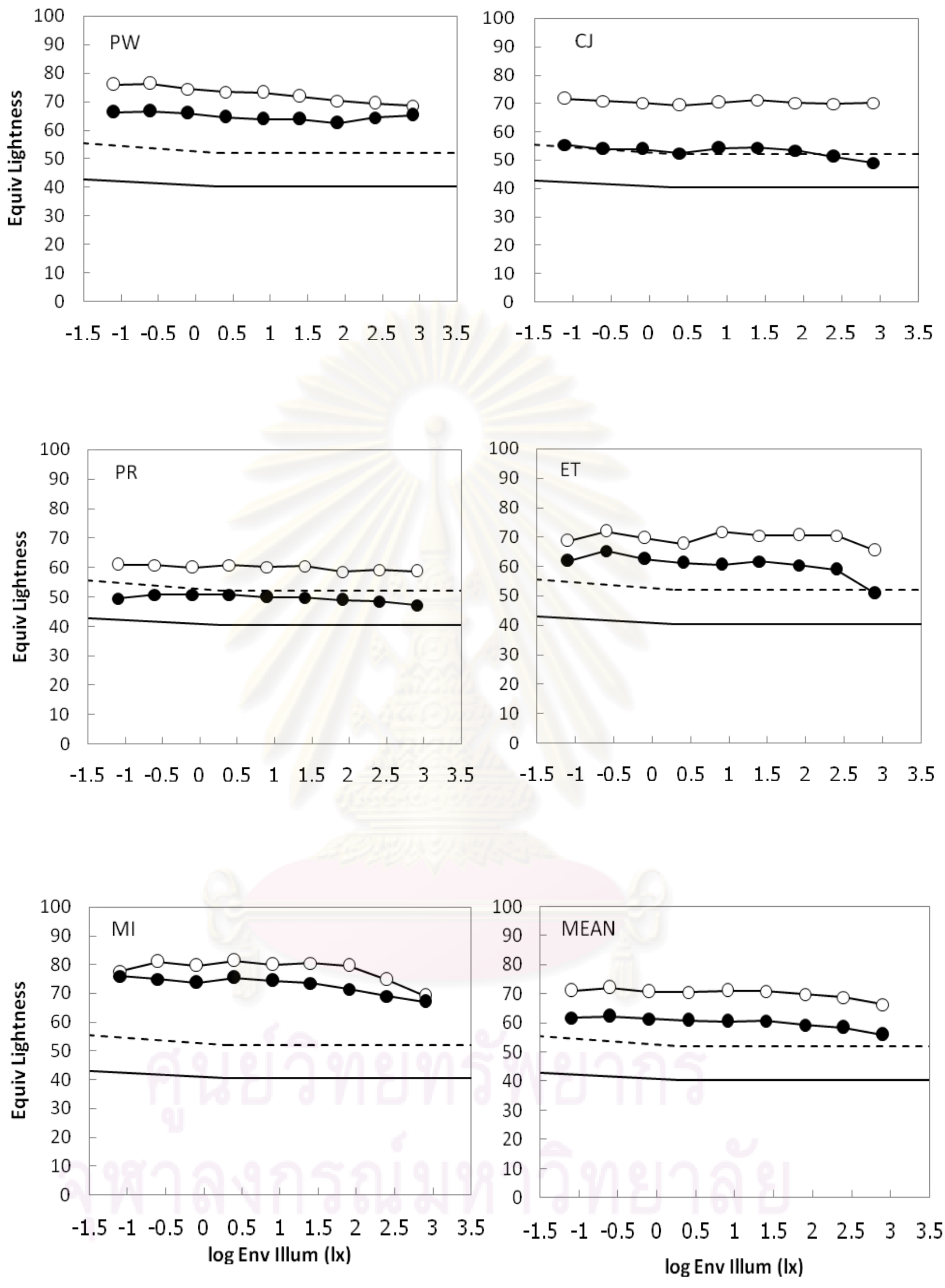

(a)

Fig. 6.5 Equivalent lightness measured under the environment-stimulus independent experiment without (○) and with goggles (●) expressed by the normal eye perception from five subjects and the mean for four colored stimuli, a, red; b, yellow; c, green; d, blue.



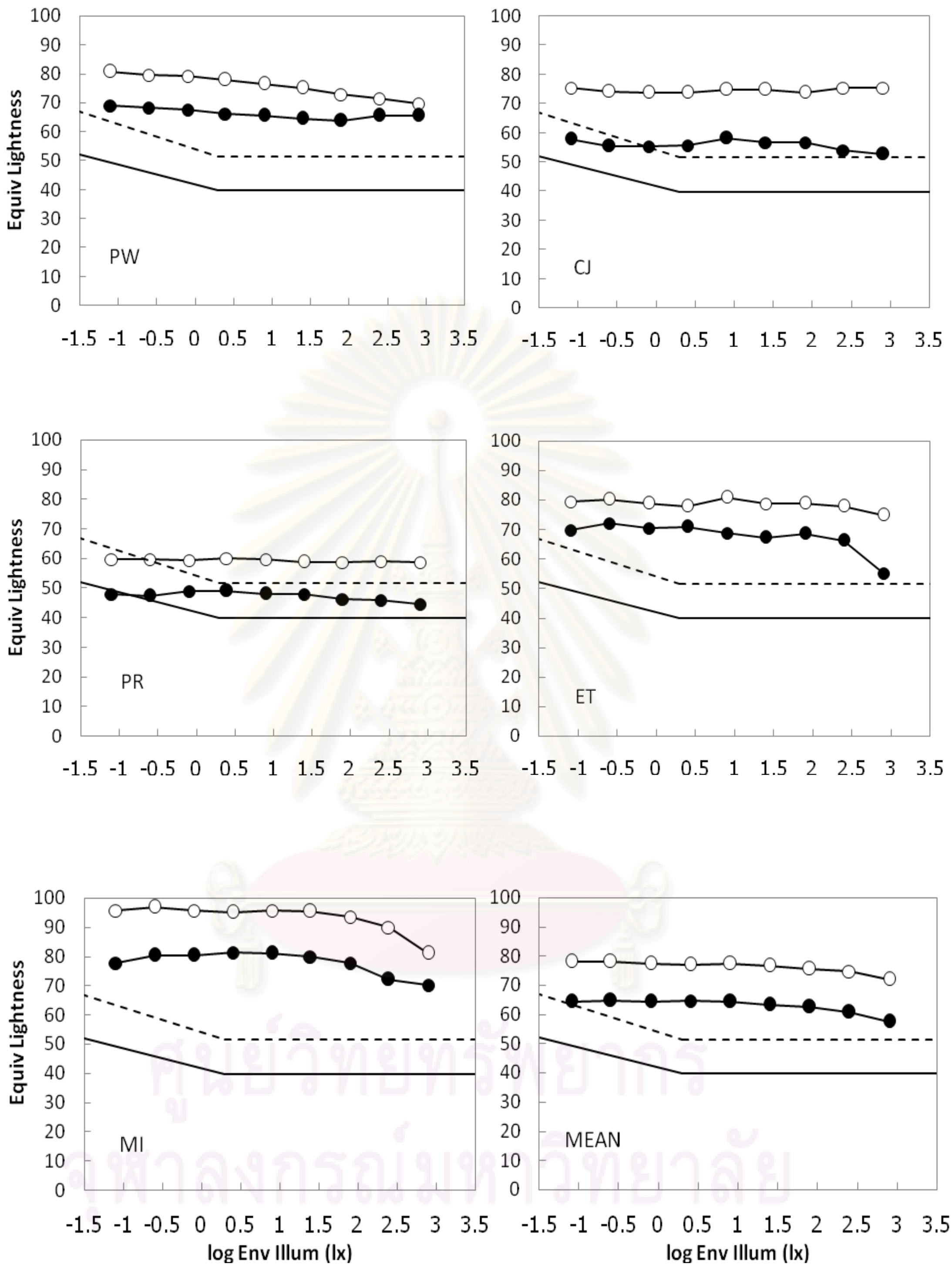

(b)

Fig. 6.5b Yellow stimulus




(c)

Fig. 6.5c Green stimulus




(d)

Fig. 6.5d Blue stimulus

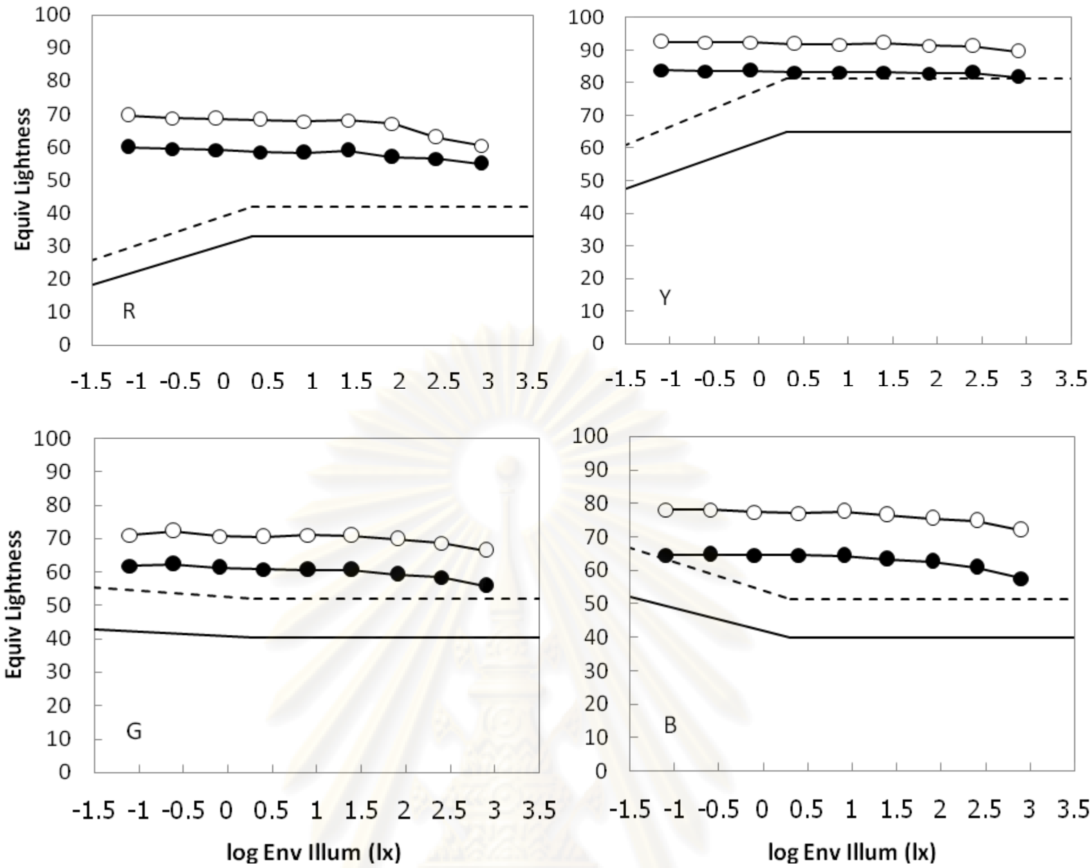
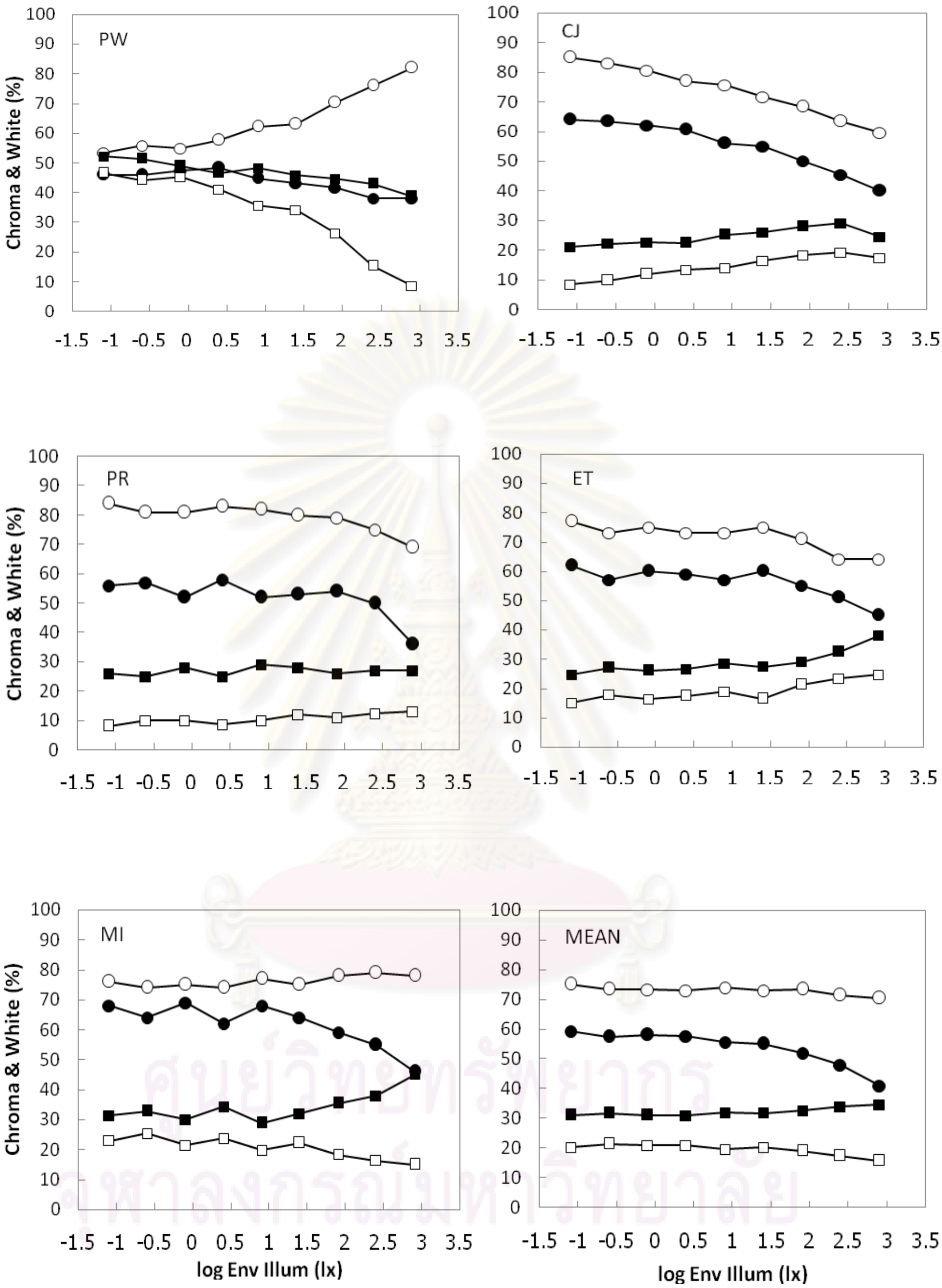



Fig. 6.6 Mean equivalent lightness of five subjects under the environment-stimulus independent experiment without (○) and with goggles (●) expressed by the normal eyes.

that without goggles, but it remains about same for all the illuminance levels. It slightly goes down for higher illuminance indicating the effect of environment increases slightly.

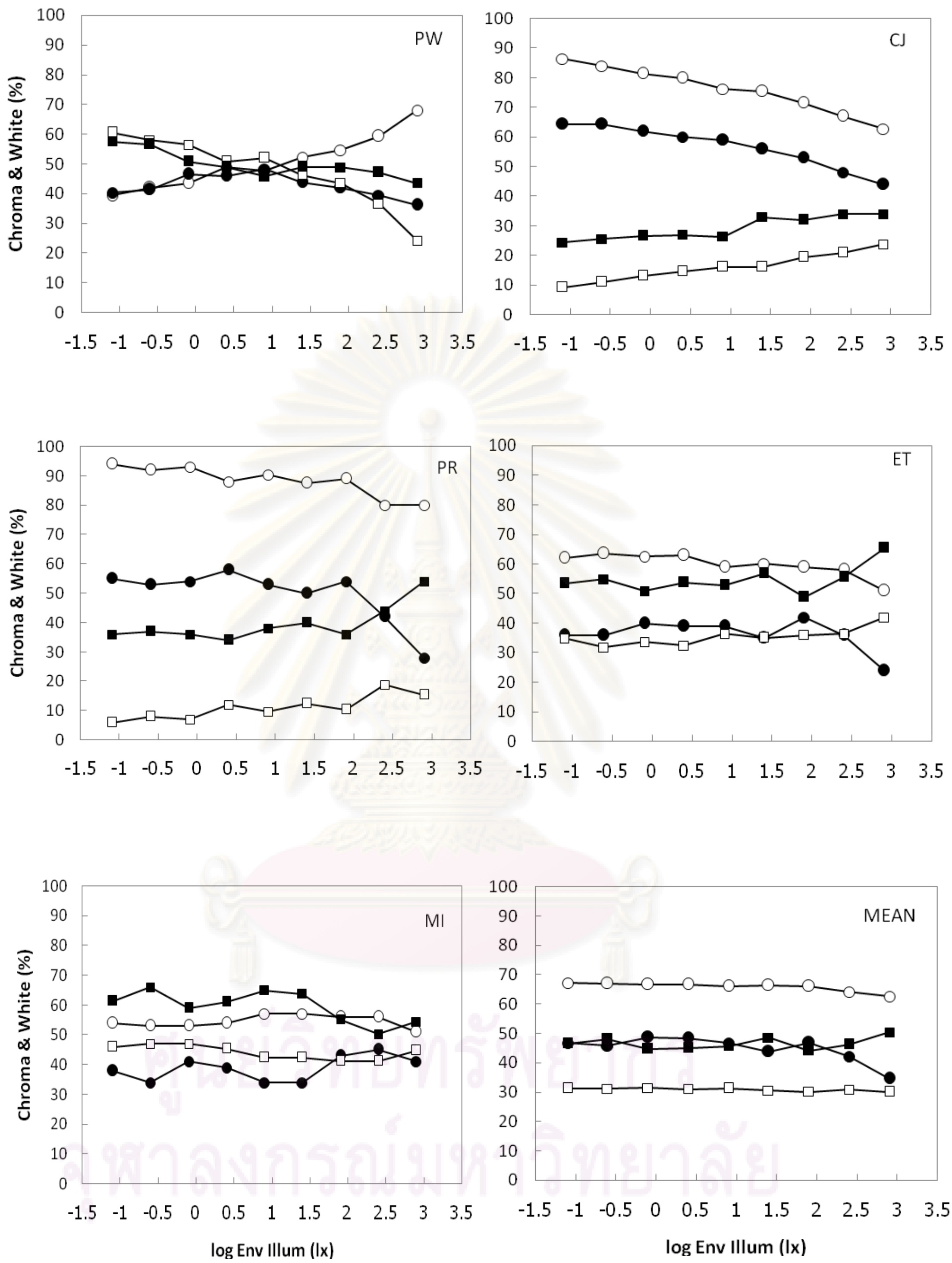
### 6.4 Color naming experiment and results

Results of color appearance experiment are shown in Fig. 6.7 as in Fig. 5.8 of the normal viewing experiment. All the subjects but PW showed rather constant chromaticness and whiteness shown by open circles and by open squares, respectively, for room illuminance when the red stimulus was observed without goggles as seen in Fig. 6.7a. In the case of the subject PW the chromaticness increased rapidly and the whiteness decreased also rapidly for higher illuminance. With goggles the chromaticness slightly decreased and the whiteness increased for higher illuminance, particularly at the highest three illuminance levels in most subjects. The subject PW showed a different result with goggles also.



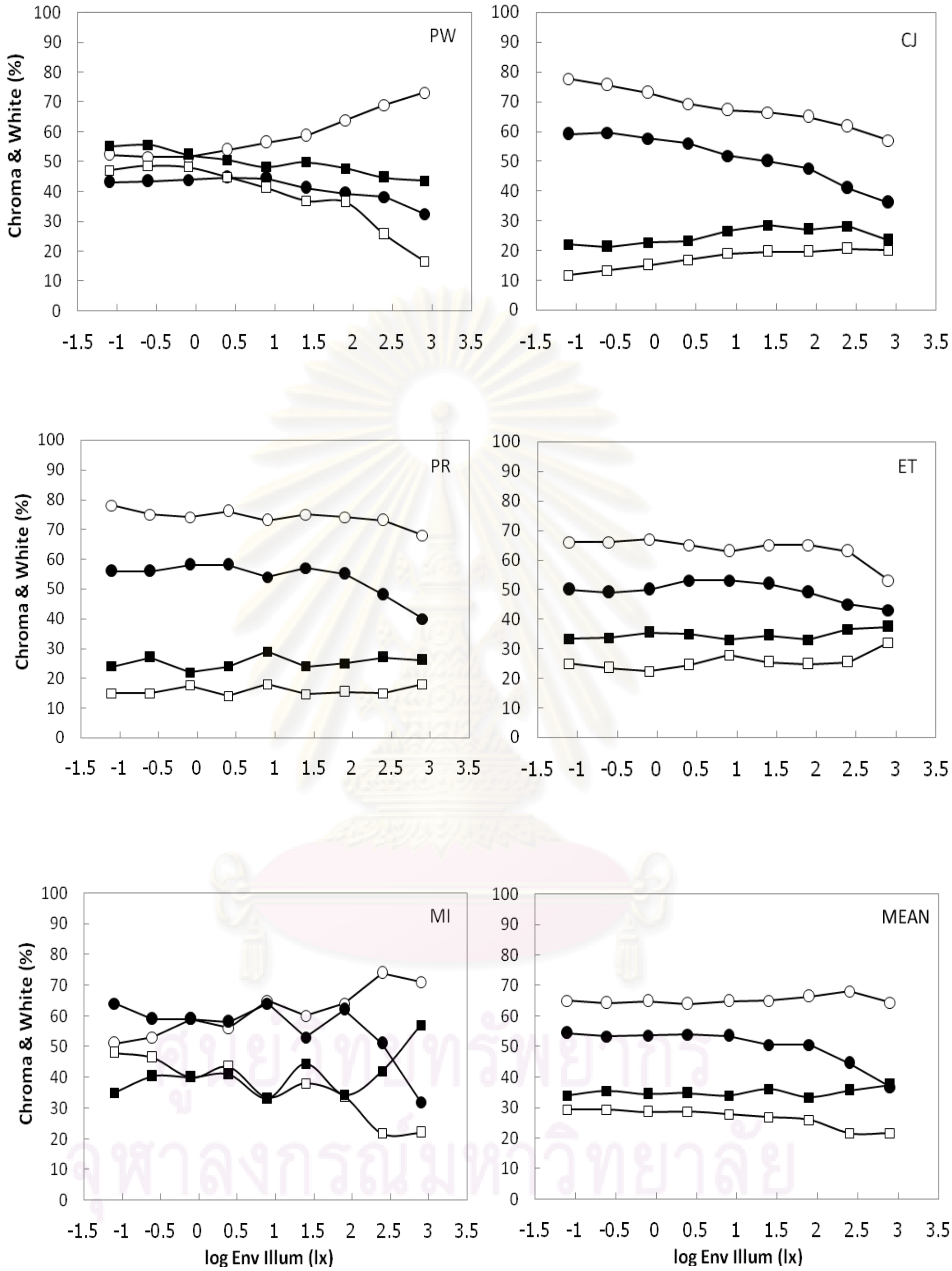

(a)

Fig. 6.7 Results of the color appearance experiment under the environment-stimulus independent condition for all subjects. The mean of the five subjects is shown at the bottom right. a, red; b, yellow; c, green; d, blue.



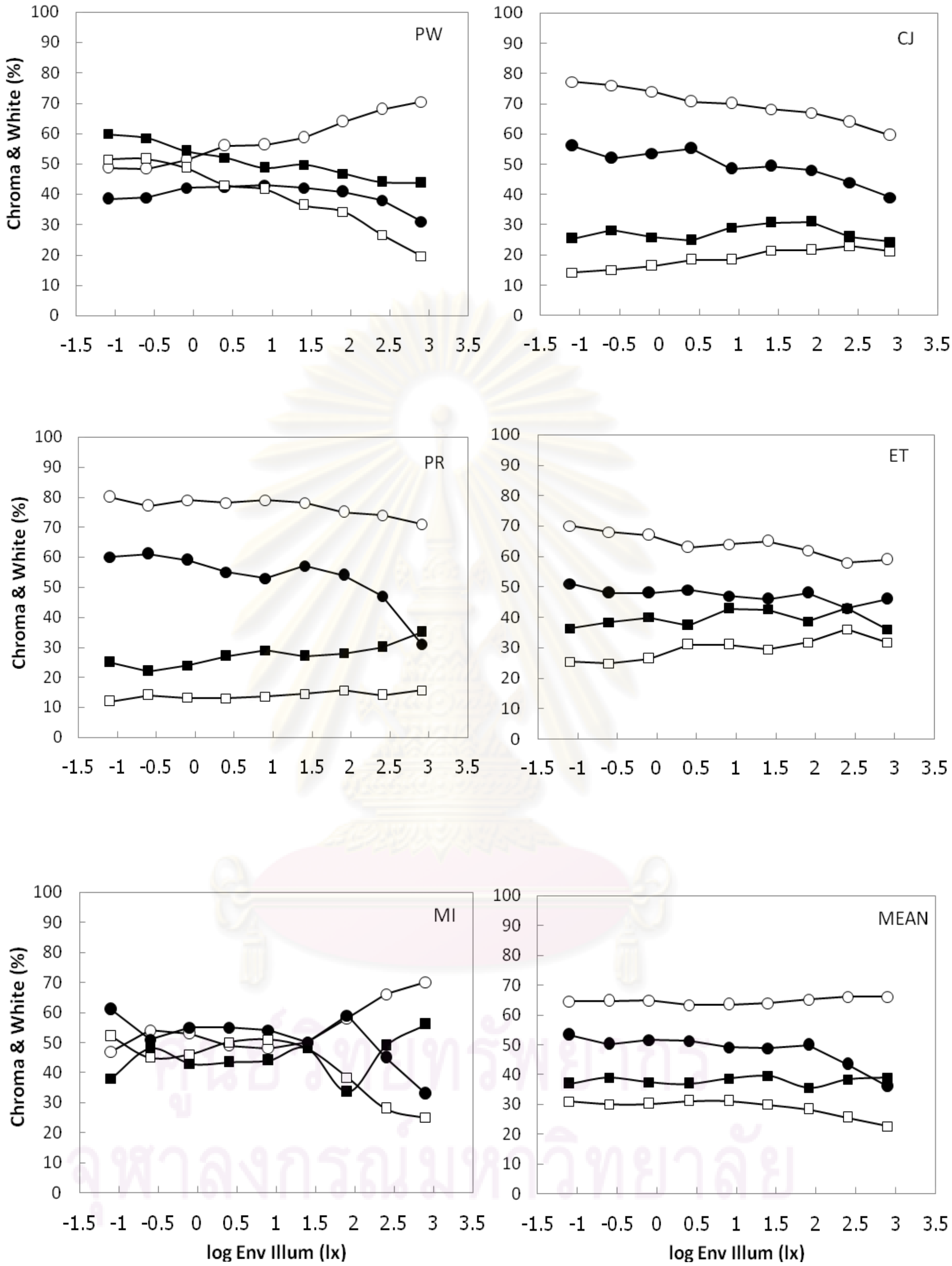

(b)

Fig. 6.7b Yellow stimulus




(c)

Fig. 6.7c Green stimulus




(d)

Fig. 6.7d Blue stimulus

The mean results of five subjects are summarized in Fig. 6.8. It is clearly shown that the chromaticness stays constant for all the illuminance levels without goggles. This should assure the equivalent lightness stays constant for all the illuminance levels

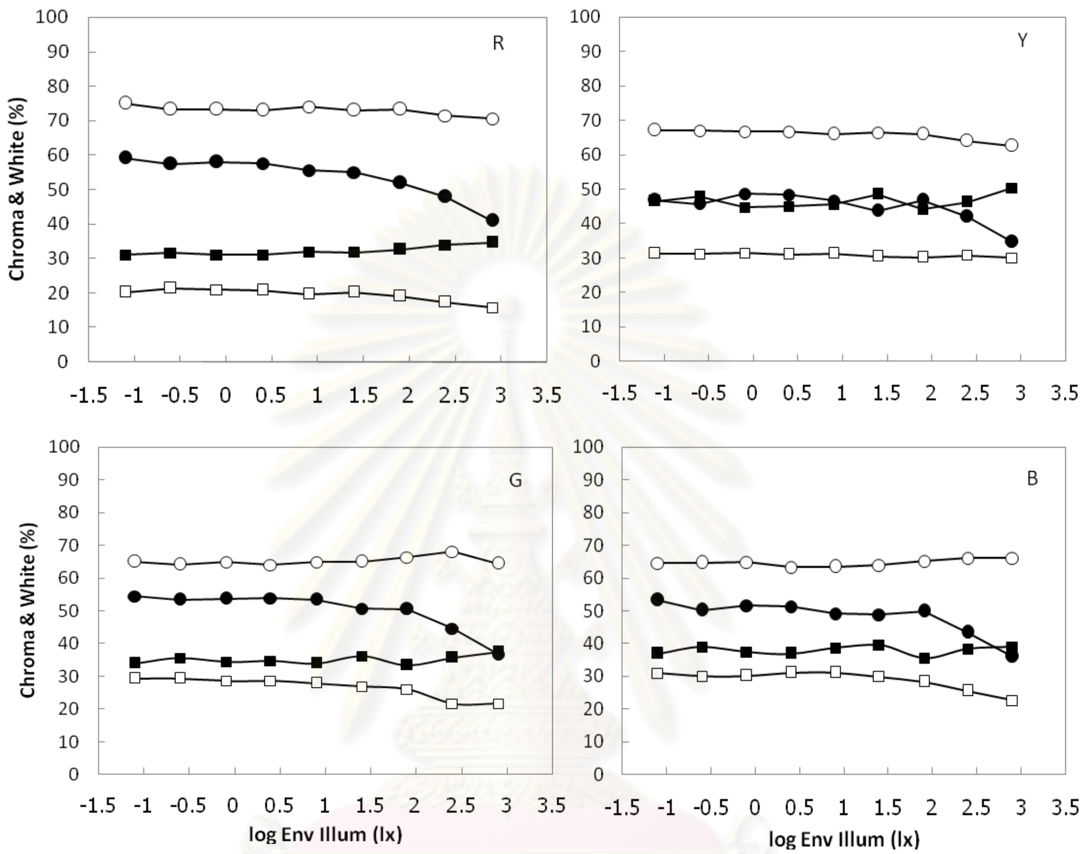



Fig. 6.8 Mean results of five subjects of the color appearance for chromaticness and whiteness.

and it can be confirmed in Fig. 6.6. With the goggles the chromaticness stays almost constant but it drops down at highest two illuminance levels, 250 and 800 lx in all the stimuli. It should predict the drop of the equivalent lightness also at the two levels but as far as we see in Fig. 6.6 such drop is not clearly seen. The superposition of white environment light over the test stimuli protected from the drop of the equivalent lightness as discussed in the previous chapter for the normal viewing experiment.

# CHAPTER VII
# GENERAL DISCUSSION

The equivalent lightness was obtained in two viewing conditions, the normal viewing condition and the environment-stimulus independent condition. We will compare the two results in this chapter. The two curves obtained with goggles are plotted in Fig. 7.1, one by the normal viewing condition (◆) and the other by the environment-stimulus independent condition (▲). Four sections correspond to the stimulus colors, red, yellow, green, and blue. Those are averaged results of five subjects. As already pointed out in the previous chapters L*eq by the normal viewing

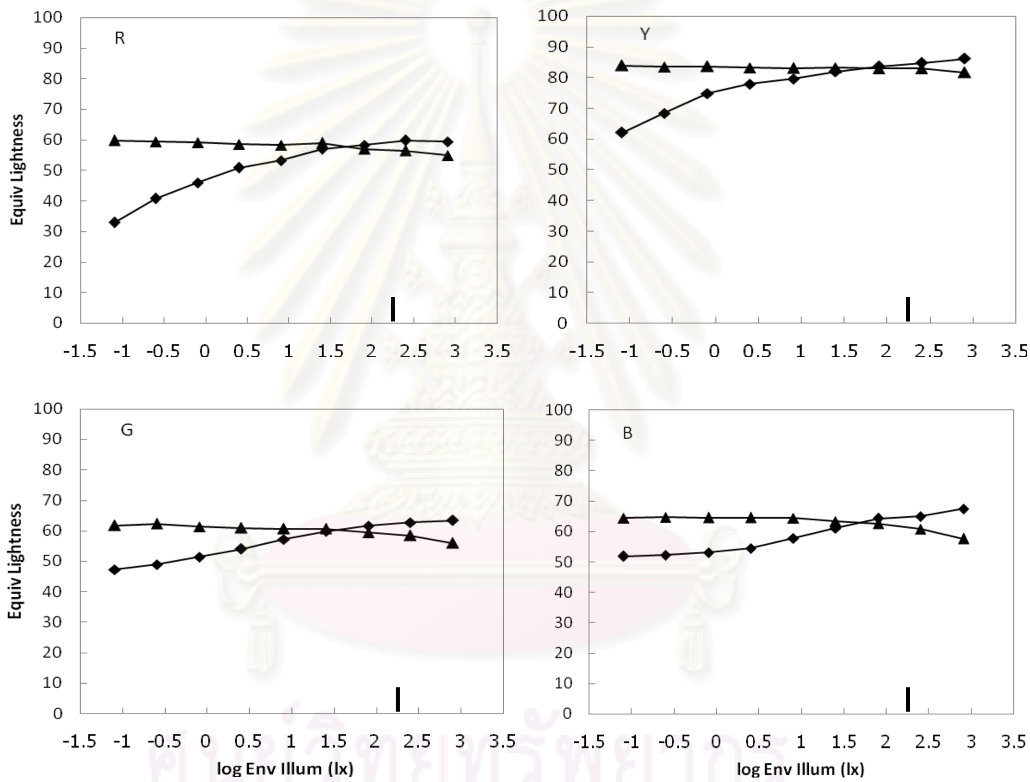



Fig. 7.1 Equivalent lightness determined by the normal viewing condition (◆) and by the environment-stimulus independent condition (▲). Both curves were obtained with goggles.

condition increases monotonically for higher illuminance but on the other hand L*eq by the environment-stimulus independent condition gradually decreases. They intersect at around 1.8 log lx or 63 lx in all the colors, not far from 200 lx of the stimulus room in the environment-stimulus independent experiment, when both rooms appeared almost continuous in brightness. The gradual decrease of L*eq in the environment-stimulus independent condition is certainly because of the increase of effect from the scattered environment light. The effect is to reduce the color saturation and consequently L*chr, which is lightness coming from color. In the other expression the color saturation and thus the equivalent lightness can be increased by employing the environment-stimulus independent technique and reducing the illuminance of the subject room.

The change of the color saturation can be seen more directly by taking the ratio of chromaticness to whiteness obtained in the color appearance experiments in Chapter 5 and 6. The results are shown in Fig. 7.2. Tendency of two curves is very similar to

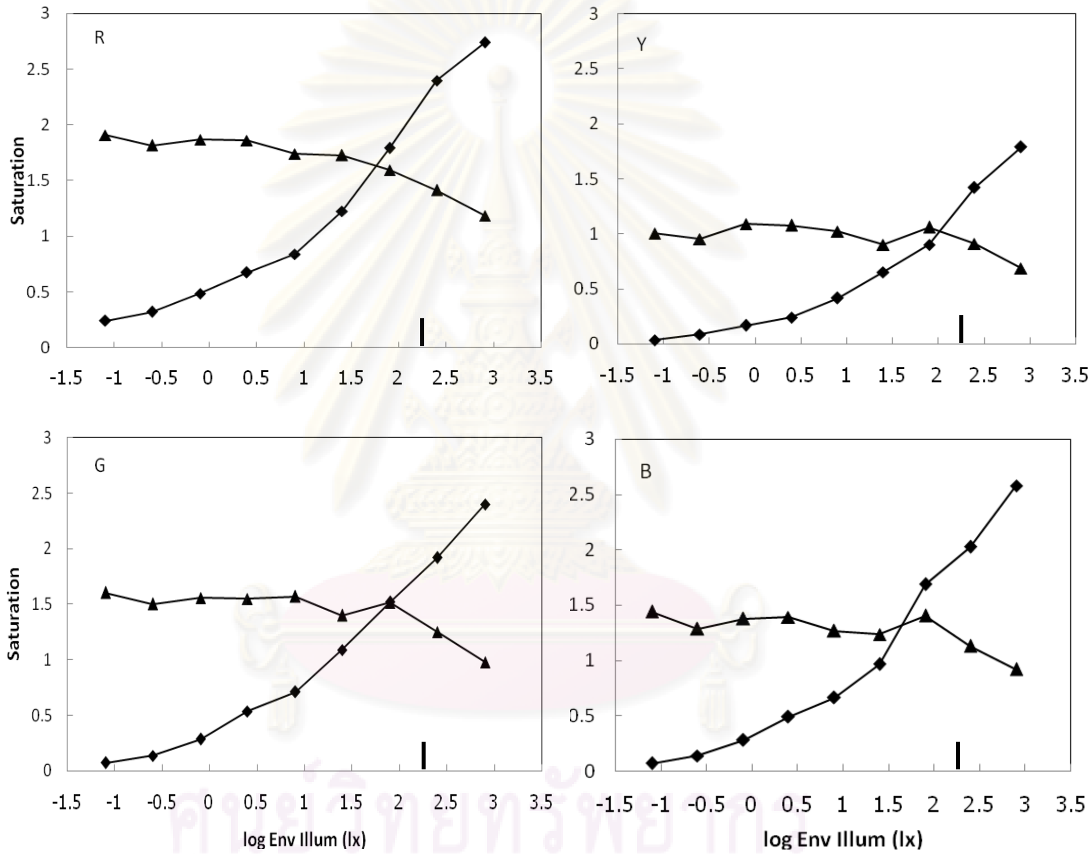



Fig. 7.2 Color saturation of stimuli observed with goggles from the normal viewing condition (◆) and the environment-stimulus independent condition (▲).

that found in Fig. 7.1. This should mean that the equivalent lightness is closely related to the color saturation and confirms the validity of Eq. (1.1). But it was noticed by subjects that the impression for the stimulus becomes very vivid when the room illuminance was reduced in the environment-stimulus condition than the saturation's increase. This discrepancy suggests that the pattern perception is another important feature to be investigated beside the equivalent lightness and the color appearance.

# CHAPTER VIII
# CONCLUSIONS

The cataract experiencing goggles developed by Panasonic Co. were used throughout the present experiment. The goggles were developed to simulate the cataract vision of which owners started some inconvenience in their daily life such as “everything appears foggy”, “can’t see a TV clearly”, and “people’s faces are now clearly recognized”. As every body gets cataract soon or later as age advances the investigation using the goggles is useful to understand the elderly vision. Four young students participated in the experiment and one elderly person whose eyes were operated for the cataract and replaced by the intraocular lenses, which made his brightness and color perception normal.

In the present paper the equivalent lightness which is an important visual perception to express the brightness of objects was measured with the goggles and with the normal eyes without the goggles for four colored stimuli and under nine illuminance levels, 0.08, 0.25, 0.8, 2.5, 8, 25, 80, 250, and 800 lx covering mesopic and photopic vision. The heterochromatic brightness matching method was employed. The color appearance of test stimuli was also measured by using the elementary color naming method.

The measurement was made under two viewing conditions, the normal viewing condition and the environment-stimulus independent condition.

In the normal viewing condition the equivalent lightness L*eq increased monotonically as the illuminance level increased both without and with goggles. But L*eq with goggles was always smaller than L*eq without goggles by the amount of about 10 in L* unit. This means that the elderly people perceive brightness for objects darker by 10 in L* unit.

The cause for the change of the equivalent lightness was analyzed and it was suggested that the equivalent lightness L*eq of elderly people can be expressed as sum of the achromatic lightness L*achr, and the chromatic lightness L*chr, and the environment lightness L*env. L*chr decreases as age but L*env increases as age because of the foggy crystalline lens. As a consequence the equivalent lightness of elderly people appears to be determined only by the transmission reduction of the crystalline lens.

The environment-stimulus independent condition was proposed to keep the equivalent lightness and the color appearance as much as high in the elderly person. A stimulus was placed in a separated space and a subject observed it from a subject room through a small window between the two rooms. The illumination of the stimulus room and that of the subject room were independently controllable by this arrangement, and the scattering light into the eyes coming from the environment can be reduced while the illumination for the stimulus was kept constant. The reduction of L*chr could be minimized by this technique. The expectation was confirmed to some extent.

It was true, however, that the expectation that the equivalent lightness could be kept same as young eyes when the environment-stimulus independent technique was employed was not completely fulfilled, but partly. It was suggested that some other visual perception should be also considered other than the equivalent lightness and the color appearance. That is the pattern perception. All the subjects noticed that a stimulus appeared clearly when it was observed in the environment-stimulus experiment in spite of fact that the color appearance did not change significantly. The judgment for the brightness and that for the color appearance were made only for the stimulus itself and its appearance relative its surrounding was not counted for the judgment. In considering the improvement of infrastructure for elderly people it is important to investigate also the pattern perception. This will be a future investigation.

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