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Defining the visual adaptation field for mesopic photometry: Does surrounding luminance affect peripheral adaptation?

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CIE 191:2010 recommends a mesopic photometry system that defines the luminous efficiency function for peripheral visual tasks, which vary depending on the adaptation state of observers. For implementation of the system, an adaptation field to determine the adaptation state needs to be defined. To address this issue, vision experiments have been conducted to measure surrounding luminance effects on the adaptation state at a peripheral task point. The results reveal that the adaptation state depends mainly on the local luminance at the task point but there is also a small effect of the surrounding luminance. The results suggest that the surrounding luminance effect is larger than the veiling luminance predicted with existing foveal models; nevertheless, it is not significant for the mesopic luminance on uniform luminance distributions.

1. Introduction

The peak spectral sensitivity of human eyes shifts towards shorter wavelengths in the mesopic range. Although this phenomenon has been known as the Purkinje effect since the 19th century, and although most outdoor lighting scenarios are in the mesopic range, lighting engineers and designers cannot take this effect into account for lighting applications and products. While the current photometry system adopted by international metrology standards[1,2] covers the photopic and the scotopic ranges with the luminous efficiency functions, $V(\lambda)$ and $V'(\lambda)$, no luminous efficiency function has been defined for the mesopic range.

To address photometry in this omitted region, the International Commission on Illumination (CIE) has published a technical report CIE 191[3] that recommends a mesopic photometry system based on task performance. It describes the mesopic spectral luminous efficiency function $V_{\mathrm{mes}}(\lambda)$ as a linear combination of $V(\lambda)$ and $V'(\lambda)$, according to an equation:

$$M(m)V_{\mathrm{mes}}(\lambda) = mV(\lambda) + (1 - m)V'(\lambda) \quad (1)$$

where m is a coefficient, the value of which depends on the visual adaptation conditions and $M(m)$ is a normalization function. The range of coefficient m is 0–1, inclusive.

Although the mesopic photometry system is expected to enable lighting industries to develop more efficient energy and/or more visually effective products and applications for outdoor lighting, it is still not practically applicable for real lighting applications because of some remaining issues. CIE established a technical committee JTC-1 to address these issues.[4] The issues under consideration in CIE JTC-1 are: Defining the visual

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adaptation field; defining lighting applications where the mesopic photometry system could be used and providing guidelines for implementing the mesopic photometry system. The Illuminating Engineering Society of North America (IESNA) Mesopic Committee also pointed out several issues in TM-12-12,[5] which is a guideline for lighting design with the mesopic photometry system. One of the more important issues noted above is the definition of the visual adaptation field. It is clear that in Equation 1, the mesopic luminous efficiency function varies depending on the adaptation state of observers' eyes, which is represented by the parameter m. According to CIE 191, the value of m is determined by the luminance (the photopic and scotopic luminance) called 'adaptation luminance' to which the eyes are adapted. The field of view contributing to the adaptation luminance is called the 'adaptation field'. Thus, $V_{\mathrm{mes}}(\lambda)$ cannot be determined for any lighting scenes unless the adaptation field is defined. However, at the present, no international definition for the shape and size of the adaptation field is agreed upon. IESNA TM-12-12 recommends use of the local luminance (the luminance of the test object) as the adaptation luminance,[5] whereas some researchers think that the adaptation luminance is determined by calculating average luminance (or weighted average luminance) of a field that has a certain area.[4,6]

The CIE 191 mesopic photometry system is based on peripheral task performances measured with a number of experiments, primarily at 10° eccentricity.[7–11] For most of these experiments, determining the photopic and scotopic luminance levels of the adaptation field is straightforward, because the experiments employed uniform background luminance levels in the whole field of view, and the adaptation luminance can be considered to be equal to the background luminance.

On the other hand, it is not easy to determine the adaptation luminance for real lighting scenes, which have non-uniform and more complicated luminance distributions. This is because the adaptation state at a peripheral task point on the retina could be affected by the local luminance as well as by the surrounding luminance, which is the luminance distribution of the field outside the task point.

There are some existing and ongoing studies to address this issue. Puolakka and Halonen[4] suggested that studies regarding luminance distributions and observers' line of sight would be useful to the adaptation field definition. A report by the Netherlands Organisation for Applied Scientific Research (TNO) pointed out that the veiling luminance should be taken into account to determine the adaptation luminance and proposed that the adaptation luminance should be the average luminance of the entire field of view tentatively.[12] As cited above, IESNA TM-12-12 recommends determining mesopic luminance by using only local luminance as the adaptation luminance.[5] This is called the 'point-by-point' method. This method is based on an experimental study that shows task performances when night driving are more predictable with local luminance at the task point than the road surface luminance, which was much higher than the local luminance.[13]

Narisada[14] reported that the fovea is adapted to the sum of the local luminance at the fovea and the equivalent veiling luminance caused by the surrounding luminance. The equivalent veiling luminance can be calculated with a disability glare formula, such as the CIE general disability glare equation[15] and the Stiles–Holladay disability glare formula.[16]

The questions to be considered here are whether the surrounding luminance affects the peripheral adaptation state, and, if so, whether the surrounding luminance effect is significant in determining mesopic quantities. According to the studies above, there are two factors that make surrounding luminance affect the adaptation state: one is the movement of line of sight and the other is a factor including veiling luminance and lateral neural interactions on retina, visual cortex, etc. The second makes surrounding luminance affect the adaptation state even when the observer's line of sight is fixed. Characteristics of the second factors are independent of lighting application, whereas the eye movement varies depending on the application.

The effect of application-independent factors must be considered to define the adaptation field for all lighting applications. As seen above, some studies pointed out that the application-independent factor can be described with the veiling luminance. However, empirical evidence employed or corrected for this notion and the glare formulae are based on foveal task performance.[14,17–21] It is not clear whether the notion and formulae are applicable to the peripheral tasks, for which the mesopic photometry system is designed.[22–24]

Therefore, we conducted a series of visual experiments to measure surrounding luminance effect on adaptation state at a peripheral task point.

2. Method

The experiments were designed to estimate the adaptation state of a subject by measuring the luminance contrast detection threshold for a visual target. Generally, the luminance contrast detection threshold varies, depending on target size, duration of the target presentation, target position, background luminance and the adaptation state. Therefore, when a subject adapts to a luminance distribution, while factors other than the adaptation are fixed, the threshold can represent the adaptation state corresponding to the luminance distribution.[25]

2.1. Experimental set-up

The experimental set-up is shown in Figure 1. A computer-controlled liquid crystal display (LCD) was employed to present

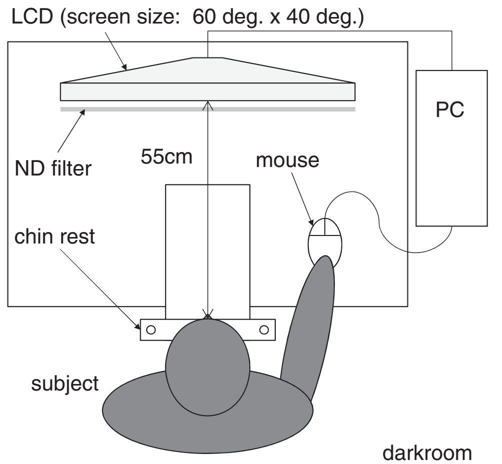

Figure1 Depiction of the experimental set-up.

stimuli consisting of the target to be detected and surrounding patterns, which were the luminance distributions on the entire LCD screen. Neutral density filters were put in front of the LCD to lower the luminance to the mesopic range while maintaining the LCD's ability to control luminance with high resolution. Prior to every experimental session, the LCD was warmed up to ensure that stabilization was reached. The luminance of the LCD was automatically monitored and it was judged that stability was reached when the variation of the luminance over 20 minutes, taken 5 minutes apart, was less than 0.5%. It took more than one hour. Then, before the experiment, the luminance at the target position on the LCD screen was measured by using a calibrated luminance meter placed at the subject's eye position. The uniformity of the LCD was checked at nine points on the screen, and one standard deviation of the luminance was 6.5%, which was not considered significant for the experiments. The experiments were done using three different colour stimuli on the display: white, red and blue. The target and the surrounding patterns of the same colour were presented in each experiment. The spectral power

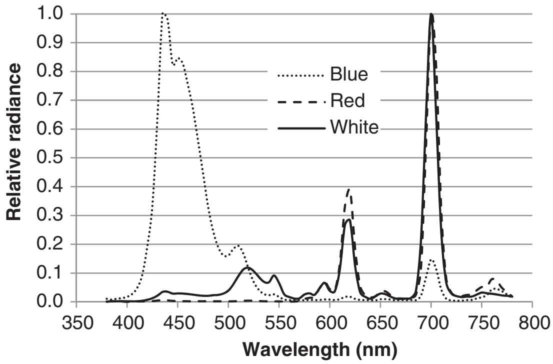

Figure 2 Spectral power distributions for white (solid line), red (dashed line) and blue (dotted line) stimuli presented on the display.

distribution of each colour stimulus is shown in Figure 2. The S/P ratios, which are ratios of the scotopic luminance to the photopic luminance, of the light stimuli were 1.57, 0.26 and 10.9, for the white, red and blue stimuli, respectively.

A subject was positioned at a viewing distance of 55 cm and fixed his/her head on a chin rest during adaptation and experimental trials. At this distance, the LCD screen subtended $60^\circ \times 40^\circ$ of visual angles, which were large enough to test the hypotheses proposed in Section 2.2.1. Subjects responded whether he/she saw a target on the LCD by clicking a mouse. The response data were automatically collected by a computer, which also controlled the LCD. All experiments were conducted in a dark room.

2.2. Procedure and stimuli

2.2.1. Experiment 1

Experiment 1 was conducted in order to measure the surrounding luminance effect by comparing three adaptation patterns depicted in the top row of conditions A, B and C in Figure 3. Additionally, condition D was conducted to verify whether this experiment can show the Purkinje effect. The bottom row of Figure 3 shows task patterns, which were presented for only a short time while the subject conducted the detection tasks. Each adaptation pattern and task pattern for a condition was presented sequentially as described later. The presentation of the task patterns was brief enough so that it did not affect the adaptation condition. The luminance of the illuminated field on the task pattern is referred to as the 'task background luminance', while that of the adaptation pattern is referred to as the 'luminance of the adaptation pattern'. All conditions were conducted for the three light stimuli of different colours (white, red and blue).

A fixation point was presented at the centre of the screen during the adaptation and task presentations. The target to be detected by the subject was a circular dark spot, the diameter of which was 1° of visual angle. It always appeared in the same position, which was at the lower right of the fixation point. The visual angle between the fixation point and the target was 10°.

The adaptation pattern for conditions A, C and D had a circular illuminated area, the radius of which was 12.4° of visual angle. The circle was centred at the target position. The radius of the circle was set so that the area of the circle was equal to 20% of the entire screen. On the other hand, the condition B had uniform luminance distribution for the adaptation pattern. The luminance levels of the adaptation pattern were 0.42 cd/m^2 for conditions A and B, and 2.1 cd/m^2 for conditions C and D. These luminance levels were chosen after considering the CIE luminance recommendations for road lighting.[26]

Note that the target size, position, duration and the task background luminance were the same for conditions A, B and C. Thus the detection thresholds could be affected only by the adaptation patterns. In principle, the luminance distribution of the task pattern for condition B should also be the same circular pattern as for the other conditions. However, change of the subject's view from the uniform adaptation pattern to the circular

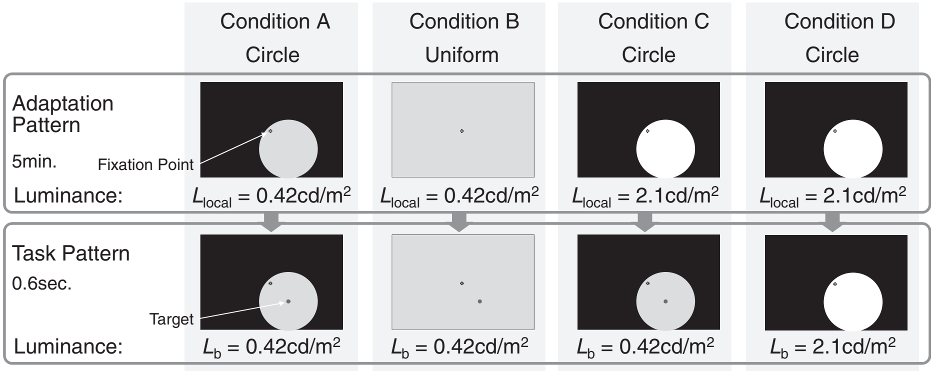

Figure 3 Adaptation patterns and task patterns used for the experiment. The top row shows the adaptation patterns and the bottom row shows the task patterns, for each condition A–D. The circular illuminated area of the adaptation pattern for condition C is 20% of the entire screen illuminated for condition B, and the luminance is five times higher than that for condition B. Thus, the mean luminance levels of the adaptation pattern for conditions B and C are nearly equal.

task pattern tended to cause significant disturbance in the attention of the subject, and this caused large variations in experimental results with naive subjects. On the other hand, the veiling luminance caused by the uniform task pattern affects the detection threshold, but this effect is considered insignificant based on previous studies. It was also verified with repeated experiments with a well-trained subject. Thus, the task pattern for condition B was set to the same uniform pattern as the adaptation pattern for that condition.

The measurements for the four conditions depicted in Figure 3 were conducted in one session on a given day. The order of the conditions was randomized. The procedure for a measurement is described below. During all procedures, the subject was asked to fix his/her line of sight on the fixation point.

1) The subject was asked to adapt to the adaptation pattern for 5 minutes.

2) After the adaptation, the pattern was changed to the task pattern at the same condition for 0.6 seconds.

3) The target was presented for 0.2 seconds in the middle of the task pattern duration.

4) After the task pattern duration of 0.6 seconds, the adaptation pattern returned to the screen.

5) The subject responded whether he/she could/could not see the target.

6) The adaptation pattern was maintained for 5 seconds after the subject's response to preserve the adaptation state.

7) Steps (2)–(6) were repeated with different values of target luminance (contrast ratio) until enough response data were collected according to the random-staircase method.

To maintain the adaptation state at the level where the subject fully adapts to the adaptation pattern, the duration of the task pattern should be as short as possible. In addition, the repeatability of the target duration also has to be ensured. The target duration, 0.2 seconds, was chosen considering these conditions. The time lags between the adaptation pattern and the target presentation were provided to avoid possible forward/backward effects due to delays in neural response.[14,27] The time length of 0.2 seconds was chosen based on these previous studies and for the same reasons for the target duration.

Before an experimental session, the subject adapted to a uniform pattern that had the same luminance as the adaptation pattern of the first condition for at least 5 minutes.

The assumptions about how the experiment can estimate the surrounding luminance effect are below. If the adaptation state is not at all affected by surrounding luminance, such as for the difference between conditions A and B, the luminance contrast detection threshold depends only on the local luminance of the adaptation pattern at the target position. Thus, the threshold for condition B should be equal to condition A, and very different for condition C. This will be referred to as the 'local adaptation hypothesis'.

On the other hand, if the adaptation state is strongly affected by the surrounding luminance and correlates with the average luminance of the whole field of view (i.e. the entire screen), the threshold for condition B should be equal to that for condition C, because the adaptation pattern for condition B was set so that the average luminance of the entire screen was equal to that for condition C. This is referred to as the 'global adaptation hypothesis'. Note that the illuminated area of the adaptation pattern for condition C is one-fifth of that for condition B, and the luminance is five times that for condition B.

In other words, we can check which hypothesis is true by comparing luminance contrast detection thresholds for conditions A, B and C.

2.2.2. Experiment 2

Experiment 2 was conducted to determine the relationship between the threshold and the luminance of the circular adaptation pattern.

When the surrounding luminance affects the adaptation state partially, the threshold for condition B could be between those for conditions A and C. If the function from the luminance of the circular adaptation pattern to the threshold varies monotonically between the luminance levels for conditions A and C, then the function is bijective. In this case, the threshold for condition B can be converted to a luminance of the circular adaptation pattern by this function, and the surrounding luminance effect for condition B can be described as the luminance of the circular adaptation pattern that causes equivalent adaptation state with the condition B.

To determine the degree of the surrounding luminance effect, the thresholds at two more luminance levels between conditions A and C on circular adaptation patterns were measured. The luminance levels were $0.72\,cd/m^2$ and $1.23\,cd/m^2$. For the measurements, the stimuli and procedures were exactly the same as for conditions A and C in Experiment 1, except for the luminance of the adaptation pattern. For white stimuli, this experiment was conducted in the same experimental session as Experiment 1.

2.3. Subjects

Eleven subjects with normal vision participated in Experiment 1 with each colour stimulus. Their ages were 29–68 years, but most of them were between 30 years and 50 years. Five out of 11 subjects participated in experiments with all colour stimuli, and the other six subjects were different between white and blue/red stimuli.

All subjects who participated in Experiment 1 with white stimuli took part in Experiment 2 with white stimuli. One of them was employed for Experiment 2 with red/blue stimuli.

3. Results

3.1. Experiment 1

The mean luminance contrast detection thresholds of all subjects are shown in Figure 4. The thresholds represented by A, B, C and D in Figure 4 correspond to the conditions represented by the same letters in Figure 3. For clarity, depicted luminance

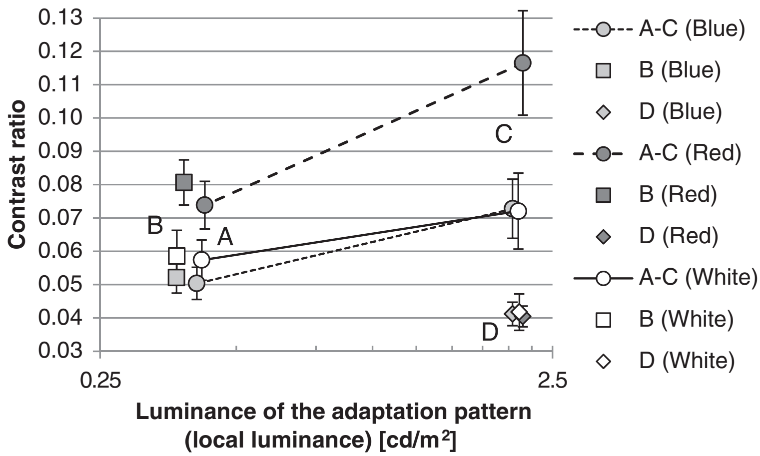

Figure 4 The mean luminance contrast detection thresholds for all subjects in Experiment 1. The circle symbols show the thresholds for conditions A and C, which have the same task background luminance and the circular adaptation patterns of different luminance levels. The square symbols show thresholds for condition B, which has the uniform adaptation patterns. The diamond symbols show thresholds for condition D. The white, light grey and dark grey symbols show thresholds for white, blue and red stimuli, respectively.

levels of the adaptation pattern are slightly shifted from actual luminance levels to avoid the points overlapping with each other. For example, all points for conditions A and B in the figure are at the same $0.42\,\mathrm{cd/m^2}$. The luminance levels for conditions C and D are also equal. Figure 4 shows the luminance contrast detection threshold C_{th} as the ordinate. The threshold C_{th} was calculated from the equation:

$$C_{\mathrm{th}} = \frac{L_{\mathrm{b}} - L_{\mathrm{t}}}{L_{\mathrm{b}}} \tag{2}$$

where L_{b} is the task background luminance and L_{t} is the target luminance at the threshold. Thus, higher C_{th} means a lower task performance.

For all three colour stimuli, it is observed that the condition B threshold levels are much closer to those for condition A than to those for condition C, which favours the local adaptation hypothesis. The error bars in Figure 4 show the standard deviation of the mean, which is considered to include the inter-subject variations in contrast sensitivity. To possibly remove these inter-subject variations, the individual results are normalized to the value for condition A, as shown in Figure 5. The normalization in Figure 5 removed the inter-subject variations and served to examine only the relative positions for condition A versus condition B or C. As a result, the error bars, which indicate one standard deviation of the mean for each point after normalization, are much smaller in Figure 5. This graph shows the tendency of the detection thresholds, which supports the local adaptation hypothesis, more clearly. Additionally, there are also small differences between the results for conditions A and B. These seem to demonstrate a small effect of the surrounding luminance distribution.

To assess such observations on Figures 4 and 5, a two-way analysis of variance (ANOVA) was conducted using all of detection thresholds for conditions A, B and C in Figure 4. The number of data was 99 (11 subjects $\times$ three colour stimuli $\times$ three adaptation conditions). Table 1 shows the results of the ANOVA. Both the adaptation condition and the colour of the stimuli affect the detection threshold significantly, but there is

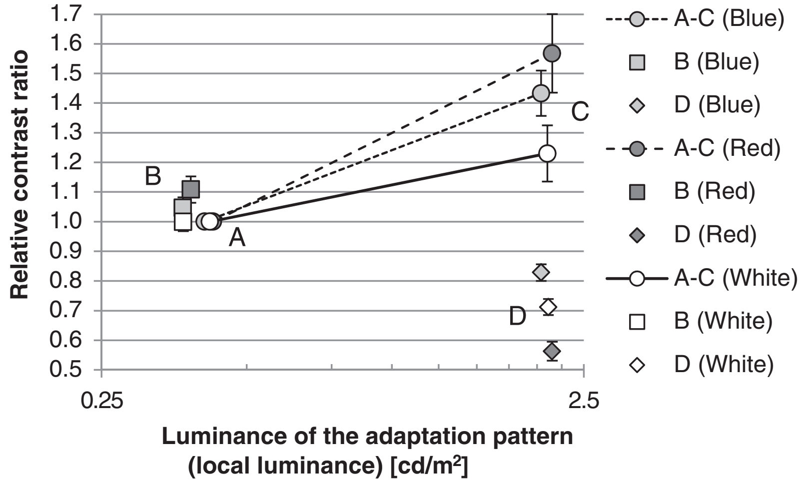

Figure 5 The mean luminance contrast detection thresholds normalized for the condition A thresholds in Experiment 1. Each symbol shows the same type of data as in Figure 4.

Table 1 Two-way ANOVA for conditions A, B and C

Source of variation	SS	df	MS	F	p	
Colour of the stimulus	0.0198562483	2	0.009928	11.689	0.000	**
Adaptation pattern	0.0138909207	2	0.006945	8.177	0.001	**
Interaction	0.0025550319	4	0.000639	0.752	0.559	

**Significance criterion: $p<0.01$.

no interaction between them. Then, a multiple comparison test between conditions A, B and C was conducted on all data for the three colour stimuli by using the Bonferroni method. The detection thresholds are significantly different between A and C ($p<0.01$,) as well as between B and C ($p<0.01$,) but there are no significant differences between A and B. The statistical analysis also supports the local adaptation hypothesis clearly.

For conditions A and D, the luminance levels of the adaptation pattern and the task background luminance were the same. Thus, subjects adapted to a luminance and performed the detection task at the same luminance. This situation is similar to an experiment by Freiding *et al.*[7], which provided some of the basic data for the mesopic photometry system. Focusing on conditions A and D in Figure 4, the relative positions of the thresholds shows some consistency with their experiment. For example, a lower luminance of the adaptation pattern causes a higher luminance contrast detection threshold. It is also consistent in that a lower S/P ratio condition implies a higher threshold at low luminance of the adaptation pattern. These consistencies suggest that the experiment shows the Purkinje effect. However, another ANOVA for the conditions A and D does not detect both the colour effect and an interaction between the colour and the luminance, as shown in Table 2. This is probably because the luminance difference between

Table 2 Two-way ANOVA for conditions A and D

Source of variation	SS	df	MS	F	p	
Colour of the stimulus	0.0014826117	2	0.000741	2.480	0.092	
Luminance of the adaptation pattern	0.0061986158	1	0.006199	20.736	0.000	**
Interaction	0.0017332315	2	0.000867	2.899	0.063	

**Significance criterion: $p < 0.01$.

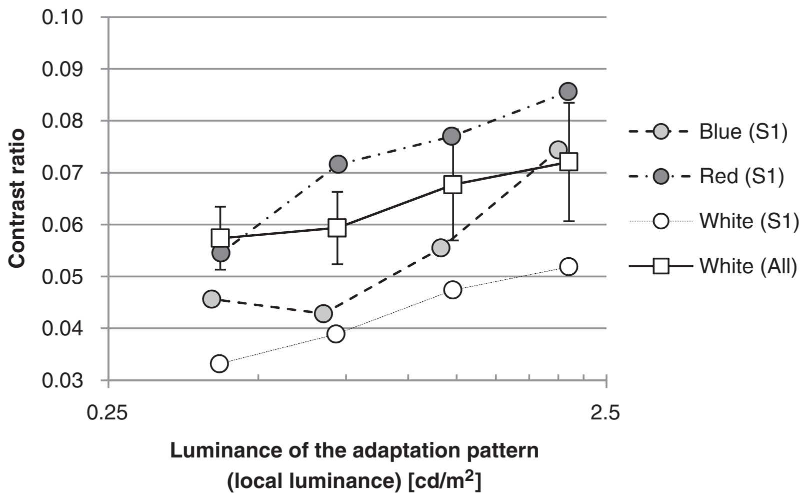

Figure 6 The variation depending on the luminance of the circular adaptation pattern in Experiment 2. The square symbols show thresholds by 11 subjects for white stimuli. The circle symbols coloured white, light-grey and dark-grey symbols show thresholds by the same one subject for white, blue and red stimuli, respectively.

conditions A and D is too small for the Purkinje effect to be shown significantly by this experiment.

An inexplicable observation on the statistical analyses is that the colour effect is significant on the first ANOVA, while it is not significant on the second ANOVA. This is mainly caused by the difference between the detection thresholds for red stimuli and the others under condition C. According to the mesopic photometry system, both conditions have the same adaptation pattern, which induces a mesopic luminous efficiency function that is relatively close to the $V(\lambda)$. Thus, all detection thresholds for condition C should be nearly equal to each other, as should those for condition D. This inconsistency seems to be due to some visual mechanisms that are not taken into account to the mesopic photometry system. Further research is needed for this phenomenon.

3.2. Experiment 2

The results of Experiment 2 are shown in Figure 6. The white square symbols with error bars show the mean luminance contrast detection thresholds for 11 subjects for white stimuli. Both ends of the data are the same as conditions A and C in Figure 4. The other symbols without error bars show the detection thresholds for red, blue and white stimuli for one subject.

The thresholds for white and red stimuli monotonically increase while those for blue stimuli show a different curve with a local minimum around 0.72 cd/m^2. This means that the surrounding luminance effect can be easily quantified for white and red stimuli with regression lines determined from the thresholds. However, the quantification is not applicable to blue stimuli, because the linear regression is not appropriate for the blue results.

The relationship of the detection threshold level between colour stimuli for one subject is not consistent with that in Figure 4, which shows results for 11 subjects. This is probably due to the day-to-day intra-subject variation, which can be cancelled by repetition of the experiment. Each experiment for a colour of the stimuli was conducted on a different day.

4. Discussion

The thresholds for condition B in Figure 5, which have the uniform adaptation pattern, are close to the thresholds for condition A and far from those for condition C. This strongly supports the local adaptation hypothesis. The adaptation state at the peripheral task point depends mostly on the local luminance in the circle.

The small differences between results for conditions A and C are not significant statistically; nevertheless, the systematic differences seem to imply a small effect of the surrounding luminance distribution outside of the circle. To evaluate these effects, those for the white and red stimuli were quantified by converting to the luminance of the circular adaptation pattern, which would cause an equivalent adaptation state (without surrounding luminance distribution). This adjusted luminance is referred to as the 'effective adaptation luminance'. The steps to determine the effective adaptation luminance for the white stimuli are given below (see also Figure 7.) First, a logarithmic regression line was determined from the thresholds in Figure 6. Second, the threshold levels for condition B was projected onto the regression line. Finally, the luminance at the intersection was read as the effective adaptation luminance for condition B. The steps for the red stimuli are almost the same; except for the fact that the regression line was determined only from the thresholds at 0.42 cd/m^2 and 2.1 cd/m^2 in Figure 4. A regression line based on the red data in Figure 6 is not applicable to the red data in Figure 4 for the determination of the effective adaptation luminance. This is because the data in Figure 6 are the result for one subject, while the data in Figure 4 are the mean threshold for 11 subjects.

The calculated effective adaptation luminance levels for condition B were 0.47 cd/m^2 for white stimuli and 0.58 cd/m^2 for red stimuli. Because the local luminance at the peripheral task point of the adaptation pattern for condition B was 0.42 cd/m^2, the surrounding luminance outside of the circle increases the effective adaptation luminance by 0.05 cd/m^2 and 0.13 cd/m^2, respectively.

There are two questions regarding the effective adaptation luminance. The first question is how significant is the surrounding luminance effect on the calculated mesopic luminance. Another question is whether the effective adaptation luminance can be predicted by the sum of the local luminance and the veiling luminance calculated by glare equations, as well as the properties of the fovea. To consider these questions, photopic effective adaptation luminance and mesopic luminance of a target, the photopic luminance of which is 1 cd/m^2, were calculated with the experimental results and three models. The models to calculate those luminance levels are as follows:

1) the sum of the photopic local luminance and the veiling luminance calculated

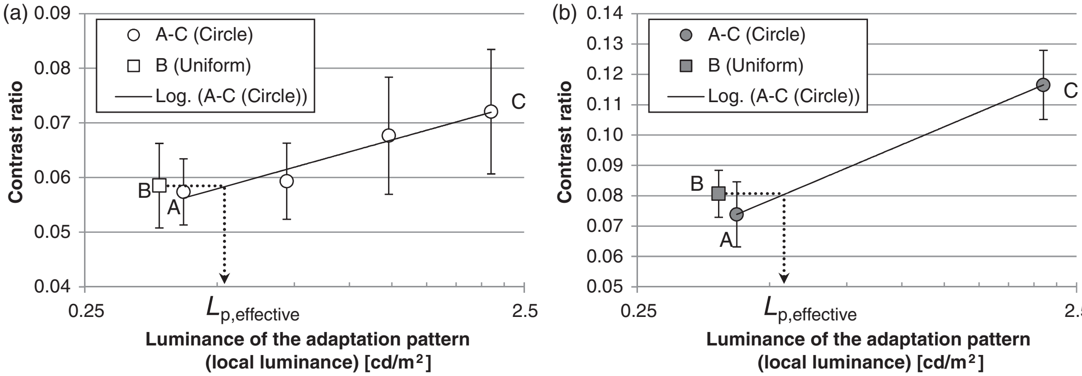

Figure 7 Conceptual diagrams for how to determine the effective adaptation luminance for (a) white and (b) red stimuli. Logarithmic regression lines (solid lines) were determined from thresholds for the circular adaptation pattern (circular symbols.) Using these regression lines, the threshold levels for the uniform adaptation pattern (square symbols) were converted to the effective adaptation luminance $L_{p,effective}$ (arrowed dot line.) The regression line for red stimuli was determined from the detection thresholds for conditions A and C.

with the CIE general disability glare equation,[15]

2) the sum of the photopic local luminance and the veiling luminance calculated with the Stiles–Holladay formula[16] and

3) only the photopic local luminance.

Note that the local luminance is equal to the luminance of the adaptation pattern in the experiments.

In models 1 and 2, the veiling luminance that was caused by the difference image between the uniform adaptation pattern and the circular adaptation pattern was calculated. The difference image was divided into pixels, 0.2505 mm on a side, and then the veiling luminance caused by each pixel was calculated and integrated. The pixels were assumed to be Lambertian sources. In the definition of the veiling luminance equations, angle θ means the angle between the line of sight (fixation point) and a glare source. But, for this analysis, θ was interpreted as the angle between the peripheral task point and a glare source (pixel). The uniform adaptation pattern was assumed to have ideally uniform luminance distribution of $0.42\,cd/m^2$. The luminance of the surrounding part of the circular adaptation pattern was assumed to be $0\,cd/m^2$. For model 2, the veiling luminance for each subject was calculated from each subject's age and eye pigmentation factor, and averaged. The calculated photopic effective adaptation luminance and mesopic luminance are shown in Table 3. The model predictions for the effective adaptation luminance are still lower than the effective adaptation luminance derived from the experimental results. The uncertainty of the effective adaptation luminance is too large to make a firm conclusion, yet this result suggests that the surrounding luminance effect at a peripheral task point is larger than the effect at the fovea based on the CIE general disability glare equation or the Stiles–Holladay formula.

However, for uniform luminance distributions such as the uniform adaptation pattern, the errors related to the models do not prevent us from predicting the mesopic luminance of a target. The errors of the mesopic luminance are at most 0.5% for the white stimuli and 2.8% for the red stimuli. The calculation of the mesopic luminance is not sensitive to the error in the effective adaptation luminance.

Table 3 The photopic effective adaptation luminance and mesopic target luminance calculated from the experimental data and models

Method	Photopic effective adaptation luminance				Mesopic target luminance for $L_{p,t} = 1.0\,cd/m^2$			
	Red		White		Red		White	
	$L_{p,a}$ (cd/m^2)	Error	$L_{p,a}$ (cd/m^2)	Error	$L_{mes,t}$ (cd/m^2)	Error	$L_{mes,t}$ (cd/m^2)	Error
Experiment	0.58	–	0.47	–	0.88	–	1.09	–
1. $L_{local} + L_{veil}$ (CIE glare equation)	0.43	25.8%	0.43	8.6%	0.86	2.6%	1.10	0.4%
2. $L_{local} + L_{veil}$ (Stiles-Holladay)	0.43	25.5%	0.43	8.2%	0.86	2.5%	1.10	0.4%
3. L_{local}	0.42	27.4%	0.42	10.9%	0.85	2.8%	1.10	0.5%

When a lighting scene has high-luminance sources such as luminaires or headlights of oncoming cars, their effects on the adaptation state may significantly affect the mesopic luminance. Some studies also pointed out that the glare models for fovea cannot give sufficient prediction for the peripheral tasks.[22–24] Further experimental research is needed to evaluate such high-luminance source effects on the adaptation state at a peripheral task point.

Let us discuss the definition of the adaptation field based on the local adaptation hypothesis. We suggest that the adaptation field for a lighting scene should take into account: the surrounding luminance effect, which was investigated by the experiment; the task area in the lighting scene and the movement of line of sight. The local adaptation means that the size and shape of the adaptation field depends on the movement of line of sight and the task area. Since those depend on the lighting application, the adaptation field definition is also application dependent.

The point-by-point method, which is adopted in IESNA TM-12-12,[5] seems to be appropriate considering the local adaptation hypothesis. However, it neglects the movement of line of sight, which is probably significant in most lighting scenes. And, for road lighting scenes, the luminance distribution on the road surface moves in the driver's field of view as the car goes forward. Thus, even when the driver's eye movement can be neglected, the projected luminance onto a peripheral point on the retina varies temporally. If the adaptation speed is slower than such luminance temporal change, the adaptation luminance can deviate from the luminance at each point. These points need to be verified for the point-by-point method.

5. Conclusions

Experiments to measure the surrounding luminance effect on adaptation state at a peripheral task point were conducted for possible definition of the adaptation field to implement the mesopic photometry system in lighting applications.

The results showed that the adaptation state on a peripheral task point depends on local luminance mainly. It was suggested that the small effect of the surrounding luminance is larger than the veiling luminance at the fovea. While high-luminance sources may significantly affect the effective adaptation state and the mesopic luminance, when high-luminance sources do not exist in the field of view and the luminance distribution is uniform, the adaptation state can be predicted simply by the local luminance around the task point.

To define the adaptation field for real applications, the movement of line of sight and the task area of the lighting scene should also be taken into account. The point-by-point method in IESNA TM-12-12,[5] which recommends using the local luminance as the adaptation luminance, neglects them. These factors can make the adaptation field have significant area. Because the factors depend on lighting applications, the adaptation field can also vary depending on lighting applications.

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