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Research Article

Luminous Efficiency as a Function of Age and Gender

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Abstract

I report the results of a study that investigated the combined effects of gender and age on luminous efficiency as measured by heterochromatic flicker photometry. Luminous Efficiency functions were derived for 13 male and 14 female color normal subjects between the ages of 8 and 72 years. Three age groups were used for recruitment and analysis: under 18 years (young), 21-45 years (adult) and over 60 years (older adult). Stimuli were 2° circular patches of monochromatic light (420 – 676 nm) presented in Newtonian-view. Each stimulus alternated at 20 Hz and was adjusted by observers to match the brightness of a 3.4 cd/m2 broadband reference patch of equal size. Normalized relative luminous efficiency data were analyzed across wavelengths by multivariate measures analysis of variance with gender and age group as fixed factors. Univariate analyses were repeated for each age group with gender as a fixed factor and again for males and females with age group as a fixed factor. There were no main or interaction effects of gender or age group across wavelengths. Older adult subjects did have significantly lower relative efficiency at low wavelengths (420 and 450 nm). Significant correlations were also found between relative efficiency and age for half of the tested wavelengths. Correlation results were similar when analyzed separately for males and females. These results provide support for requiring age-matched samples in studies of luminous efficiency, particularly for very young subjects. There was, however, little evidence that males differed from females overall or for any age group.

INTRODUCTION

It is a relatively easy task for a viewer to compare the brightness of two lights if the wavelengths of the lights are similar. As the chromatic properties of the two lights increasingly differ, this task becomes more difficult. Small brightness differences can, however, be quantified by photometric techniques such as heterochromatic flicker photometry (HFP). In HFP, light of a particular wavelength temporally alternates at a relatively high rate against a reference monochromatic or broadband light. If the flicker rate is high enough—greater than 7 Hz being suggested by at least one study [1]—stimuli that are perceived as equally bright (within a phase shift) will appear to be nearly continuous.

While measuring HFP at a given wavelength, the greater the light intensity required for minimizing flicker, the less efficient light at that wavelength is at producing a brightness sensation. The efficiency at each wavelength is the reciprocal of the intensity required to match, and the data are normalized by dividing the efficiency at each wavelength by the maximum measured efficiency across all measured wavelengths. These normalized data yield the relative luminous efficiency function, which represents the conversion of light to brightness perception for an individual observer. As it would be impractical to calculate conversions for every individual, these functions have been derived for a so-called standard observer. The most commonly used of these standard functions, CIE V(λ),was introduced in 1924 as the International Commission on Illumination's (CIE) Spectral Luminous Efficiency Function for Photopic Vision [2]. It has often been acknowledged that the 1924 CIE V(λ) function underestimates the contribution of lower wavelengths to an individual's perception of brightness so there have been multiple attempts to improve the function, starting with CIE [3], then by Judd in 1951 [4]. Vos [5] and, more recently, Sharpe et al. [6,7], further developed the functions to be even more consistent with established cone fundamentals.

As previously reported by the author, gender effects on chromatic sensitivity are equivocal [8]. However other authors have reported *age-related* changes in luminous efficiency measured by HFP [9,10]. In this study, our derived relative efficiency functions are grouped by age and gender and qualitatively compared to Judd's 1951 correction to CIE V(λ). Comparisons between mean derived functions are also made to determine if there are quantitative differences by age or gender.

METHODS

Participants

The institutional review board of the University of Missouri–St. Louis approved the experimental protocol which was carried out in accordance with the Code of Ethics of the World Medical

Association (Declaration of Helsinki), and informed consent was obtained from each of the 27 (14 female and 13 male) participants between the ages of 8 and 72 years. Participants were eligible if they self-reported a complete eye examination within the last twelve months, had best-corrected visual acuity of 20/20 or better in each eye and normal color vision as tested with pseudo isochromatic plates and the Medmont C100 color vision screener (Medmont International PTY Ltd., Nunawading, Australia). Three age groups were used for recruitment which, for convenience, are referred to as young (<18 years), adult (21-45 years), and older adult (>60 years) subjects. Refer to Table 1 for the age distribution of participants.

Apparatus

A two-channel optical Newtonian-view system produced a 2° circular field viewed by the right eye of each subject. The output light from a 1000-watt Xenon arc lamp was split into two illumination channels. A motorized, computer-controlled narrow band pass interference filter (NBIF) wheel produced the following 16 wavelengths in the test channel: 420, 450, 480, 500, 510, 520, 532, 540, 550, 560, 568, 580, 600, 620, 650 and 676 nm. The second channel produced a spectrally broad reference patch that was spatially merged with the test channel. The two channels were temporally separated via a remote-controlled mirrored optical chopper rotating at 20 Hz and alternately illuminated optically frosted ends a 0.75-inch acrylic cylinder which served as a diffuse circular viewing screen.

Calibration and data collection

In order to use the filter wheel settings as an indirect measure of luminance, we modeled the angle of rotation of the counter-rotating neutral density filters (in 5° increments from 0° to 360°) to luminance measured with a spectroradiometer (Photo Research Inc., Chatsworth, CA). Luminance modeled to filter settings according to exponential equations with nearly ideal correlations (R^2> 0.99) for all 16 wavelengths.

Each experimental session began by adapting each subject to a background room luminance of approximately 0.4 cd/m^2 for at least five minutes. Participants then practiced the flicker task while the Xenon bulb was allowed to warm up for at least thirty

Table 1: Age distribution of participants.

Age Group	Age Statistics		
	Mean ± S.D.	Range	N
All age groups	33.6 ± 22.4	9 – 72	27
Females	33.4 ± 22.2	9 – 69	14
Males	33.9 ± 23.4	9 – 72	13
<18 yrs	12.9 ± 3.4	9 – 16	10
Females	12.8 ± 3.6	9 – 16	5
Males	13.0 ± 3.7	9 – 16	5
21-45 yrs	30.8 ± 7.8	23-42	10
Females	29.0 ± 8.0	23-42	5
Males	32.6 ± 8.1	23-41	5
>60 yrs	67.1 ± 4.2	61-72	7
Females	64.5 ± 3.4	61-69	4
Males	70.7 ± 1.5	69-72	3

minutes. After this practice period, the reference luminance was adjusted to an upper mesopic light level of 3.4 cd/m^2. This luminance level corresponds to the recommended range for accurate HFP measures [11] while ensuring reliable, uniform cone contributions to neural systems sensitive to brightness [12]. The test channel luminance was adjusted to the same level with the NBIF wheel in the open (broadband) position.

Before each set of trials at a test wavelength, the subject adapted for thirty seconds to the broadband reference stimulus to reduce selective bleaching from the previous narrowband stimulus. This also served to decrease any Purkinje shift in relative sensitivity to lower wavelengths due to low background and room luminance [13].

After adapting to the reference field, participants adjusted the intensity of the test stimulus by rotating the neutral density filter wheel control knob until the flicker sensation was minimized. The setting from the filter wheel controller used to adjust the test (color) intensity was exported to an Excel spreadsheet (Microsoft Corporation, Redmond, WA) and converted into luminance values using the exponential regression equations. The filter wheel setting was then reduced by 50 to 100 degrees, representing approximately 1 to 2 log units of intensity. Three trials were performed in succession for each tested wavelength, and the process was repeated at random for all 16 wavelengths.

Data reduction and analyses

The mean luminance value of the three trials was divided by the maximum measurable luminance at the respective wavelength. The proportion of the maximum luminance at each wavelength provided a percent-transmission that was multiplied by the maximum lamp radiant output (in W/sr-m^2) at each tested wavelength to yield the radiance required for match. The reciprocals of the radiance required to match (or efficiencies) were then divided by the peak efficiency to derive the normalized relative luminous efficiency function for each observer.

These relative luminous efficiency measures were analyzed across wavelengths by multivariate measures analysis of variance with age group and gender as fixed factors (Pillai's Trace statistic reported). Univariate analyses were repeated for each age group with gender as a fixed factor and for each gender with age group as a fixed factor. Lastly, relative efficiency at each wavelength was correlated with age for all subjects as well as for males and females separately. All statistical analyses were performed using SPSS for Windows (SPSS Inc., Chicago, IL) and R (R Programming Language, Free Software Foundation, Boston, MA).

RESULTS

Luminous Efficiency functions

The normalized efficiency functions were derived as described above and used in all analyses. Relative efficiency data were normally distributed overall and for all wavelengths except at 420, 550 and 676 nm. Since peak sensitivity for individuals ranged from 540 – 580 nm, functions—when averaged for comparisons between groups—did not contain a peak at 1.0 as expected for normalized functions. Therefore, for qualitative and

Table 2: Correlation coefficients of luminous efficiency with age of participants.

Wavelength (nm)	HFP Measures		
	$r_{all\ subjects}$	$r_{females}$	r_{males}
420	**-0.48[a]**	**-0.73[a]**	**-0.29**
450	**-0.44[a]**	**-0.31**	**-0.63[a]**
480	**-0.29**	**-0.12**	**-0.49[a]**
500	**-0.18**	**-0.06**	**-0.35**
510	**-0.11**	**0.19**	**-0.37**
520	**-0.07**	**-0.21**	**0.09**
532	**0.41[a]**	**0.45**	**0.37**
540	**0.40[a]**	**0.48[a]**	**0.31**
550	**0.14**	**-0.03**	**0.35**
560	**0.39[a]**	**0.16**	**0.71[a]**
568	**0.38[a]**	**0.47[a]**	**0.28**
580	**0.50[a]**	**0.36**	**0.68[a]**
600	**0.36[a]**	**0.46[a]**	**0.24**
620	**0.12**	**0.04**	**0.20**
650	**0.26**	**0.02**	**0.52[a]**
676	**-0.19**	**-0.29**	**-0.12**

[a]p < 0.05 level

graphical comparisons between groups and with a standardized function, the mean functions were again normalized for each group comparison and plotted in Figures 1-4. Statistical analyses and comparisons, however, were performed on the actual calculated mean functions for each group.

Overall normalized functions

As shown in Figure 1, the normalized function for all subjects shows higher efficiencies to lower wavelengths and is somewhat narrowed overall compared to Judd's correction to CIE (λ).

There was no difference in relative luminous efficiency between males and females (F = 0.375, p = 0.941; Figure 2a). Neither was there an interaction of age and gender (F = 1.98, p = 0.16) nor a main effect of age group (F = 1.07, p = 0.50) across wavelengths (Figure 2b). Older adult subjects were less efficient at the low wavelengths of 420 nm (F = 4.95, p = 0.02) and 450 nm (F = 4.10, p = 0.03) than both young and adult subjects. While it appears that most subjects in each age group had peak sensitivity near 550 nm, very young subjects had significantly decreased sensitivity at 532 nm (F = 3.70, p = 0.04) and 580 nm (F = 5.02, p = 0.02).

Comparisons by gender

Gender comparisons for each age group are shown in Figure 3. There were not enough subjects to perform multivariate ANOVA, but one-way analysis revealed no effect of gender across wavelengths for any age group. It appears that—qualitatively—young males had higher relative sensitivity than young female subjects from 420 – 510 nm, but the only significant effect at any wavelength was at 450 nm (F = 6.55, p = 0.034; Figure 3a). For adult subjects (21-45 years), there was a shift in peak sensitivity from 550 nm to 568 nm for women (Figure 3b). While there were no differences across wavelengths between males and females at any age, functions for men and women over 60 years old were essentially equivalent (F = 0.002, p = 0.967; Figure 3c).

Comparisons by age

Age group comparisons for male and female subjects are shown in Figures 4a and 4b, respectively. For males, there were significant differences among age groups at 450, 560 and 580 nm (Figure 4a). Post-hoc analyses—by least squared differences (LSD)—reveal that young male subjects had significantly lower efficiency at 560 and 580 nm but higher relative efficiency than

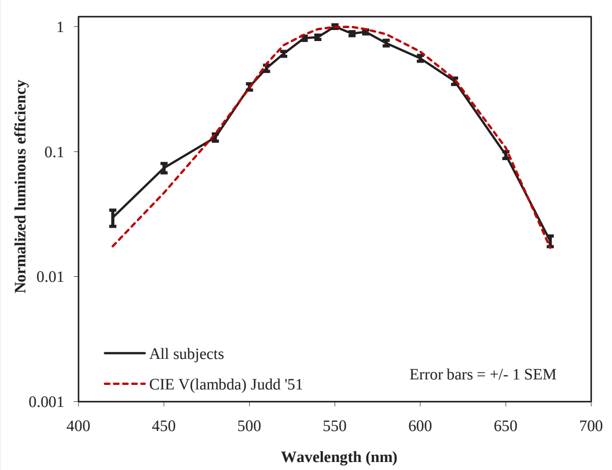

Figure 1 Relative luminous efficiency for all subjects.

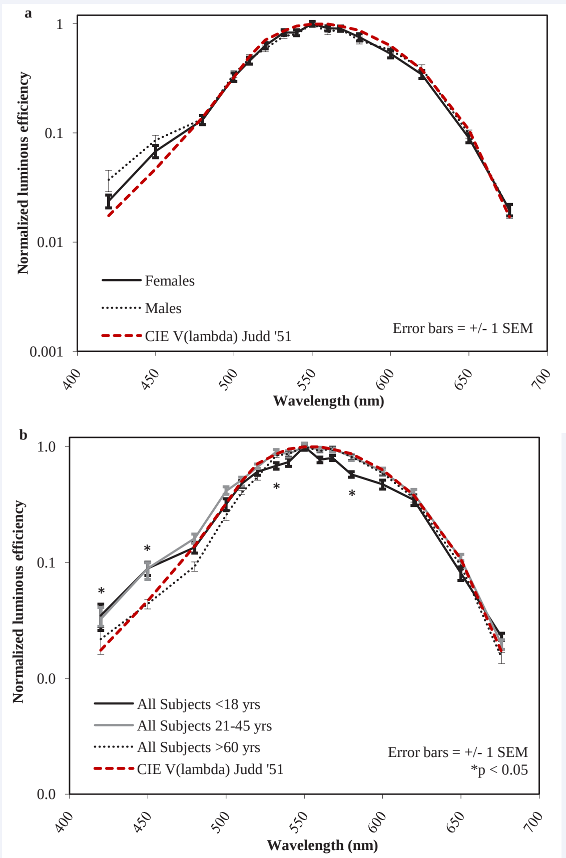

Figure 2 Relative luminous efficiency for all subjects by gender (a) and by age group (b).

older male subjects at 450 nm. The same analysis for female subjects showed that older adult women had significantly lower efficiencies at 420 and 450 nm than both young and adult women (Figure 4b).

Correlations between luminous efficiency and age

It is possible that some resolution was lost when categorizing subjects into young, adult and older adult age groups. Therefore, we examined the linear relationship between relative efficiency at each wavelength and raw age (in years). Overall, our results show a decrease in spectral efficiency with increased age at wavelengths from 420 – 520 nm and an increase with increased age at wavelengths greater than 520 nm (Table 2).

These findings are statistically significant for half (8 out of 16) of our tested wavelengths and are in general agreement with at least two previously published studies [9,10] that showed a significant decrease in HFP efficiency with age at wavelengths from 420 – 500 nm but a significant increase with age in efficiency at wavelengths greater than 560 nm. Correlation results were similar when analyzed separately for males and females, but fewer of these trends (4 of 16 for females, 5 of 16 for males) were statistically significant.

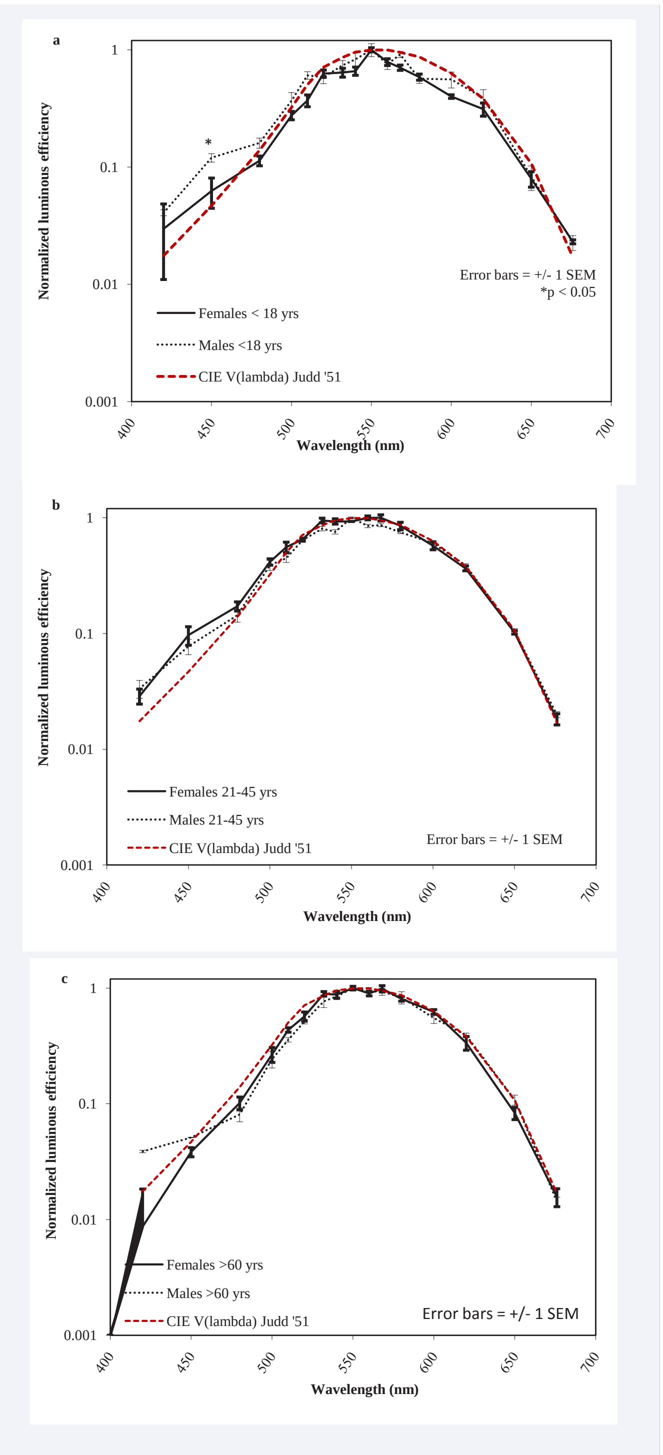

Figure 3 Relative luminous efficiency by gender for (a) young subjects, (b) adult subjects, and (c) older adult subjects.

DISCUSSION

As seen in Figure 1, the normalized function for all subjects showed higher relative efficiencies at lower wavelengths than the Judd-modified CIE curve. This is possibly due to the high proportion (10 of 27) of our subjects who were under 18 years of age. This increased efficiency at lower wavelengths among younger subjects is not surprising as it is due to limited media absorption, a well-established concept in the literature [9,10,14,15].

Narrowed functions in younger subjects

More surprising is the narrowing seen in the overall normalized function (Figure 1). This may also be due to the number of young subjects in our study, as adult data (subjects > 21 years of age) correspond well to the Judd-modified curve when genders are combined (Figure 2b). Figure 2b also shows that young subjects showed an even more narrowed function relative to Judd-modified CIE V(λ) between 520 and 600nm. It is tempting to attribute the shape of the curve to a greater difficulty in very young subjects to adequately perform the HFP task. If this were the case, one would expect to see increased variability in the data for young subjects at all wavelengths. However, the data for young subjects appear no more variable than for adult or older adult subjects.

Another plausible cause is an immaturity of the post-receptor mechanisms that initiate brightness perception for the flickering stimuli used in our experiment. Many studies have suggested that very young subjects (less than 8-10 years of age) might have an immaturity of the magnocellular (M-) system [16-19], the visual pathway tuned for optimal response at the higher flicker rates used in this study. The M-system does show a contrast function that peaks at the flicker rate (20 Hz) used in this study [20-22], and one can see in Figure 5 that the functions in our young subjects are even further narrowed for the four subjects less than 10 years of age (compared to the six 10-17 year-olds).

An alternative to M-system immaturity is the idea of an alternate pathway triggering brightness to wavelengths from 560 – 620 nm in a manner distinct from that of the standard adult observer. This phenomenon has been well-described previously and arises from middle- versus long-wavelength sensitive cone antagonism or subtraction causing a *Sloan notch* (named after Louise Sloan) in spectral efficiency around 580 nm [23-25]. Photopic luminous efficiency curves as measured by HFP are not typically prone to Sloan notches in adult observers, but there is insufficient information to dismiss it as an explanation for the

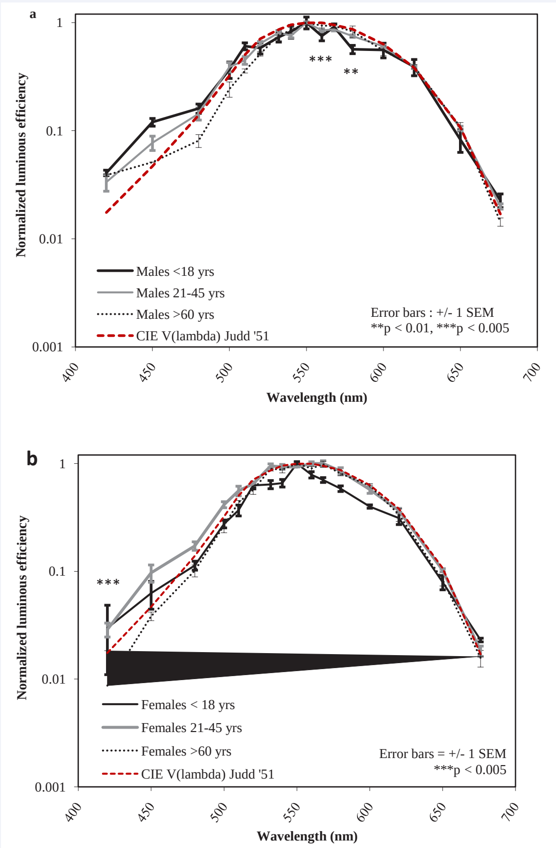

Figure 4 Relative luminous efficiency by age group for (a) male and (b) female subjects.

shape of the functions for young children in this study. Either way, the exact mechanism of this effect deserves further study.

Gender findings

In another study originally designed as a computer HFP simulation, the authors found a significant increase in spectral efficiency in women compared to men for colors representing blue, green, yellow, and red [26]. However, in the current study, the only significant effect of gender was that young (<18-year-old) males had higher efficiency than females at 450 nm (Figure 3a). There was also a qualitative shift in peak sensitivity from 550 to 568 nm for adult female subjects (Figure 3b), but no significant differences in efficiencies between adult men and women. While some studies have shown that shifts in the wavelength positions of unique green are seen in frequency distributions of women but not men [27,28], those studies manipulated subtractive mechanisms (e.g., L-M or S-[L+M]) rather than the additive mechanism manipulated by flicker photometry. Subsequent studies could utilize direct brightness matching techniques to isolate alternative (i.e. parvocellular) color mechanisms to investigate gender differences in chromatic contribution to brightness.

Limitations

Number of subjects: Limitations of this study include relatively few, particularly older (> 60 years of age), subjects. While there were ten subjects in the very young (<18 years of age) and adult (21 – 45 years of age) groups, there were only seven older subjects. While previous benchmark studies of age-related changes in relative spectral efficiency have utilized 50-100 subjects [9,10], their categorical (or *by decade*) analyses contained fewer than 10 subjects in each group. In addition, the derived functions for adult subjects in this study correspond very well with previous photopic standard observer curves.

Mesopic light level: Another issue that could weaken inferences about age or gender-based differences in photopic luminous efficiency is the reference light level used. A background luminance of 3.4 cd/m^2 is technically not in the photopic luminance range and actually represents the upper end of the mesopic (0.03 – 3 cd/m^2) range. There is no such thing as a standard mesopic observer, as rod-cone interactions and post-receptoral processes vary significantly across the mesopic luminance range, and attempts at modeling mesopic luminous efficiency with a simple linear combination of photopic and scotopic functions have proven challenging for the same reasons (see Stockman & Sharpe, 2006, for a more complete discussion [29]). Ikeda & Shimozono proposed the following log-linear combination of photopic and scotopic functions: $\log S_{mes}(\lambda) = a \log S_R(\lambda) + b \log S_A(\lambda) + c$, where $S_{mes}(\lambda)$ is the theoretical calculated mesopic efficiency, $S_R(\lambda)$ is the measured luminous efficiency function at the reference level, $S_A(\lambda)$ is the measured luminous efficiency at the adaptation luminance level, and *a*, *b*, and *c* are dimensionless regression coefficients [30]. Yaguchi & Ikeda [31] later applied this(Ikeda-Shimozono) formula in deriving luminosity curves and found that for the adaptation and reference levels (3.4 cd/m^2) used in this study, *a* and *b* would be very close to 1 and 0, respectively, indicating that mesopic luminous efficiency can be approximated, within a constant term, as the derived function collected at 3.4 cd/m^2.

Other authors have proposed a simple linear combination of photopic and scotopic efficiency [32]. In this model, mesopic luminous efficiency can be modeled as: $V_{mes}(\lambda) = x\, V(\lambda) + (1 - x)\, V'(\lambda)$, where $V(\lambda)$ is the 1924 CIE photopic luminous efficiency function, $V'(\lambda)$ is the 1951 CIE scotopic luminous efficiency function, and *x* is a dimensionless adaptation coefficient that depends on mesopic reference luminance and reaction time. At least one group applying this model using 2° stimuli [33], has

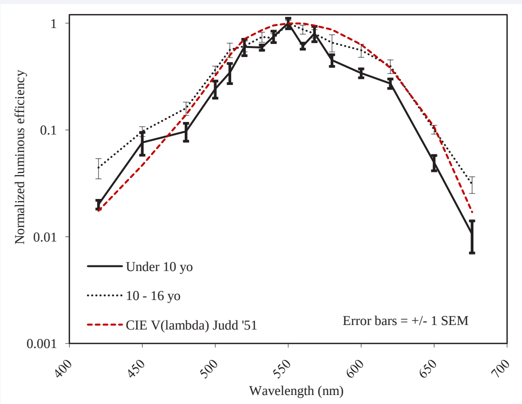

Figure 5 Relative luminous efficiencyfor very young subjects.

demonstrated that x approaches unity—and $1–x$ approaches zero—at the luminance level (3.4 cd/m^2) used in this study. Based on these results, it is therefore reasonable and appropriate to compare the derived functions in this study with photopic luminous efficiency functions for standard observers.

CONCLUSIONS

These results provide further support for requiring using age-matched samples in studies of luminous efficiency. In particular, very young subjects (less than 10 years of age) appeared to have narrowed functions which may be owed due to an immaturity in or an alternate process to the magnocellular visual pathway. There was, however, little evidence that males differed in relative luminous efficiency from females overall or for any age group.

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REFERENCES

1. Ikeda M, Shimozono H. Luminous Efficiency Functions Determined by Successive Brightness Matching. Journal of the American Optical Society. 1978; 68: 1767-1771.
2. CIE. Commission Internationale de l'Eclairage Proceedings, 1924. Cambridge: Cambridge University Press. 1926.
3. CIE. Commission Internationale de l'Eclairage Proceedings, 1931. Cambridge: Cambridge University Press. 1932.
4. Judd DB. Report of U.S. Secretariat Committee on Colorimetry and Artificial Daylight. In Proceedings of the Twelfth Session of the CIE, Stockholm. Paris: Bureau Central de la CIE. 1951; 1: 11.
5. Vos JJ. Colorimetric and photometric properties of a 2-deg fundamental observer. Color Research and Application. 1978; 3: 125-128.
6. Sharpe LT, Stockman A, Jagla W, Jägle H. A luminous efficiency function, V*(λ), for daylight adaptation. Journal of Vision. 2005; 5: 948-968.
7. Sharpe LT, Stockman A, Jagla W, Jägle H. A luminous efficiency function, V*(λ), for daylight adaptation: a correction. Color Research & Application. 2011; 36: 42-46.
8. Foutch BK, Peck CK. Gender Differences in Contrast Thresholds Measured by a Saturation Task. JSM Ophthalmol. 2013; 1: 1008.
9. Kraft JM, Werner JS. Spectral efficiency across the life span: flicker photometry and brightness matching. J Opt Soc Am A Opt Image Sci Vis. 1994; 11: 1213-1221.
10. Sagawa K, Takahashi Y. Spectral luminous efficiency as a function of age. J Opt Soc Am A. 2001; 18: 2659-2667.
11. deVries H. The heredity of the relative number of red and green receptors in the human eye. Genetica. 1949; 24: 199-212.
12. Lee B, Martin P, Valberg A. The physiological basis of heterochromatic flicker photometry demonstrated in the ganglion cells of the macaque retina. J Physiol. 1988; 404: 340-361.
13. Hough E, Ruddick K. The Purkinje Shift. Vision Res. 1969; 9: 313-315.
14. Said F, Wesle R. The variation with age of the spectral transmissivity of the living human crystalline lens. Gerontologia. 1959; 3: 213-231.
15. Norren D, Vos J. Spectral transmission of the human ocular media. Vision Res. 1974; 8: 1237-1234.
16. Barnard N, Crewther SG, Crewther D. Development of a Magnocellular Function in Good and Poor Primary School-Age Readers. Optom Vis Sci. 1998; 75: 62-68.
17. Crognale MA. Development, maturation, and aging of chromatic visual pathways: VEP results. J Vis. 2002; 2: 438-450.
18. Sperling AJ, Lu ZL, Manis FR, Seidenberg MS. Selective magnocellular deficits in dyslexia: a "phantom contour" study. Neuropsychologia. 2003; 41: 1422-1429.
19. Sperling AJ, Lu ZL, Manis FR, Seidenberg MS. Motion perception deficits and reading impairment. Psychol Sci. 2006; 17: 1047-1053.
20. Livingstone M, Hubel D. Psychophysical evidence for separate channels for the perception of form, color, movement, and depth. J Neurosci. 1987; 7: 3416-3468.
21. Bassi CJ, Lehmkuhle S. Clinical implications of parallel visual pathways. J Am Optom Assoc. 1990; 61: 98-110.
22. Derrington A, Lennie P. Spatial and temporal contrast sensitivities of neurones in lateral geniculate nucleus of macaque. J Physiol. 1984; 357: 219-240.
23. Calkins DJ, Thornton JE, Pugh EN. Monochromatism determined at a long-wavelength/middle-wavelength cone-antagonistic locus. Vision Res. 1992; 32: 2349-2367.
24. Miyahara E, Pokorny J, Smith VC, Szewczyk E, McCartin J, Caldwell K, et al. Computerized color-vision test based upon postreceptoral channel sensitivities. Vis Neurosci. 2004; 21: 465-469.
25. Schwartz S. Pulse-duration threshold functions obtained at the MWS/LWS cone antagonistic locus. Ophthal Physiol Opt. 2000; 20: 387-390.
26. Foutch BK, Peck CK. Gender Differences in Contrast Thresholds to Biased Stimuli. JSM Ophthalmol. 2013; 1: 1007.
27. Jordan G, Mollon JD. Rayleigh matches and unique green. Vis Res. 1995; 35: 613-620.
28. Volbrecht VJ, Nerger JL, Harlow CE. The Bimodality of Unique Green Revisited. Vis Res. 1997; 37: 407-416.
29. Stockman A, Sharpe LT. Into the twilight zone: the complexities of mesopic vision and luminous efficiency. Ophthal Physiol. 2006; 26: 225-239
30. Ikeda M, Shimozono H. Mesopic luminous-efficiency functions. J Opt Soc Am. 1981; 71: 280-284.
31. Yaguchi H, Ikeda M. Mesopic luminous-efficiency functions for various adapting levels. J Opt Soc Am A. 1984; 1: 120-123.
32. He Y, Bierman A, Rea MS. A system of mesopic photometry. Lighting Res Technol. 1998; 30: 175-181.
33. Szalmas A, Bodrogi P, Sik-Lanyi C. Characterizing luminous efficiency functions for a simulated mesopic night driving taskbased on reaction time. Ophthal Physiol Opt. 2006; 26: 281-287.

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