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Original Article

Use of an Eyeglass-Type Measuring Device to Assess Exposure of the Eye to Light Among Urban Office Workers

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ABSTRACT

Background: Exposure of the eye to light (EEL) has various adverse effects. High-illuminance blue light causes acute disorders of the retina and is a suspected cause of age-related maculopathy. Nighttime blue-light exposure suppresses internal secretion of melatonin, which can cause various conditions. We developed and used an eyeglass-type measuring device (Ray Sensing Glass System: RaySeG) to measure EEL levels during working hours among urban office workers, who constitute a high percentage of the workforce in Japan.

Methods: Time-dependent changes in the individual EEL levels of 39 office workers (classified as sales and deskwork groups) in Tokyo were recorded during working hours for a period of 5 days, after which mean EEL irradiance (mEEL, $\mu W/cm^2$) values for the total waveband and individual wavelength bands were estimated. The intergroup ratio of average mEEL values in the sales and deskwork groups was calculated. mEEL was divided into quartiles to evaluate differences among individuals. The ratios in each quartile were calculated, and the lowest quartile served as reference.

Results: The intergroup mEEL ratios were 4.59 (total), 4.86 (red), 4.18 (green), 4.60 (blue), and 26.5 (ultraviolet). Total mEEL for the two groups was 229 $\mu W/cm^2$ (sales group) and 50.0 $\mu W/cm^2$ (deskwork group). The ratio in the highest quartile of total wavebands was 2.95 in the sales group and 2.22 in the deskwork group.

Conclusions: mEEL levels depend strongly on individual behavior, and interindividual differences were large for both outdoor lighting conditions and relatively homogeneous indoor lighting environments.

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KEYWORDS: exposure assessment, blue light, ultraviolet radiation, visible light, eye

The development of light-emitting diode (LED) and computer technologies has drastically changed our lighting en-

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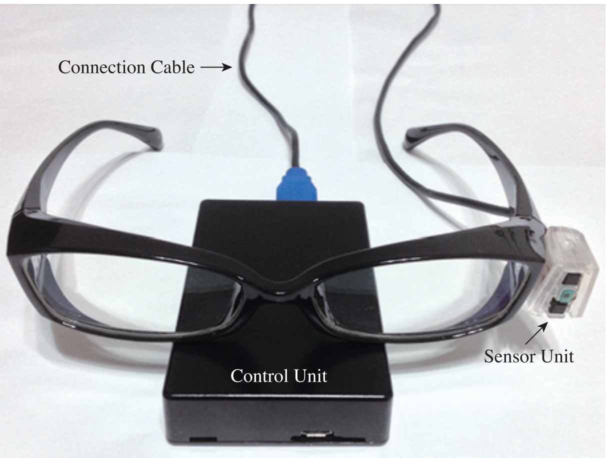

Fig. 1 Photograph of the Ray Sensing Glass System (RaySeG)

The RaySeG consists of two parts—a sensor unit and control unit—which are connected with a thin wire. The sensor unit is fitted to the left temple of the glasses so that the sensor surface is always pointing in the same direction as the face. The size and weight of the control unit are similar to those of portable music players. Sampling is performed at 1 kHz, and data are recorded on a microSD card so that passive and active changes in light energy caused by the weather and participants' individual behavior are reflected in the stored data.

vironment, and these changes should be investigated from the perspective of public health. In premodern times, humans rested their eyes in the darkness of night, but in the modern world it is difficult, even at night, to escape the wide variety of light-emitting devices, such as lighting equipment, televisions, computer displays, and smart phones. The light spectrum of LEDs differs from those of tungsten and fluorescent lamps, particularly as one of the peaks in the LED spectrum is in the blue-light range.

Despite the important roles light plays in the health of the human eye and various biological activities, the quantity and quality of light to which we are exposed in modern daily life have not been fully investigated, and the effects of light on human health are unclear. Although the association between exposure of the eye to light (EEL) and several diseases, including cataract, pterygium, age-related maculopathy (ARM), and circadian rhythm disorder have been reported,[1–9] research in this field is limited. One reason for the lack of studies is the difficulty of accurately measuring the amount and timing of EEL in daily life. Several investigators have developed devices to measure light exposure, but all are designed to be worn on the arm or torso.[10, 11] We have developed an eyeglass-type device, the Ray Sensing Glass System (RaySeG), which directly measures EEL. RaySeG is easy to use, and spectral irradiance (red, green, blue, and ultraviolet bands) to the eye can be measured while the user is wearing the device. Time-dependent changes in light exposure are recorded by a control unit connected to the RaySeG. The accuracy and validity of the device have been reported previously.[12]

Our ultimate goal is to examine the relationship between EEL and health in order to determine how the modern light environment affects human health. To achieve this goal, we are collecting data on EEL levels in people of various occupations, including white-collar workers and workers in primary industries such as agriculture, fishing, and forestry. The difference in EEL levels between white-collar workers and workers in these industries is presumably large, since the former work primarily indoors, while the latter spend much more time outdoors. However, even within a group of workers engaged in the same occupation or sharing the same office, attention needs to be paid to how differences in the tasks and behaviors of individual workers affect their EEL levels. If interindividual differences in EEL levels among such workers are reasonably small, fixed-point measurements of environmental light energy can be used to estimate EEL levels for the entire group. This would limit the need to measure precise levels in individuals with different patterns of behavior.

The purpose of the study was to investigate interindividual differences in EEL among workers engaged in the same occupation. For this, we chose urban office workers, because office work is a common occupation in Japan, accounting for more than 51% of all workers,[13] and because we thought it would be relatively easy to measure EEL levels accurately in people working in relatively homogeneous lighting environments. Accordingly, we measured EEL levels in selected urban office workers during regular working hours and analyzed differences in EEL in relation to the type of work they performed (sales or deskwork) and individual behavior patterns.

Methods

This study was approved by the Ethics Committee of Tokai University (No. 13047). All participants signed an informed consent form that complied with the requirements of the Declaration of Helsinki.

Measuring devices

The RaySeG is shown in Fig. 1. The sensor unit is attached to the left temple of the glasses so that the sensor surface is always pointing in the same direction as the face. Nine participants who wore prescription glasses used a clip-type sensor that could be attached to their own glasses (not shown in Fig. 1). The face and eyes (in primary position) are usually oriented in the same direction, so the sensor makes reliable measurements of light entering the eyes. The sensor unit contains two sensors: a digital color sensor (S9706; Hamamatsu Photonics K.K., Hamamatsu, Japan) and a GaAsP photodiode (G5842; Hamamatsu Photonics K.K.). The color sensor is sensitive to the red (590–720 nm), green (480–600 nm), and blue (400–540 nm) bands, and the GaAsP photodiode is sensitive to the ultraviolet band (260–400 nm).[12] Thus, these two sensors allow detection of the entire spectrum of visible and ultraviolet light entering the eyes. The sensitivity limit is 0.5 μW/cm^2 for the color sensor and 7 μW/cm^2 for the GaAsP photodiode. Values under the detection limits were classified as zero. Sampling was performed at 1 kHz, and data on the passive and active changes in EEL caused by weather and participant behavior were recorded on a microSD card.

Participants

The study participants were 39 urban office workers (34 men and 5 women, age range: 23 to 57 years, average: 40.1 ± 8.6 years). All worked for the same sales company in Tokyo (latitude 35° N, longitude 139° E). Their offices measured 643 m^2 and had a ceiling height of 2.8 m. Each office had windows facing southeast or northwest. Direct sunlight was shut out all day with window shades. Fluorescent lighting was used to illuminate the offices, and the brightness was set at 750 lux or greater, in accordance with Japan Industrial Standards (JIS) recommendations on lighting levels.[13]

The participants were categorized into two groups according to their work as salespeople (n=19) and desk workers (n=20). All participants in the deskwork group basically remained in the office during working hours. The participants in the sales group started work in the same building in the morning, but their work occasionally took them outside during the daytime, where their activities included driving, walking, using public transportation systems, and/or visiting customers. They generally returned to their office before the end of the working day. Detailed information on participants' locations and activities (*i.e.*, use of personal computers, tablet computers, and self-illuminance devices) was not recorded. When a participant made a business trip, the period of the trip was excluded from the observation time, because the participant was exposed to different weather conditions. Periods thus excluded accounted for 7.18% of the whole study period.

Measurement of office workers' exposure to light

EEL was measured over a 5-day period (September 9–13, 2013). The weather was sunny on 2 days and cloudy on 3 days. The measurement period each day was 08:30 to 17:15 (total: 8 hours and 45 minutes), matching the participants' working hours. The participants wore the RaySeG glasses (see Fig. 1) from just before they started work until the end of the measurement period and were asked to keep the RaySeG on during breaks as well as while they were working. They kept the device control unit in a pocket. Whenever a participant removed the RaySeG for any reason, the exact time between removal and replacement was automatically recorded on the microSD card.

Data analysis and statistical methods

Mean EEL irradiance (mEEL, μW/cm^2) was calculated for each participant as follows: mEEL (μW/cm^2)=total amount of EEL irradiance (J/cm^2)/total measurement time (seconds). The intergroup ratio was defined as the ratio of average mEEL values in the sales and deskwork groups. mEEL was divided into quartiles to evaluate differences among individuals. The ratios in each quartile were calculated, and the lowest quartile (Q1) served as reference. The unpaired *t*-test was used to compare the mEEL levels of the sales and deskwork groups. ANOVA and the Dunnett test (multiple comparison procedure) were used to compare mEEL levels in each quartile. Statistical analyses were performed with IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA), and statistical significance was set at a two-sided p value of <0.05 or <0.01.

Results

The participants complied with our directions for wearing the RaySeG for an average of 79.4% of the observation time, which was thus the period for which we obtained valid EEL measurements (Table 1). The difference in compliance between the sales and deskwork groups was not statistically significant (p=0.317, unpaired *t*-test).

mEEL irradiance for total wavebands ranged from 16.4 μW/cm^2 to 473 μW/cm^2 overall (Fig. 2). In the deskwork group it ranged from 16.4 μW/cm^2 to 75.1 μW/cm^2, and in the sales group it ranged from 112 μW/cm^2 to 473 μW/cm^2. Thus, the maximum mEEL irradiance in the deskwork group was lower than the minimum in the sales group. The mEEL in the deskwork group (50.0 ± 15.0 μW/

Table 1 Ray Sensing Glass (RaySeG) wear time, by group

	n	Measurement Time			
		Mean (min)	SD	Minimum	Maximum
Sales group	19	1870	460	959	2410
Deskwork group	20	2020	420	746	2480
All subjects	39	1950	440	746	2480

The difference in RaySeG wear time between groups was not statistically significant (p = 0.317, unpaired *t*-test).
SD: standard deviation

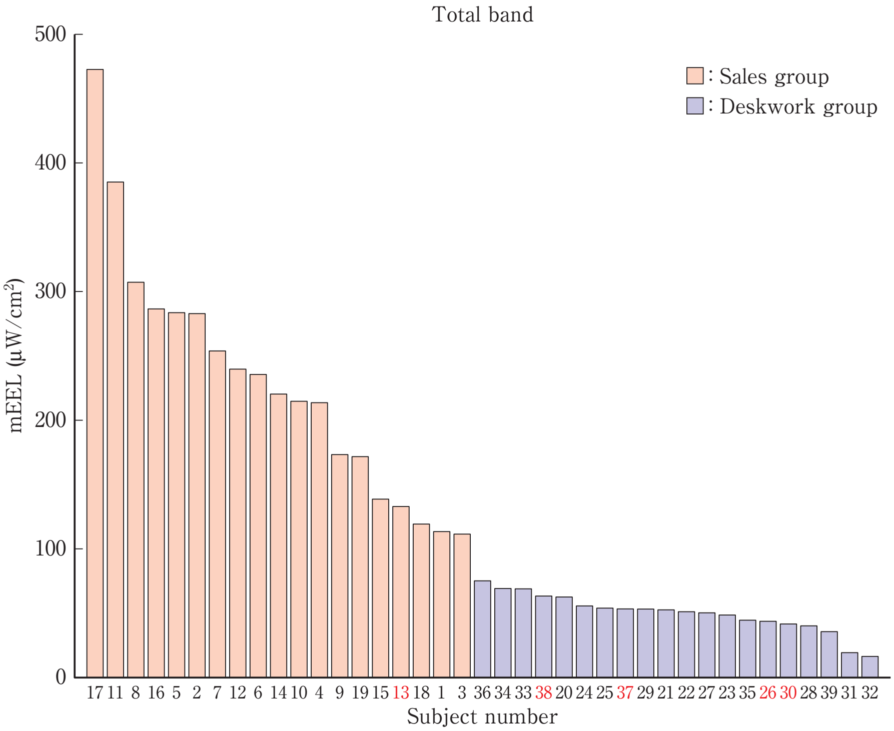

Fig. 2 Mean EEL irradiance (mEEL) (total waveband)
mEEL (μW/cm²) was calculated for the 39 office workers by dividing the sum of all EEL irradiance (J/cm²) by the total measurement time (seconds) for each participant. Female participants are indicated by red numbers on the X-axis.
EEL: exposure of the eye to light

cm²) was significantly lower than that in the sales group (229 ± 95 μW/cm²) ($p < 0.01$, unpaired *t*-test) (Table 2). Fig. 3 shows the mEEL values for both groups subdivided into four color bands (red, green, blue, and ultraviolet). The mEEL in the deskwork group was lower than that in the sales group for all four color bands, with a few exceptions in the ultraviolet band.

The actual mEEL levels in each group are shown in Table 2. The total-bandwave mEEL in the sales group was significantly higher than that in the deskwork group (sales group: 229 μW/cm², *i.e.*, approximately 953 lux in terms of illuminance; deskwork group: 50.0 μW/cm², *i.e.*, approximately 207 lux) ($p < 0.01$, by unpaired *t*-test). The intergroup ratio of average mEEL was 4.59 for the total waveband, 4.86 for the red band, 4.18 for green, 4.60 for blue, and 26.5 for ultraviolet. The large ratio for the ultraviolet band reflected the fact that the deskwork group had extremely low exposure to ultraviolet light.

Table 3 shows the mEEL quartiles in the two groups. The ratio in the highest quartile was 2.95 for the sales

Table 2 Intergroup mean mEEL ratio

	n	Total Mean (μW/cm^2) ± SD	Red Band Mean (μW/cm^2) ± SD	Green Band Mean (μW/cm^2) ± SD	Blue Band Mean (μW/cm^2) ± SD	Ultraviolet Band Mean (μW/cm^2) ± SD
Sales Group	19	**229** ± 95	**52.7** ± 21.3	**87.7** ± 35.2	**82.3** ± 34.3	**6.63** ± 5.66
Deskwork Group	20	**50.0** ± 15.0	**10.8** ± 3.3	**21.0** ± 6.1	**17.9** ± 5.6	**0.248** ± 0.600
Intergroup Ratio		**4.59**	**4.86**	**4.18**	**4.60**	**26.8**
95% CI		1.77-7.81	1.70-8.73	1.62-7.39	1.90-7.44	—

The intergroup ratio was calculated by dividing the Sales Group's mEEL by the Deskwork Group's mEEL
mEEL (μW/cm^2) = total exposure of the eye to light (EEL) irradiance (J/cm^2)/total measurement time (seconds)
The 95% confidence interval (CI) for ultraviolet band mEEL was beyond calculation (0 to infinity).
The unpaired *t*-test showed statistically significant differences between groups for all wavebands ($p < 0.01$).
SD: standard deviation, mEEL: mean EEL irradiance

group and 2.22 for the deskwork group, which indicates that the intragroup difference in mEEL was wider in the sales group than in the deskwork group. The mEEL ratio for the ultraviolet band in the sales group was higher than that for the other color bands, and in contrast to the results for the other color bands, the mEEL ratio for the ultraviolet band in the deskwork group was much higher than that in the sales group. This was probably the result of extremely low ultraviolet exposure (almost none) in Q1.

The four participants with the longest measurement records were selected as representatives of the two groups on September 9, 2013 from 08:30 to 17:15 (cloudy weather): participants No. 11 and 22 were selected as Q1 representatives of the sales and deskwork groups, respectively, and participants No. 9 and 39 were chosen as Q4 representatives, respectively. Time-dependent changes in EEL for these four participants are shown in Fig. 4. The upper two columns in Fig. 4 show time-dependent EEL changes in the sales group, and the lower two columns show the corresponding figures for the deskwork group. The horizontal axis represents time, and the vertical axis represents EEL irradiance. The boxplot shows the EEL irradiance distribution of the red, green, blue, and ultraviolet bands for each of the representative participants. The mEEL for the total waveband was 343 μW/cm^2 for participant No. 11, 108 μW/cm^2 for No. 9, 60.9 μW/cm^2 for No. 22, and 22.1 μW/cm^2 for No. 39. EEL varied with time, especially in the sales group. This result was predicted, because the members of the sales group spent time both in the office and outdoors, including under direct sunlight.

Discussion

In the present study, we used the RaySeG to measure EEL over a relatively long period in urban office workers. RaySeG detects EEL accurately, and the eyeglass design makes it easy for participants to wear. However, the average time the participants actually wore the device accounted for only 79.4% of the total observation time allotted to the study, which was a lower rate than we had expected. The main reason for the slightly low compliance rate was undoubtedly the somewhat odd appearance of the RaySeG, which made participants hesitate to wear it when meeting customers and other people outside the company. The mean measurement time in the sales group was in fact 8% shorter than that in the deskwork group, although this difference was not statistically significant. For future studies, the appearance of the RaySeG should be improved to avoid this problem.

Mohamed et al used a wrist measurement device (Actiwatch-L; Philips Healthcare, Eindhoven, Netherlands) to compare office workers' exposure to light in workplaces with and without windows.[14] They found that average light exposure in the office with windows was 2.6 times that in the office without windows (3.00 ± 0.16 log lux, 1000 lux vs. 2.58 ± 0.55 log lux, 380 lux). In another study, Miller compared exposure to light among nurses working day shifts with other nurses working rotating shifts and found that exposure in the former group was 1.6 times that in the latter (302 lux vs. 188 lux).[15] These reports suggest that environmental factors (*e.g.*, the presence or absence of windows) and differences in individual behavior can result in large variation in EEL levels, even in a relatively low-irradiance indoor environment. In our study, Q4 EEL levels in the deskwork group were more than double Q1 levels. However, this difference cannot be accounted for by exposure through windows, because the windows of the

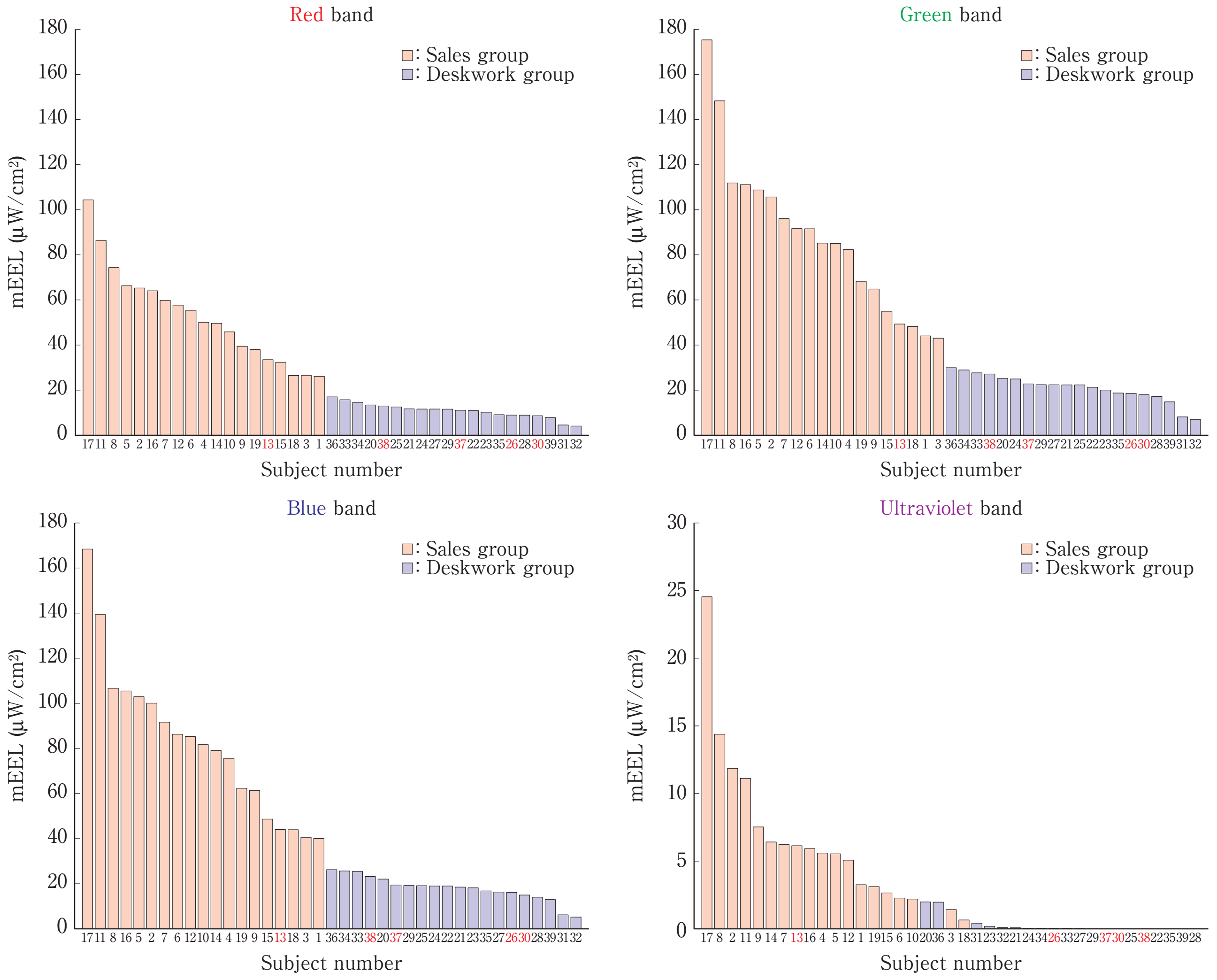

Fig. 3 mEEL (individual wavelength bands)

mEEL for each wavelength band (red, green, blue, ultraviolet) was calculated by dividing the sum of mEEL irradiance for each band by the total measurement time (seconds) for each participant. Female participants are indicated by red numbers on the X-axis.

EEL: exposure of the eye to light, mEEL: mean EEL irradiance

offices occupied by our participants had ultraviolet-protective glass and light-blocking shades. Since direct exposure to sunlight was highly restricted even during daylight hours in the office environment, the short duration of outdoor behaviors drastically changed the amount of ultraviolet band exposure (Fig. 3, participants No. 20 and 36). We conclude, therefore, that the difference was attributable to individual behaviors, such as length of time spent in front of computer monitors or personal preferences regarding the use of desk lamps. Unfortunately, we collected no detailed information on participants' work activities, so future studies should analyze the relationship between EEL and the actual work performed by office workers.

The average mEELs for the visible light bands in the sales group were more than four times those of the deskwork group, and the mEEL for the ultraviolet band was more than 26 times higher for the sales group. Moreover, within the sales group, the Q4 EEL for the visible light bands was three times that of Q1, and Q4 EEL for the ultraviolet band was approximately eight times that of Q1. These findings indicate substantial interindividual differences in behavior among participants working outside the office. Among participants who went outside during daylight hours, EEL irradiance instantly reached several thousand μW/cm^2 in some cases, as shown in Fig. 4. Obviously, outside sunlight is much more intense than lighting inside office buildings, so those who spend long periods outdoors, such as workers in primary industries like agriculture,

Table 3 Intragroup mean mEEL ratio
The lowest quartile (Q1) was used as the reference to calculate the quartile ratio of each group.

Sales Group

		Total Band		Red Band		Green Band		Blue Band		Ultraviolet Band	
	n	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test
Q1	5	123 ± 12 **1.00**	—	29.0 ± 3.6 **1.00**	—	47.9 ± 4.8 **1.00**	—	43.5 ± 3.4 **1.00**	—	1.84 ± 0.80 **1.00**	—
Q2	5	199 ± 24 **1.61**	*	44.6 ± 5.6 **1.54**	*	77.1 ± 9.8 **1.61**	*	72.0 ± 9.5 **1.66**	*	4.52 ± 1.23 **2.46**	N.S.
Q3	5	259 ± 23 **2.10**	**	60.4 ± 4.2 **2.09**	**	98.7 ± 8.0 **2.06**	**	93.2 ± 8.0 **2.15**	**	6.45 ± 0.63 **3.51**	N.S.
Q4	4	363 ± 85 **2.95**	**	82.9 ± 16.6 **2.86**	**	137 ± 31 **2.85**	**	130 ± 30 **2.99**	**	15.5 ± 6.2 **8.41**	*

The ratio for each band was calculated using the lowest quartile (Q1) in each band as reference.
The differences between each quartile and the reference quartile were statistically significant in all wavebands (one-way ANOVA, $p < 0.01$).
SD: standard deviation, NS: not significant, mEEL: mean exposure of the eye to light irradiance

Deskwork Group

		Total Band		Red Band		Green Band		Blue Band		Ultraviolet Band	
	n	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test	Mean (μW/cm^2) ± SD Ratio	Dunnett Test
Q1	5	30.6 ± 11.9 **1.00**	—	6.80 ± 2.31 **1.00**	—	13.0 ± 5.1 **1.00**	—	10.7 ± 4.6 **1.00**	—	0.000097 ± 0.000093 **1.00**	—
Q2	5	47.7 ± 3.3 **1.56**	**	10.0 ± 1.0 **1.48**	*	20.2 ± 1.6 **1.55**	**	17.2 ± 1.1 **1.61**	**	0.0104 ± 0.0130 **108**	N.S.
Q3	5	53.7 ± 1.2 **1.76**	**	11.8 ± 0.4 **1.74**	**	23.0 ± 1.1 **1.76**	**	19.1 ± 0.2 **1.79**	**	0.0503 ± 0.0141 **520**	N.S.
Q4	5	67.8 ± 5.1 **2.22**	**	14.7 ± 1.7 **2.17**	**	27.8 ± 1.8 **2.13**	**	24.5 ± 1.8 **2.29**	**	0.930 ± 0.965 **9615**	*

The ratio for each band was calculated using the lowest quartile (Q1) in each band as reference.
The differences between each quartile and the reference quartile were statistically significant in all wavebands (one-way ANOVA, $p < 0.01$).
SD: standard deviation, NS: not significant, mEEL: mean exposure of the eye to light irradiance

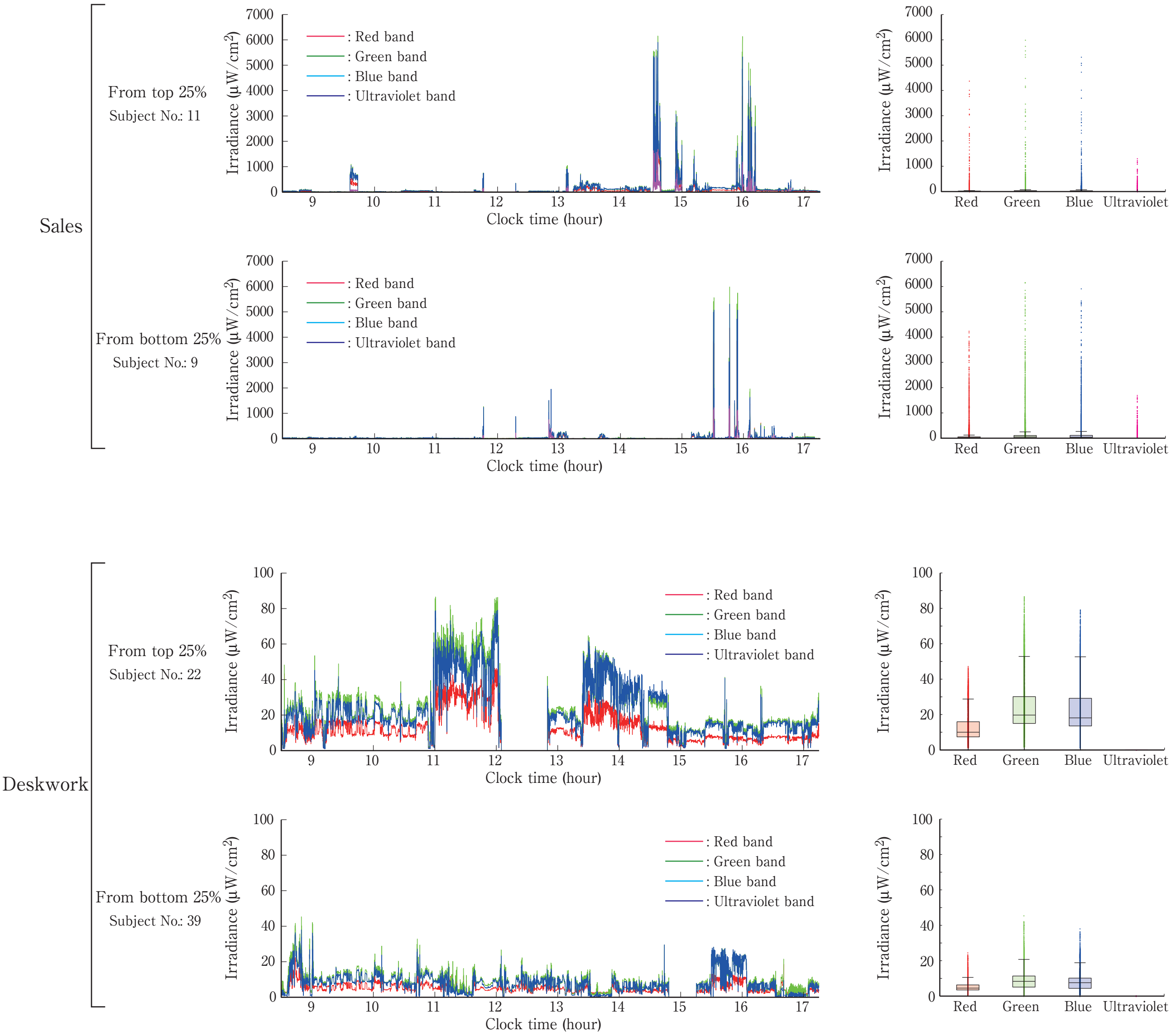

Fig. 4 Time-dependent changes in EEL for four representative participants

Participants No. 11 and 22 were selected as representatives of the highest quartile (Q4) of the sales and deskwork groups, respectively, and participants No. 9 and 39, respectively, were selected to represent the lowest quartile (Q1). The panels on the left show time-dependent changes in EEL for the four participants from 08:30 to 17:15 (cloudy weather); the horizontal axes represent time and the vertical axes show EEL irradiance. The boxplot shows the EEL irradiance distribution of the red, green, blue, and ultraviolet bands for each of the representative participants.

EEL: exposure of the eye to light

fishing, and forestry, are exposed to much higher levels of irradiance than indoor workers. However, EEL still varies widely from person to person.

Fixed-point measurements of environmental light can be used to investigate the relationship between EEL and human health.[16] This method is convenient and less burdensome for study participants. As our study shows, however, variation in EEL levels can be substantial, depending on individual behavior, even in relatively homogeneous lighting environments. Therefore, future studies of the association between EEL and its effects on health should measure EEL levels with careful consideration of individual behavior patterns.

A limitation of this study is that participants wore the RaySeG for an average of only 79.4% of their total working time, which was not as long as we had hoped. We could have obtained more accurate EEL measurements if the participants had worn the device longer. In addition, in our analyses, EEL values under the sensors' detection limits were defined as zero, which means that some of the data may be underestimates. Another possible limitation is that although the RaySeG detects light coming from the direction in which the participant is facing, movements of the eyeballs, pupil size (miosis/mydriasis), and palpebral movements are not taken into account. The effects of these factors, especially retinal exposure, on EEL levels warrant investigation.

The widespread use of self-luminous devices (personal computer [PC] monitors, tablets, smart phones, etc.) has drastically changed the lighting environment in which we live. Recent reports suggest that light-induced oxidative stress is an important factor in ARM, and that even a few lux of very dim light can affect the circadian rhythm and lead to problems such as obesity.[16] It has also been reported that long-term exposure to artificial light (especially white light) at night affects the visual cycle.[17] While our study showed that EEL levels vary greatly in relation to individual behavior, the effects of these varying exposures on individuals' health and biological conditions need further study. We plan to examine such effects and to focus on melatonin secretion. To assess the effects of light on human health, data must be collected on time-dependent changes in EEL as well as total and peak EEL levels in daily life. Thus, we plan to collect data on EEL levels in people working in a wide range of job categories. We believe the RaySeG will be useful in achieving this goal, as it addresses many previous difficulties related to extended measurement of EEL.

In conclusion, EEL levels were strongly associated with individual behavior, and large interindividual differences are found under outdoor and indoor lighting conditions. Studies of the relationship between EEL and human health should consider the effect of individual behavior patterns.

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Conflicts of interest: None declared.

References

1）Youssef PN, Sheibani N, Albert DM. Retinal light toxicity. Eye (Lond). 2011; 25: 1-14.

2）Algvere PV, Marshall J, Seregard S. Age-related maculopathy and the impact of blue light hazard. Acta Ophthalmol Scand. 2006; 84: 4-15.

3）Czeisler CA. Perspective: casting light on sleep deficiency. Nature. 2013; 497: S13.

4）Kolla BP, Auger RR. Jet lag and shift work sleep disorders: how to help reset the internal clock. Cleve Clin J Med. 2011; 78: 675-84.

5）Obayashi K, Saeki K, Iwamoto J, Ikada Y, Kurumatani N. Exposure to light at night and risk of depression in the elderly. J Affective Disord. 2013; 151: 331-6.

6）Megdal SP, Kroenke CH, Laden F, Pukkala E, Schernhammer ES. Night work and breast cancer risk: a systematic review and meta-analysis. Eur J Cancer. 2005; 41: 2023-32.

7）Jia Y, Lu Y, Wu K, Lin Q, Shen W, Zhu M, et al. Does night work increase the risk of breast cancer? A systematic review and meta-analysis of epidemiological studies. Cancer Epidemiol. 2013; 37: 197-206.

8）Kamdar BB, Tergas AI, Mateen FJ, Bhayani NH, Oh J. Night-shift work and risk of breast cancer: a systematic review and meta-analysis. Breast Cancer Res Treat. 2013; 138: 291-301.

9）Van Someren EJ, Kessler A, Mirmiran M, Swaab DF. Indirect bright light improves circadian rest-activity rhythm disturbances in demented patients. Biol Psychiatry. 1997; 41: 955-63.

10）Price L, Khazova M, O'Hagan JB. Performance assessment of commercial circadian personal exposure devices. Lighting Res Technol. 2011; 44: 17-26.

11）Figueiro MG, Overington D. Self-luminous devices and melatonin suppression in adolescents. Lighting Res Technol. 2015; 1477153515584979.

12）Eto N, Tsubota K, Tanaka T, Nishiwaki Y. [Development of a monitor for quantifying personal eye exposure to visible and ultraviolet radiation and its application in epidemiology]. Nihon Eiseigaku Zasshi. 2013; 68: 118-25. Japanese.

13）Japanese Industrial Standards Committee Standards Board, Technical Committee on Electricity Technology. General rules of recommended lighting levels. JIS Z 9110: 2010 (E). Tokyo: Japanese Standards Association; 2010.

14）Boubekri M, Cheung IN, Reid KJ, Wang CH, Zee PC. Impact of windows and daylight exposure on overall health and sleep quality of office workers: a case-control pilot study. J Clin Sleep Med. 2014; 10: 603-11.

15）Miller D, Bierman A, Figueiro M, Schernhammer E, Rea M. Ecological measurements of light exposure, activity, and circadian disruption. Light Res Technol. 2010; 42: 271-84.

16）Obayashi K, Saeki K, Iwamoto J, Okamoto N, Tomioka K, Nezu S, et al. Exposure to light at night, nocturnal urinary melatonin excretion, and obesity/dyslipidemia in the elderly: a cross-sectional analysis of the HEIJO-KYO study. J Clin Endocrinol Metab. 2013; 98: 337-44.

17）Wenzel A, Grimm C, Samardzija M, Remé CE. Molecular mechanisms of light-induced photoreceptor apoptosis and neuroprotection for retinal degeneration. Prog Retin Eye Res. 2005; 24: 275-306.