Report on the Workshop Use and Application of the new CIE s 026/e:2018, Metrology for ipRGC-influenced responses to light "specifying light for its eye-mediated non-visual effects in humans"

Report on the Workshop USE AND APPLICATION OF THE NEW CIE S 026/E:2018, METROLOGY FOR IPRGC-INFLUENCED RESPONSES TO LIGHT "SPECIFYING LIGHT FOR ITS EYE-MEDIATED NON-VISUAL EFFECTS IN HUMANS"

Conveners: Luc Schlangen, NL, Luke Price, GB, David Sliney, US, Manuel Spitschan, GB

In December 2018, the international standard CIE S 026/E:2018 "CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light" (doi.org/10.25039/S026.2018) was published. This standard defines spectral sensitivity functions, quantities and metrics to describe the ability of optical radiation to stimulate each of the five retinal photoreceptor classes that can contribute, via the melanopsin-containing intrinsically-photosensitive retinal ganglion cells (ipRGCs), to the retinally mediated non-visual effects of light in humans. This one-hour workshop started with four 10 minute presentations about the standard, followed by a general discussion and questions. The four presentations focused on the following topics:

1) Introduction to CIE S 026 and its quantities (Luc Schlangen)
2) Demonstration of toolkit (in preparation) to calculate CIE S 026 quantities (Presented by Luc Schlangen on behalf of Luke Price)
3) Accounting for field of view (David Sliney)
4) ipRGCs and pupil response (Manuel Spitschan)

In the first presentation, Luc Schlangen discussed the relevance of the new standard CIE S 026/E:2018 for lighting practice and scientific research: it helps to specify lighting conditions that may promote (or diminish) certain non-visual-responses to light. Moreover, it allows scientists and practitioners to explore whether one can predict non-visual response amplitude from photoreceptor input(s).

CIE S 026/E:2018 defines five spectral weighting functions (e.g. action spectra), $s_\alpha(\lambda)$, for the five retinal photoreceptor classes: S cone, M cone, L cone, rhodopsin and melanopsin-encoded photoreception of ipRGCs. For each of these five (α-opic) photoreceptors an α-opic irradiance (or radiance etc.) can be calculated from the spectral irradiance of a light source, see Table 1. The α-opic irradiance of a light source divided by its illuminance defines the α-opic efficacy of luminous radiation (α-opic ELR) of this source, see Table 1. Moreover, one can also express how much daylight (D65) is needed to achieve a given α-opic irradiance. This quantity is denoted as the α-opic equivalent daylight (D65) illuminance (α-opic EDI), and is expressed in lx, see Table 1. The ratio of the α-opic ELR of a test source to the α-opic ELR of standard daylight (D65) defines the α-opic daylight (D65) efficacy ratio (α-opic DER), see Table 1.

Three different systems are commonly used to physically measure and specify light: the photon system, the radiometric system and the photometric system. Figure 1 shows the quantities and units for various ways to characterize light within these three systems. The corresponding α-opic quantities as defined in CIE S 026/E:2018 are included in the figure.

The informative annex of CIE S 026 discusses various ways to measure (α-opic) irradiance. Some examples are discussed in the workshop (see also David Sliney's presentation below):

- (α-opic) irradiance on a vertical plane (analogous to vertical illuminance)
- (α-opic) irradiance on a vertical half cylinder (analogous to semi cylindrical illuminance)
- (α-opic) irradiance measured with field-of-view restriction (horizontal 180° extent, vertical: +20° to –70° for indoors, and +50° to –70° for outdoors)

Table 1 – Examples of α-opic quantities as defined in CIE S 026/E:2018. The table provides definitions based on irradiance and illuminance. However, also radiance and luminance can be used to define the corresponding α-opic quantities, see Fig. 1.

α-opic quantities in CIE S 026 – some examples

α-opic can be: S-cone-opic (α=sc) M-cone-opic (α=mc); L-cone-opic (α=lc); Rhodopic (α =rh); Melanopic (α=mel)

	Quantity	Formula	Meaning	Unit
	α-opic irradiance	$E_\alpha = \int E_{e,\lambda}(\lambda)\, s_\alpha(\lambda)\, d\lambda$ *α-opic action spectrum*	weighted spectral irradiance, $E_{e,\lambda}$, integrated over wavelength	W·m^{-2}
α-opic ELR	α-opic efficacy of luminous radiation	$K_{\alpha,v} = E_\alpha / E_v$	quotient of α-opic irradiance, E_α, and illuminance, E_v	W·lm^{-1}
α-opic EDI	α-opic equivalent daylight (D65) illuminance	$E_{v,\alpha}^{D65} = E_\alpha / K_{\alpha,v}^{D65}$	Illuminance level of daylight (D65), producing an equal α-opic irradiance, E_α, as the test source	lx
α-opic DER	α-opic daylight (D65) efficacy ratio	$\gamma_{\alpha,v}^{D65} = K_{\alpha,v} / K_{\alpha,v}^{D65}$	ratio of the α-opic ELR of the test source, $K_{\alpha,v}$, to the α-opic ELR of daylight (D65), $K_{\alpha,v}^{D65}$.	-

Practical example

1 lx of standard daylight (D65) has a melanopic irradiance of 1.33 mW/m2

melanopic efficacy of luminous radiation (for D65) = melanopic irradiance/ illuminance

$K_{mel,v}^{D65}$ = 1.33 mW / lm

converting melanopic irradiance ⇒ melanopic equivalent daylight (D65) illuminance (melanopic EDI)

E_{mel} = 1.33 mW/m2 ⇒ melanopic EDI = 1 lx

E_{mel} = 133 mW/m2 ⇒ melanopic EDI = 100 lx

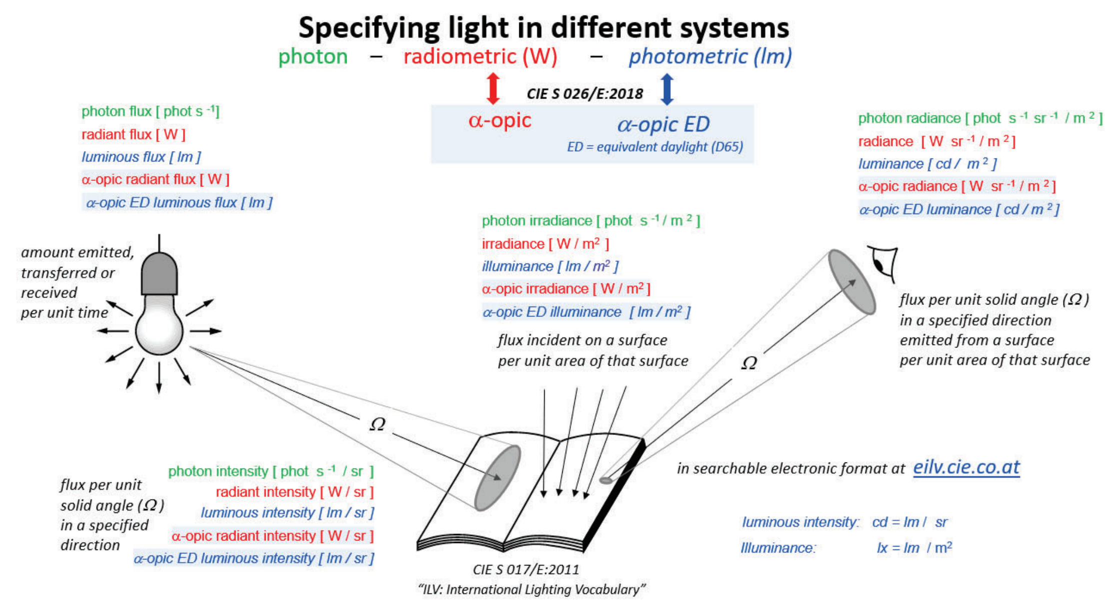


Figure 1 – CIE defined quantities and their units which can specify light in the photon system, the radiometric system and the photometric system. The corresponding α-opic parameters as defined in CIE S 026/E:2018 are also shown.

In the second presentation Luc Schlangen discussed the slides made by Luke Price about the toolbox with CIE S 026 calculations. This toolbox is in preparation and will be published (doi.org/10.25039/S 026.2018) on the CIE webpage of the standard (see above). The main features of the toolbox are:

- CIE S 026 calculations and conversions: weighted and unweighted quantities (see Figure 2), α-opic equivalent daylight (D65) illuminance (α-opic EDI), etc.
- Irradiance or radiance geometry: illuminance or luminance, α-opic equivalent daylight (D65) illuminance or luminance, etc.
- Built-in illuminants: A, D65, E, F11, LED-B3
- User-defined Test spectrum: choice of resolution (1 nm, 2 nm, 4 nm, 5 nm, 8 nm, 10 nm) and SI prefixes (E, P, T, G, M, k, , m, µ, n, p, f, a) / (, c, m)[2]
- Backward compatibility with the CIE TN 003 Toolbox (Lucas et al., Trends in Neuroscience 2014, Toolbox)
- User-defined reference function: enter your own spectrum, or use standard illuminants A, D65, E, F11, LED-B3
- Glossary and spectral weighting charts
- Implementation of age adjustment for α-opic quantities is in consideration, if included the toolbox will always provide standard quantities alongside age-adjusted quantities.

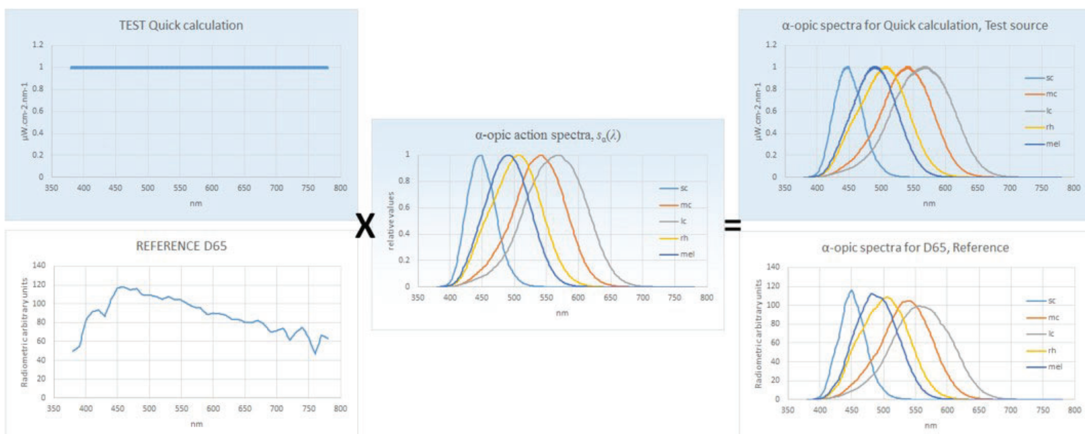


Figure 2 – Example of one of the worksheets within the CIE S 026 toolbox. In this example, the spectral irradiance of an equi-energy spectrum (top left panel) is used as the test source. The bottom left panel gives the spectrum of the D65 reference source. Weighting both these spectra with the α-opic action spectra yields the α-opic spectral irradiance for each spectrum, which, after integration over wavelength, yields the α-opic irradiance (see Table 1).

In the third presentation, David Sliney discussed retinal exposure and spatial aspects of the visual field of view (FoV). Retinal exposure rate (either irradiance or illuminance) can be directly related to the radiance (or luminance) of the object (e.g. light source) being viewed. However, the retinal exposure rate it is not directly related to measured corneal irradiance (or illuminance)! Historically, around 1983, in the early days of light therapy (at a meeting held at NIH, USA), illuminance was applied to quantify retinal exposure for a large, line-of-sight fixed light source. While this is informative for the same type of large source, it can introduce errors and lack of reproducible results when comparing the many different sources/configurations as used in light and lighting research today. Likewise, the α-opic EDI metric, which only adjusts for the spectral characteristics of the α-opic photoreceptor (see Table 1), does not really characterize what light (and spectrum) is really falling on the retina. The upper eyelid plays an important role in how much light reaches the retina, and what parts of the retina are really exposed. The position of the eyelid depends on the brightness of the scene viewed. Outdoors, the eyelids typically restrict the field of view to between +15°-25° and -70° in the vertical direction, while indoors the field of view expands from +45° to -70° in the vertical direction. Also, the area of the pupil aperture (which is highly variable between individuals for a given luminance) determines the amount of light entering the eye. Other factors contributing to interindividual variability of retinal exposure are sun avoidance behaviour, eye-lid opening and lens transmittance. The latter is known to vary with age and latitude. In clinical perimetry, the primary FoV in the vertical direction expands from +40° to -60° only, and in the horizontal direction from 50° nasally to 60° temporally (side). Another point that David thought important related to the relative distribution of the ipRGCs, and he cited recent studies mapping their relative concentration in different retinal locations (ipRGCs were more dense in the inferior retina and Glickman, in J. Biol. Rhythms, 2003, had measured a stronger melatonin suppression when the inferior retina was exposed to light). So what measurements would be most useful? By placing an elliptical cone hood (baffle) over an irradiance/illuminance meter or a digital camera, one can measure a spatially averaged irradiance/illuminance that is integrated over an effective solid angle field-of-view (Ω) using:

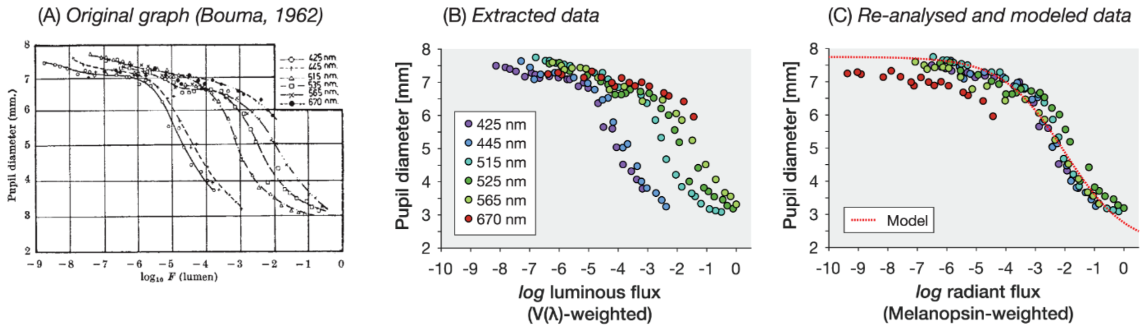
- ~ 3,2 sr (total geometry) for outdoor assessments
- ~ 4,2 sr (total geometry) for indoor assessments

Although the meter should be cosine-corrected within the field-of-view, it is the spatial limits that are the crucial characteristics. Instead of a hooded irradiance/ illuminance meter, one can also consider use of a radiance/luminance meter (set at the largest field-of-view, e.g. 6◦) and move it around the visual scene as to establish a time weighted average radiance/ luminance that effectively represents a spatially averaged radiance/luminance. For simplicity, one can also employ a 1-sr circular hood (~57°) that allows the illuminance reading of lx to have the same numerical value as the luminance in $cd \cdot m^{-2}$ (i.e. $lm \cdot m^{-2} \cdot sr^{-1}$) and move this over the visual field.

In conclusion David mentioned the following points:

- A measurement of overhead sunlight or overhead artificial lighting luminaires is not highly related to retinal illumination, since good lighting design will place luminaires above ~45° so that a bright luminaire is outside the visual FoV.
- Vertical illuminance is a metric that is really only relevant to light boxes within the direct FoV.
- The reflectance of natural or built materials in the lower field-of-view dominates retinal illumination, and for most woods and building materials, the short-wavelength reflectance is low compared to the reflectance at longer visible wavelengths.
- Individuals demonstrate significant variability in upper eye-lid position and pupil size when viewing the same scene out-of-doors, and this needs to be considered in any careful research study.
- Ignoring the viewing/exposure geometry may result in false negative experimental results

In the fourth contribution, Manuel Spitschan discussed how the different photoreceptor classes contribute to the control of the pupil. It is well known that the size of the pupil depends on light level. Steady-state pupil size can be predicted by a unified formula for light adapted pupil size as proposed by Watson and Yellott in J. Vision, 2012 (doi.org/10.1167/12.10.12), though their parametrization relied on luminance, which reflects a combination of L and M cones. However, luminance does not predict pupil size. All photoreceptors (S-cone, M-cone, L-cone, rhodopsin and melanopsin-based photoreception) can drive pupil-responses, but at different time scales. Analysing existing data from Bouma (1962), melanopsin-weighted quantities, in conjunction with the Watson & Yellott's formula, adequately model intensity-dependent pupil size. It is important to realize that also other factors like age, arousal, accommodation and eye movements can also influence pupil size, though light is the strongest driver.



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In the second part of the lecture Manuel explained the principle of univariance formulated by Rushton, which states that photoreceptors cannot distinguish between changes in intensity and changes in wavelength. This principle can be used to generate stimulus conditions to selectively stimulate the different photoreceptors using the method of silent substitution (Spitschan & Woelders 2018, https://www.ncbi.nlm.nih.gov/pubmed/30538662), thereby revealing their temporal contributions.