Public Health England

Protecting and improving the nation's health

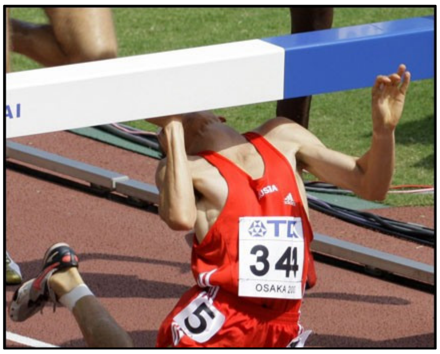
Dosimetry
Making field studies comparable

Luke L. A. Price

Light, health and shift work, Dortmund Workshop, 13 October 2016.

Experiments on people

Trying to running before we can walk …



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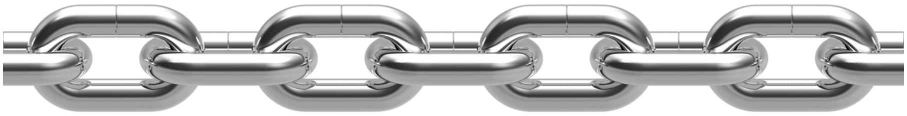
The Dosimetry Chain

Before today

Some investigators have recognised these difficulties, and have attempted to bridge the gap largely independently, often in one stride



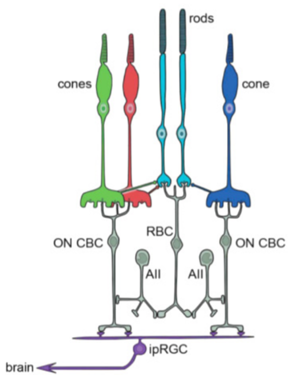
Calibration without agreed standard quantities

Measurements without calibration standards

Metrics without measurement standards

Analysis without appropriate metrics

Responses mediated by ipRGCs



Previously referred to as non-visual or non-image-forming responses
Lucas et al, TINS 37(1), 2014. CIE TN 003:2015.

The Dosimetry Chain (2)

Solutions so far

CIE JTC9 is preparing five standard spectrally-weighted quantities based on the TINS melanopic function and prior CIE work on rods and cones

Generally calibrated spectrometers (380 nm to 780 nm) are already suited to measuring these new quantities

There are no calibration standards for broadband devices, including specialised actigraphic dosimeters

Calibration based on agreed standard quantities

Measurements without calibration standards

Metrics without measurement standards

Analysis without appropriate metrics

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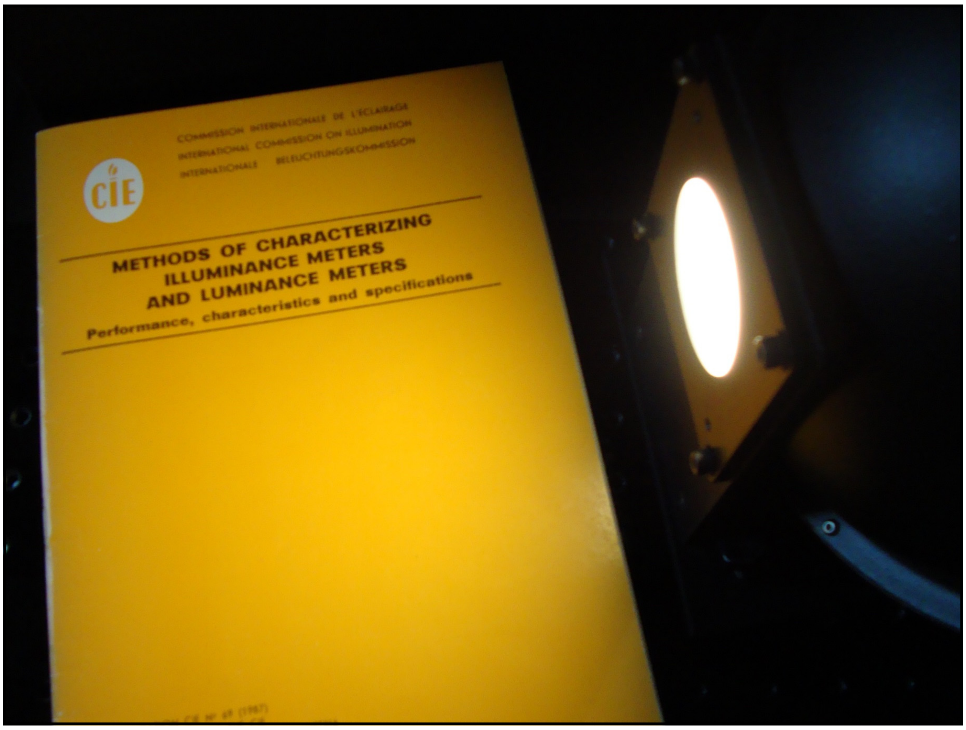

Methods of characterizing circadian light exposure loggers

Spectral response (λ)

Matching 5 photoreceptors *

Angular response (ε)

Cosine errors

Dynamic response (X)

Linear range, accuracy and resolution

Other properties

Time keeping
Motion sensing
Sleep analysis
Memory size
Sampling frequency
Download speed
Temperature
UV and IR responses
*Other optical sensors
Polarization
Dark signal
Device age
Battery age
Warm-up
Fatigue
Durability
Magnetic fields, EMF
Dust and water

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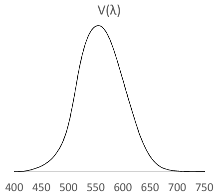
Metrics for illuminance meters

1. Spectral mismatch

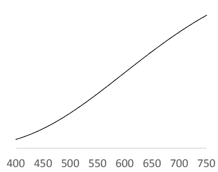
- $Y(\lambda)$ is the response at wavelength λ
- The mismatch is against $V(\lambda)$, the *spectral luminous efficacy function*
- $S(\lambda)_{\mathrm{A}}$ is standard calibration illuminant A, a blackbody with $T = 2856\ \mathrm{K}$



$$f_1' = \frac{\sum_0^\infty |s^*(\lambda)_{\mathrm{rel}} - V(\lambda)|\,\Delta\lambda}{\sum_0^\infty |V(\lambda)|\,\Delta\lambda}$$

$$s^*(\lambda)_{\mathrm{rel}} = s(\lambda)_{\mathrm{rel}} \frac{\sum_0^\infty S(\lambda)_{\mathrm{A}} V(\lambda)\,\Delta\lambda}{\sum_0^\infty S(\lambda)_{\mathrm{A}} s(\lambda)_{\mathrm{rel}}\,\Delta\lambda}$$

$$s(\lambda)_{\mathrm{rel}} = \frac{Y(\lambda)}{Y(\lambda_{\mathrm{ref}})}$$



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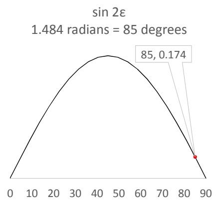
Metrics for illuminance meters

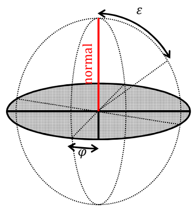
2. Directional mismatch "cosine response error"

- $Y(\varepsilon, \varphi)$ is the response at angle (ε, φ) to 'vertical' or the normal
- The mismatch is against $\cos\varepsilon$ on some axis φ through the normal
- The term $\sin 2\varepsilon$ emphasises off-axis mismatches



$$f_2 = \sum_{0}^{1.484} |f_2(\varepsilon)| \sin 2\varepsilon \, \Delta\varepsilon$$

$$f_2(\varepsilon, \varphi) = \left(\frac{Y(\varepsilon, \varphi)}{Y(0, \varphi)\cos\varepsilon} - 1 \right) \cdot 100\%$$



Metrics for illuminance meters

3. Dynamic mismatch "linearity error"

- $Y(X)$ is the response at illuminance X for a given calibration source
- The mismatch is against the maximum response Y_{limit} in the linear range when the calibration source produces an illuminance of X_{limit} lux.

$$f_3 = f_3(Y)_{\max}$$

$$f_3(Y) = \frac{Y}{Y_{\text{limit}}} \left(\frac{X_{\text{limit}}}{X} - 1 \right) \cdot 100\%$$

- This metric does not work*, and presumably the following is meant

$$f_3 = |f_3(Y)_{\text{corrected}}|_{\max}$$

$$f_3(Y)_{\text{corrected}} = \left(\frac{Y}{Y_{\text{limit}}} \cdot \frac{X_{\text{limit}}}{X} - 1 \right) \cdot 100\%$$

* For $3X = X_{\text{limit}}$ and perfect linearity, $f_3(Y) = 66.7\%$. As required $f_3(Y)_{\text{corrected}} = 0$. There are other alternatives.

Current metrics

f_1', f_2 and f_3 are based on three different principles

$$f_1' \propto \sum \left| r_{\text{output}}^{*} - r_{\text{input}} \right|$$

$$f_2 \propto \sum \left| r_{\text{output}} \cdot r_{\text{input}}^{-1} - 1 \right| \cdot \sin 2\varepsilon$$

$$f_3 = \left| r_{\text{output}} \cdot r_{\text{input}}^{-1} - 1 \right|_{\text{max}}$$

where r are ratios of signals at λ, ε or X compared to maximum input

$r_{\text{input}} = \text{ratio of expected reponses}$
$r_{\text{output}} = \text{ratio of actual reponses}$
$r_{\text{output}}^{*} = \text{ratio of renormalised actual reponses}$

Possible new metrics

The principles of these metrics could be better harmonised (p = proposed)

$${}_{\text{p}}f_1(\lambda) = \big(s(\lambda) - N(\lambda)\big)$$

$${}_{\text{p}}f_2(\varepsilon) = \big(r_{\text{output}} \cdot r_{\text{input}}^{-1} - 1\big)$$

$${}_{\text{p}}f_3(X) = \big(r_{\text{output}} \cdot r_{\text{input}}^{-1} - 1\big)$$

where $\sum s(\lambda) = \sum N(\lambda) = 1$

The final metrics would all take the same form

$${}_{\text{p}}f_i \propto \sum \left| {}_{\text{p}}f_i(a_i) \right| \cdot w_i(a_i) \cdot \Delta a_i$$

where a_i stands for λ, ε and X when i = 1, 2 and 3; $w_i(a_i)$ could be

- a uniform weighting function for λ (effectively the same as using $N(\lambda)$ for $\big(s(\lambda) \cdot N(\lambda)^{-1} - 1\big)$)
- $\sin 2\varepsilon$ for ε and
- relate to the range of the dose-response curve for X

The Dosimetry Chain (3)

The target

Researchers able to compare to interventions, their effects and test alternatives to suggested field measurement protocols and exposure metrics

Agreed dosimetry tools, i.e. the proposed calibration standards with agreed measurement protocols and exposure metrics would support this

The next step after JTC-9 could be a CIE report on methods of characterizing circadian light exposure loggers

Calibration **based on agreed standard quantities**

Measurements **based on calibration standards**

Metrics **based on suggested measurement protocols**

Analysis **based on a suggested exposure metrics**

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Not from our study!

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Initial results

Devices considered

Make, Model	Manufacturer	Performance data
Actigraph (GT3X)	ActiGraph Pensacola, US	Rejected prior to testing due to red casing Specification of underlying sensor used
CamNtech Motionwatch8 (MW8)	Direct loan from CamNtech, Cambridgeshire, UK	Complete protocol
Condor Instruments ActTrust (ATR)	Direct loan from Condor Instruments, Sao Paulo, BR	Complete protocol
Daqtix Daqtometer (DAQ)	Daqtix GmbH, Oetzen, DE Loan from BAuA, Dortmund	Rejecting during testing due to downloading difficulties No other known data available
GeneActiv Original (GAO)	Direct loan Activinsights Ltd, Cambridgeshire, UK	Complete protocol
LRC Dimesimeter (DIME)	No independent loan or purchase terms offered	Data from Figueiro et al, 2013
Actiwatch L (AWL)	No longer on market Loan from Surrey University	Previously unpublished data, Protocol as Price et al 2012.
Philips Actiwatch … 2 (AW2)	Philips Healthcare, Best, NL. Direct loan from UK supplier Linton Instruments, Norfolk, UK.	Complete protocol
… Spectrum (AWS)	Philips Healthcare, Best, NL. Previously purchased	Data from Price et al 2012
… Spectrum Plus / Pro (AWSP)	Philips Healthcare, Best, NL. Direct loan from UK supplier Linton Instruments, Norfolk, UK.	Complete protocol
LRC Daysimeter (DAYS)	Only watches and badges were considered in this study Optical performance protocol is valid for these devices Specification of underlying sensors used	
Lux-Blick (LXB)		
OT Lightwatcher (OTLW)		

Excluded devices

Only some images shown:

Inclusion / **Exclusion** criteria:

- **EITHER chest mountable**
- **OR wrist-worn sleep data**
- **Affordable availability**
- **Independence from supplier**

- **< 7 days' data storage**
- **Not waterproof or wires**
- **Data uploads to cloud**
- **Practical difficulties in use or in getting hold of device**

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Commercial wearable devices

Also see: http://www.slideshare.net/cleverthings/market-review-of-activity-trackers-and-smart-watches-ces-2014
(not an endorsement, but contains a much longer list of these types of devices)

Image compiled from online image searches e.g. "wearable activity trackers"

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Devices tested

The protocol included:

- 2 or 3 watches per model
- 2 cosine errors per sensor
- dynamic range and linearity
- spectral mismatch
- dynamic resolution

The protocol excluded:

- motion sensors
- time-keeping
- temperature dependence, etc.

Initial results presented in confidence

Initial results

Additional slides will be presented:

Spectral, angular and dynamic response and sensor resolution.

Non-linearity

Data best presented graphically (and there is no agreed weighting function)

The range covered is wider than previous published results, but a wider range at both ends would be preferable

For perfect linearity, the blue filled diamonds should be within the red outlines

Resolution

Data best presented graphically

No previous data ever published

The arrows show the response to 100 lux of equi-energy source

The arrows should ideally be far to the right vs the futhest left response

0.7 orders for a 20% error contribution
1.3 for a 5% error contribution

Thank you

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