CIE Division 6:
Photo-biology & -chemistry

Oct 19th, 2015

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Philips Research

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Licht kleurt ons leven.....

zonder licht geen dag, zonder dag geen nacht.

OUTLINE

- CIE D6 - related activities
- Light regulates the body clock & sleep-wake
- Five photoreceptor inputs: standards & regulations
- SSL-erate: EU FP7 project
  - Non-image forming light
  - Light & safety
- Light & elderly

CIE 205 Manchester, some D 6 highlights

- People see dynamic changes in lighting conditions more rapidly when doing a writing task as compared to doing a computer task.
- The perceived whiteness of a room increases when the room becomes less colorful/ more bright and/or has a more blueish color.
- The average luminance in a room alone can't fully determine perception of visual lightness. If the luminance distribution is non-uniform the room can appear more bright but also more dark, this depends on the context.
- Proposal accepted for new JTC "Quantifying ocular radiation input for non-visual photoreceptor stimulation" between D1-3 and 6
- Circadian light sensors on portable devices are poorly calibrated and lack reproducibility between devices. CIE considers to define guidelines for this (D2 and D6)

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Gezondheidsraad briefadvies Gezondheidsrisico's van LEDs, 27 jan 2015 (Aan staatsecretaris van Infrastructuur en Milieu)

positieve en mogelijk negatieve gevolgen van het gebruik van LED verlichting voor de gezondheid.

Positieve effecten gebruik van LED verlichting overdag
-voor het verbeteren van alertheid en functioneren
-voor de toepassing ter verbetering van het functioneren van avondmensen

Negatieve effecten :
-mogelijke effect van LEDs, met een groot aandeel blauw licht, op de biologische klok en slaap bij gebruik 's avonds en 's nachts.

Tevens signaleert de raad dat er onvoldoende bekend is of veevuldige blootstelling aan ledlicht bij kan dragen aan het ontstaan van oogschade. Men pleit voor meer informatie richting publiek over het gebruik van LED verlichting, met name over het gebruik 's avonds en 's nachts, voor de ontwikkeling van producten die minder blauw licht afgeven en voor meer onderzoek naar de gezondheidseffecten van ledlicht.

http://www.gezondheidsraad.nl/sites/default/files/201502_leds.pdf

CIE Division 6 Photobiology and chemistry: TCs

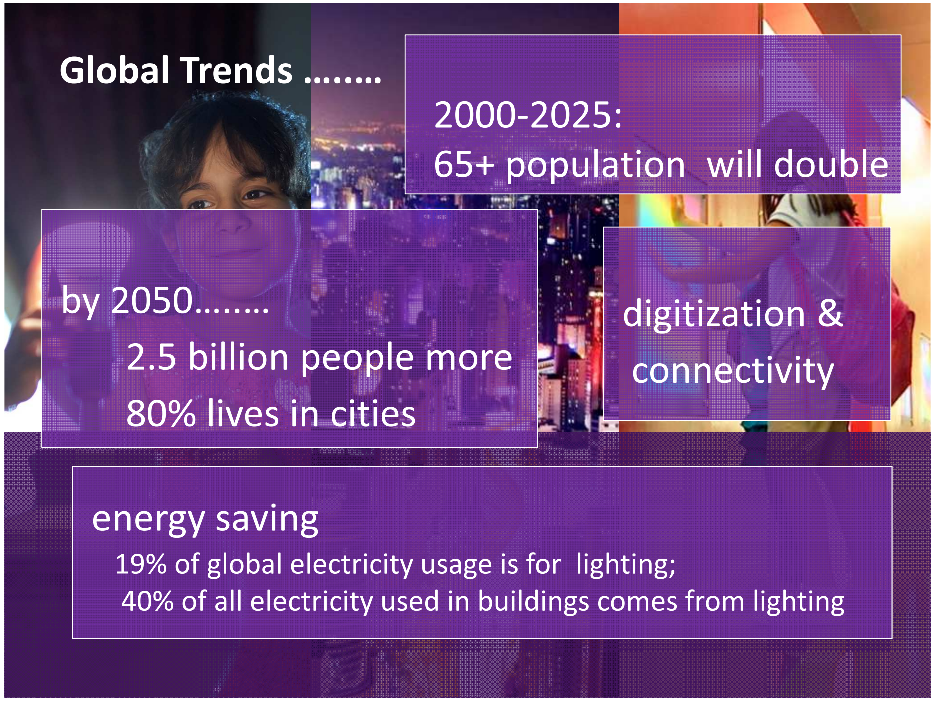
- **TC 6-66**: **Maintaining** summer levels of 25OH **vitamin D** during winter by minimal exposure to artificial UV sources; requirements and weighing the (dis)advantages
- **TC 6-64**: **Optical Safety of Infrared Eye Trackers** Applied for Extended-Duration
- **TC 6-52**: Proper Measurement of **Passive UV Air Disinfection** Sources
- **TC 6-49**: **Infrared Cataract**

CIE Division 6 Photobiology and chemistry: JTCs

- **JTC 4** (D3/D6): Visual, Health, and Environmental **Benefits of Windows in Buildings** during Daylight Hours.
- **JTC 5** (CIE-IEC): **Photobiological Safety of Lamps and Lamp Systems:** working to produce a dual-logo standard to replace CIE S009/IEC 62471.
- **JTC 9** (D1,2,3, 6) : **Quantifying** ocular radiation input for **non-visual photoreceptor stimulation**

Division 6 related activities: CIE, DIN & CEN

- CIE TN DR 6-42 "Report on the First International Workshop on **Circadian and Neurophysiological Photometry**, 2013”
- DIN SPEC 5031-100: “Optical radiation physics and illuminating engineering – Part 100: **Melanopic effects of ocular light** on human beings – Quantities, symbols and action spectra”, revision Aug 2015
- CEN TC169/WG 13 preparing report “**quantifying irradiance for eye-mediated non-image forming effects** of light in humans”
  SI compliance: radiometric iso photometric units.
- CIE TC 3-44**: LIGHTING FOR OLDER PEOPLE** AND PEOPLE WITH LOW VISION: DRAFT
  (includes chapter on Non-visual effect of light)



People spend **90%** of their time indoors.

87% of the sensory information received is from sight,
50% of our brain is used for vision.

On a sunny day people outside get 100 000 lux, on a clouded day 10 000 lux
Indoor in offices people get 500 lux and at school only 300 lux.

Staff costs*, including salaries and benefits, typically account for about*
90% of business operating costs*,* ***energy costs*** *only for* ***1%.***

There is a growing interest in **creating** Healthy Buildings **for occupants.**

The indoor climate in buildings is determined by
Air, **Light**, Temperature, Acoustics and User Control.

Light *is the most powerful regulator of the day-night-rhythm of people, and has the* ***power*** *to energize, relax, increase alertness, cognitive performance and mood.*

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Do we really master light ?

.....too little light in daytime

.....too much light by night

Consequences:

Circadian misentrainment……

Sleep problems……

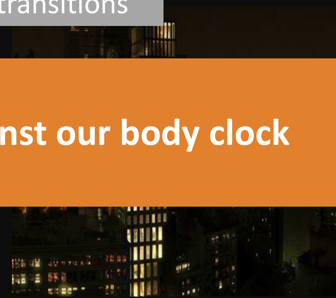
Compromised vision, well-being and functioning….

Mastering light….

…..lots of light in daytime

…..little light by night

use spectral (twilight) transitions



…..to live with and not against our body clock

innovation + you

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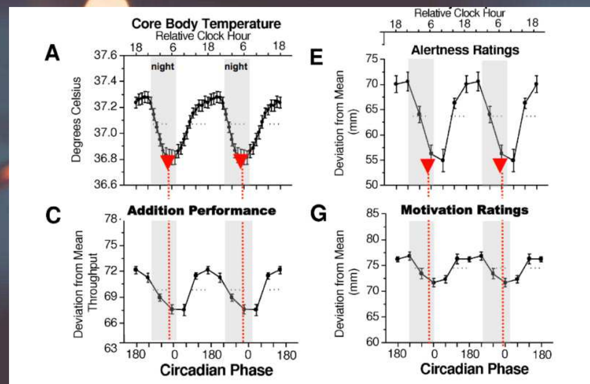
Body clock: performance, alertness and motivation

circadian (24hr) rhythms



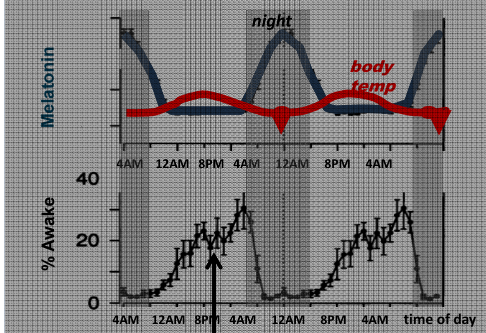
Hull et al, J. Biol. Rhythms 2003

our body clock & it's cycle

"Sleep State"

"Active State"

Melatonin – the hormone of darkness

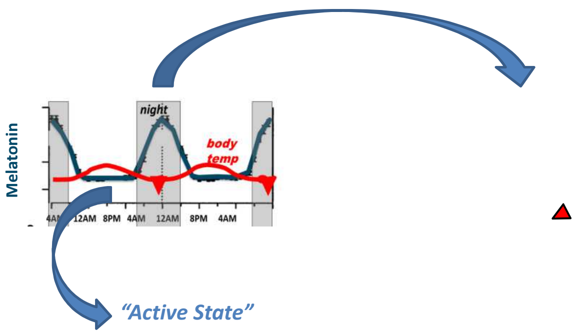


- **Melatonin produced at night only** (during regular sleep time & in darkness)
- **Lowest body temperature during melatonin peak (▼)**
- **Melatonin enables sleep** (consolidation & rapid onset)

Dijk et al., J Physiol (Lond) 1997:851

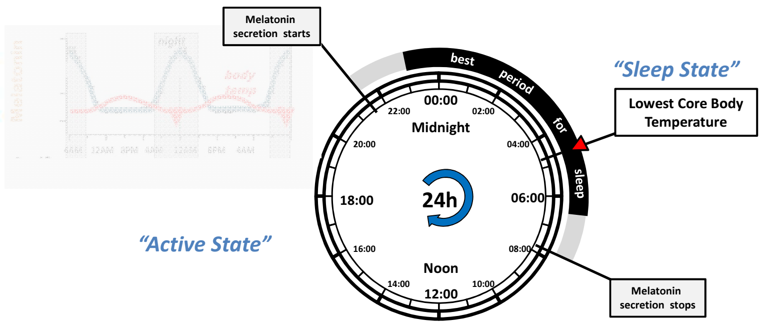
Without melatonin initiating and maintaining sleep is more difficult

our body clock & it's cycle



"Sleep State"

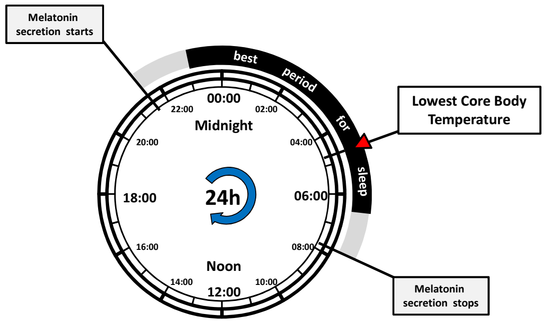
our body clock & it's cycle



Light keeps us on time

Morning light moves "sleep window" counterclockwise

makes us rise earlier (max ~ 1 hr/day)



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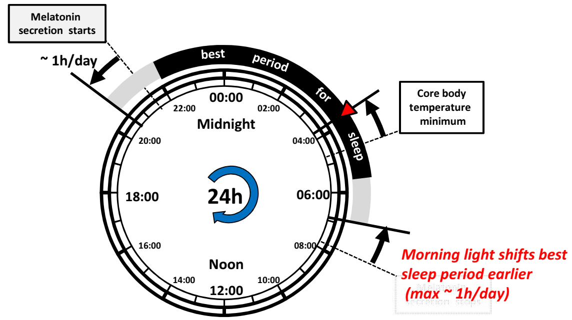
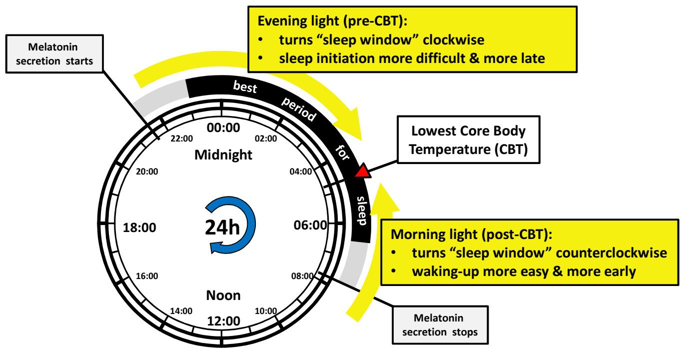


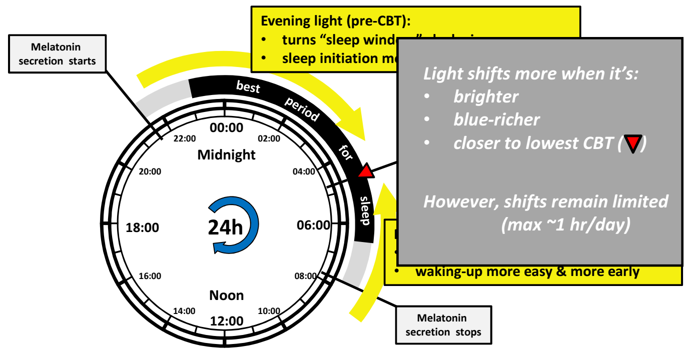
Light keeps us on time

morning light and evening light



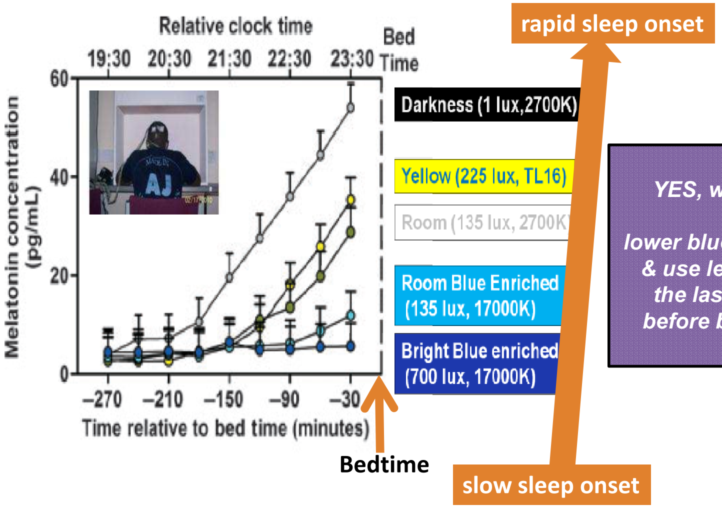
Light keeps us on time

morning light and evening light



Our electric light use in the evening disturbs sleep and delays body clock

Can we make evening light more sleep friendly?



YES, we can:

lower blue-content & use less light the last 2 hrs before bedtime

UNIVERSITY OF SURREY

Santhi et al. *J.Pineal Res. 53 (1):47-59, 2011.*

Sleep-wake disruptions are frequent:

- Night–shift workers & jet-lag
- Teenagers: sleep late, compromised functioning @ 9AM
- Elderly: early bedtimes & wake up, weaker sleep-wake rhythm
- Intensive Care Units: low circadian amplitude & delirium risk
- Neonatal ICU: preterms do better in light-dark cycles vs. constant light
- Psychiatry patients: sleep and circadian rhythm disturbances (late/irregular bedtimes) are frequent and they associate with symptom severity

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What happens when sleep and circadian rhythm are disrupted?

Emotional responses	Cognitive responses	Somatic responses
Fluctuations in mood (Banks and Dinges 2007; Oginska and Pokorski 2006; Scott et al. 2006; Selvi et al. 2007)	Impaired cognitive performance and ability to multi-task (Dinges et al. 1997; Lamond et al. 2007; Pilcher and Huffcutt 1996)	Drowsiness, micro-sleeps and unintended sleep (Basner et al. 2008a, b; Philip and Akerstedt 2006; Pilcher et al. 2000; Scott et al. 2007).
Depression and psychosis (Johnson et al. 2006; Kahn-Greene et al. 2007; Riemann and Voderholzer 2003; Sharma and Mazmanian 2003)	Impaired memory, attention and concentration (Chee and Chuah 2008; Dworak et al. 2007; Goder et al. 2007; Oken et al. 2006)	Bodily sensations of pain and cold (Kundermann et al. 2004; Landis et al. 1998; Roehrs et al. 2006)
Increased irritability, impulsivity and frustration (Dahl and Lewin 2002; Kelman 1999; Muecke 2005)	Impaired communication and decision-making skills (Baranski et al. 2007; Harrison and Horne 2000; Killgore et al. 2006a; Killgore et al. 2007; Lucidi et al. 2006)	Increased risk of cancer (Davis and Mirick 2006; Hansen 2006)
Increased risk-taking (Acheson et al. 2007; McKenna et al. 2007; O'Brien and Mindell 2005; Venkatraman et al. 2007)	Reduced creativity and productivity (Horne 1988; Jones and Harrison 2001; Killgore et al. 2008; Randazzo et al. 1998)	Metabolic abnormalities, cardiovascular disease and diabetes (Gangwisch et al. 2005; Knutson et al. 2007; Laposky et al. 2008; Maemura et al. 2007; Yang and Winkelman 2006; Young and Bray 2007)
Increased stimulant, sedative and alcohol abuse (Baranski and Pigeau 1997; Boivin et al. 2007; Killgore et al. 2006b; Roehrs and Roth 2001a, b)	Impaired motor performance (Kahol et al. 2008; Pilcher and Huffcutt 1996)	Reduced immunity to disease and viral infection (Irwin 2002; Lorton et al. 2006)
	Dissociation (Lynn et al. 2012)	Altered regulation of the HPA axis (Meerlo et al. 2008)

D. Pritchett, K. Wulff, P. L. Oliver, D. M. Bannerman, K. E. Davies, P. J. Harrison, S. N. Peirson, and R. G. Foster.
Evaluating the links between schizophrenia and sleep and circadian rhythm disruption. *J.Neural.Transm., 2012.*

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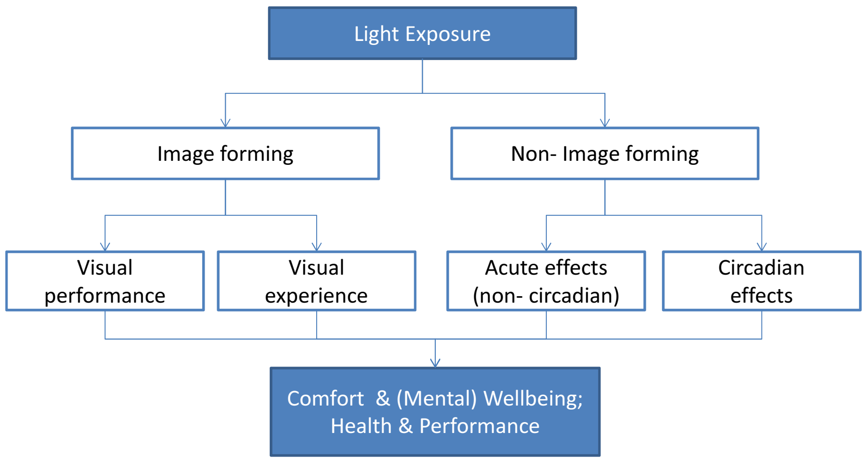
The power of light…..



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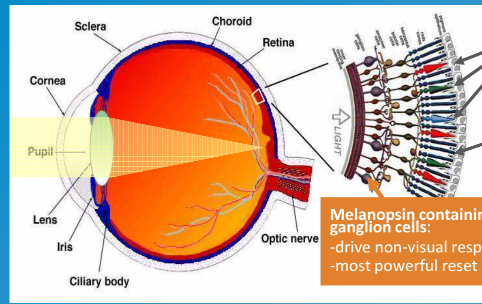
Light to time: photoreceptors (re)set our body clock



Cones (S, M, L) for day/colour vision

Rods for night vision

Melanopsin containing ganglion cells:
-drive non-visual responses
-most powerful reset signal for body clock

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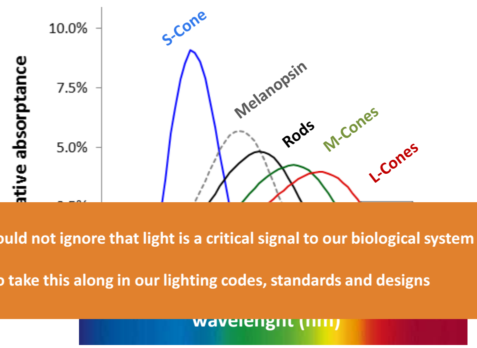
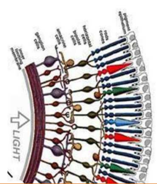
Quantifying light for visual and non-visual effects
use five photoreceptor inputs

Spectral sensitivity curves

Lucas et al., Trends. Neurosci. 2014





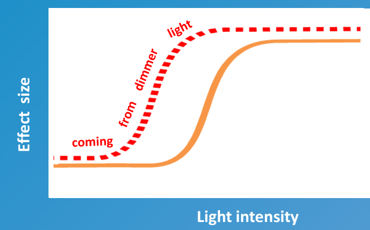
We should not ignore that light is a critical signal to our biological system

Start to take this along in our lighting codes, standards and designs

DOE: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/light_and_health_fs.pdf

Dose-response curves of light: general properties

- More light: larger effect
- Lots of light: saturation
- Coming from dim(mer) light:
  need less light for same response
- More blue-rich: larger effect



Particular effects, particular timings,...different photoreceptor interplay & different spectral sensitivity

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Global standards and regulations in lighting

- Quantifying ocular radiation for non-visual photoreceptor stimulation (CIE JTC9, *starting*)
- Create awareness for Human Centric Lighting via industry associations:
  Lighting Europe (Light4Life), SSL-erate (EU-FP7), DoE, ….
- Recommendations for light for the elderly (50+) and visually impaired (CIE-TC 3.44, *in preparation*)

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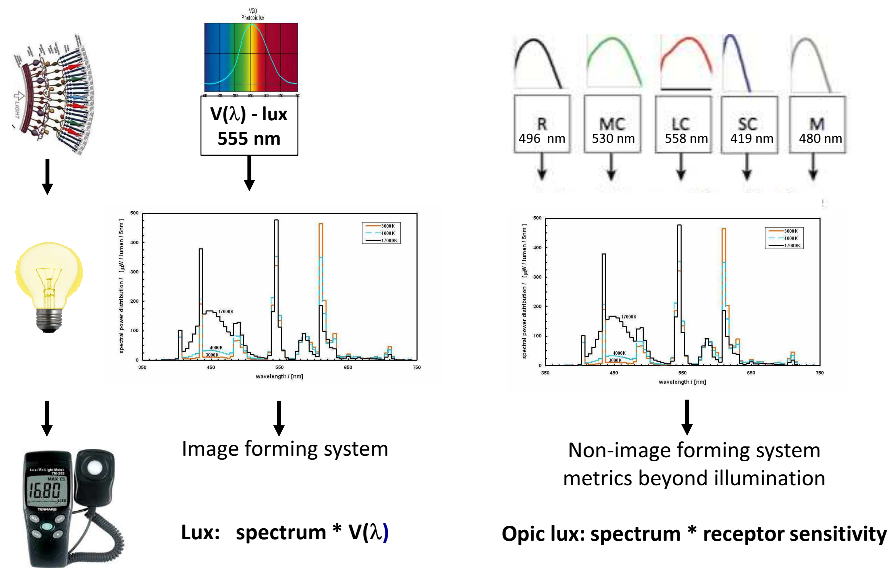
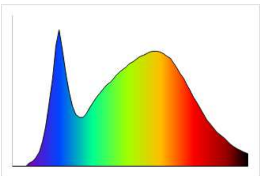
Retinal photoreceptors & their spectral sensitivity



Lucas et al., TINS 2014

Assess five photoreceptor inputs (melanopsin including); first step to quantify light for non-visual responses



Opic-lux	Receptor	λmax
Cyanopic	S cone	419.0
Melanopic	melanopsin	480.0
Rhodopic	Rod	496.3
Chloropic	M cone	530.8
Erythropic	L cone	558.4

How does 1 lux of different light sources activate each of the five photoreceptors?

illuminant	Luminous flux / [lux]	S-cone flux / [Cyanopic-lux]	M-cone flux / [Chloropic –lux]	L-cone flux / [Erythropic -lux]	Melanopsin flux / [melanopic-lux]	Rod flux / [Rhodopic -lux]
D65 sunny sunny cond	1	1.06	1.04	0.99	1.10	1.09
Fluorescent F11 (4000 K)	1	0.64	0.62	0.74	0.89	0.96
Fluorescent 17000 K	1	1.71	1.08	0.98	1.23	1.19
Blue LED (460 nm)	1	15.43	3.42	1.78	10.36	7.20
Red LED (635 nm)	1	0.00	0.33	1.29	0.00	0.02

Lucas et al., Trends. Neurosci. 2014

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People are generally unaware of the potential impact of light on human well-being

We know about the image-forming effects of light
- Visual performance
- Visual experience

But there are also non-image forming effects of light!
- Entrainment biological clock: sync the physio- and psychological processes with the 24h day *(e.g. so that we sleep at night/wake daytime)*
- Acute (direct) effects on mood, cognition, behavior

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lightingforpeople
CONNECTING OPPORTUNITIES FOR INNOVATION

SSL-erate

Human Centric Lighting

Values of lighting beyond energy efficiency

Workplaces, Education, Domestic, Healthcare, Smart Cities

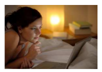
TNO, Lighting Europe (Philips, Osram, SMEs)
Universities: Oxford, Groningen, Munich, Aalto, Basel
…..

http://lightingforpeople.eu/lighting-applications/

Using light for it's non-image forming effects

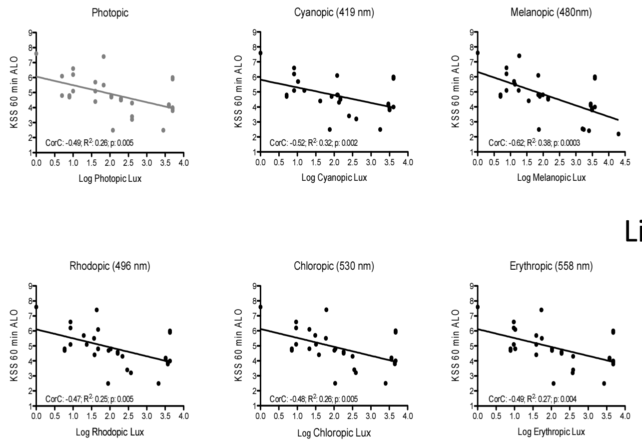
lightingforpeople
CONNECTING OPPORTUNITIES FOR INNOVATION

- Apply light in the early morning and late evening (best sensitivity)
  - In the (early) morning, dawn simulation (in the bedroom): beneficial effects on sleep inertia, daytime well-being and cognitive performance
- Increasing light intensity and more blue-enriched light: alerts (any time of day/night)
  - During ~ first 2 hrs after waking up: prevents body clock from delaying (sleeping and waking later every day)
- Decreasing light intensity and blue content: supports relaxation
  - During ~ last 2 hrs before bedtime: supports sleep (faster sleep-onset, more deep sleep and better sleep quality)
- Light at night must be handled with care, not to disrupt health



Intelligent, dynamic light solutions: simulate dawn and dusk, automated photoperiod of about 12 hours of sufficient brightness and 12 hours of reduced light (relatively dim, blue-deprived light or dark)

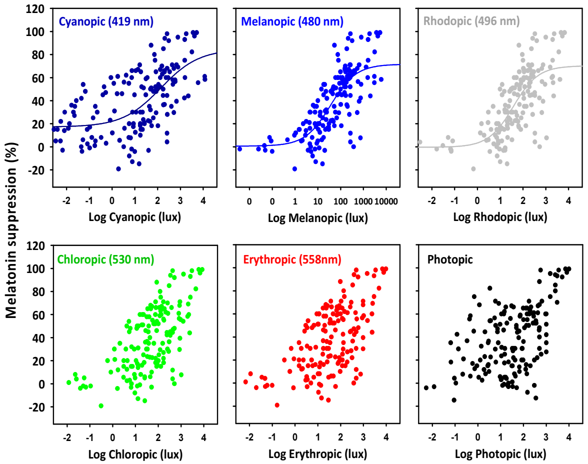
Light dose-response curve: subjective alertness/sleepiness (KSS)



Linear correlation
- ✓ All opsins show a significant correlation
- ✓ Tendency for a stronger relationship with melanopic lux

SSL-erate, preliminary data RUG, M Gimenez

Light dose-response curve: melatonin suppression



Sigmoidal correlation

✓ Best correlation for melanopic and rhodopic opsins

✓ Photopic no correlation!

SSLerate, preliminary data U. Basel, C Cajochen

Preliminary conclusions

- Commonly used standard white light conditions: alpha-opic and photopic irradiances are similar
- Tendency for stronger relationships with melanopic-lux vs photopic lux:
  - especially for studies with narrow spectral bands
  - melatonin data (best quality and range of data)
- Start using alpha-opic irradiances to design narrow spectral band sources and color temperatures to achieve, or avoid, certain NIF responses

Light & Optical Safety

1. **White LEDs are not more hazardous and do not emit more blue light than other lighting technologies that have the same CCT** [1]
   - Photobiological effects of light are related to the spectrum and intensity of light
   - They are not specific to any light source type or technology
   - A higher CCT does necessitate a higher proportion of blue light
2. **White LEDs used in general lighting applications are safe according to current international standards on blue light hazard, they do not cause any acute damage to the human eye** [1, 2, 3, 4]
3. **Light exposure (especially blue rich light exposure) near and during habitual bedtime (late evening and night) can disrupt sleep and the body clock** [5]
   a) Long term disruption of the body clock (jet lag, night shift work) has negative health effects, and is a risk factor for obesity, cardiovascular disease, and breast cancer.
   b) Melanopic flux [6] provides a simplistic way to estimate the potential of light to influence the body clock

[1] DOE fact sheet 2013 : http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/opticalsafety_fact-sheet.pdf
[2] SCENIHR, 2012: Health effects of artificial light, http://ec.europa.eu/health/scientific_committees/emerging/docs/scenihr_o_035.pdf
[3] Non-white light sources (e.g., blue LEDs) & high-risk populations (such as infants or adults with certain types of eye disease) should be considered more carefully, see also [1]
[4] Whether exposure from artificial light could have effects related to age related macular degeneration and other retinal pathologies is uncertain, more high-quality epidemiologic studies are needed, see also [2]
[5] DOE fact sheet "Solid State Lighting: True Colors", October 2014: PNNL-23622
[6] Lucas at al, Trends In Neuroscience, 37(1), p. 1-9, 2014

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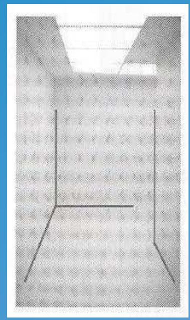
Care Home Lighting: seniors

- Need 3-5 x more light for same task
- high risk of falling / fractures
- highly sensitive to glare & brightness contrasts
- Shades become confusing (avoid small directional light sources)

"Normal"walkway



Edge emphasis

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Study: vary illuminance in simulated office

TEST ROOM (4 p)

Participants:
30yrs & 60yrs
(within subject, n=48)

4000K,
direct & indirect

E_h = 300-2700 lux

E_v/E_h = 0.53

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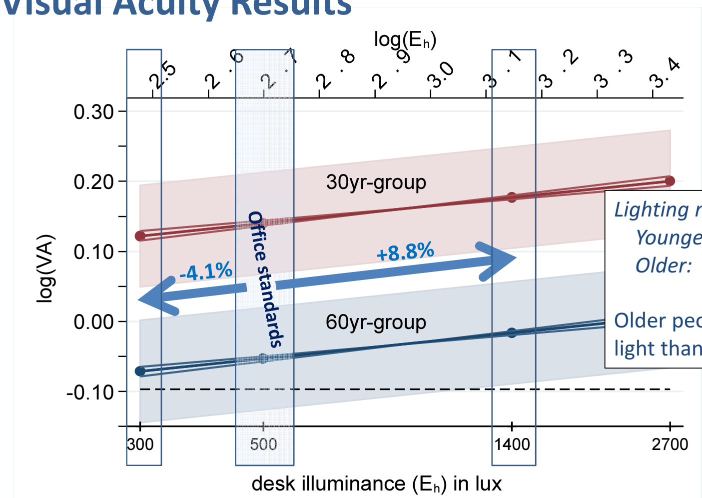
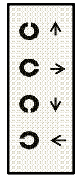
Visual Acuity Results





Lighting most comfortable ?
Younger: 500 lux best
Older: ≥ 1400 lux best

Older people prefer more light than younger people

- Acuity in 60yr group is 36% lower as compared to 30yr group
- 500 to 1400 lux: acuity improves by 8.8% (both age groups)
- 500 to 300 lux: acuity drops by 4.1% (both age groups)

Schlangen et al., Proc. 28th CIE, Vol 1, Part 1, 2015, CIE 216:2015, p. 87-95

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TC 3-44 LIGHTING FOR OLDER PEOPLE AND PEOPLE WITH LOW VISION
DRAFT NO. 2.2, DATE: 2015–4–12

Table 7.2—Visual acuity (at a viewing distance of 1.5 m and a luminance contrast of 0.94) of young, middle aged, and older people as calculated from the luminance by means of Equation 3.2 in Section 3.3.1 and Table 3.2.

Illuminance on the task area E_{task} lux	Luminance (Rewriting Equation 3.6 in Section 3.3.1.) L = Etask * ρ / π ρ = 0,80 cd/m²	VA Young group (~23yrs)	VA Middle aged group (~50yrs)	VA Older group (~71yrs)
1500	382	1.51	1.02	0.75
1000	255	1.45	0.98	0.72
750	191	1.40	0.95	0.70
500	127	1.34	0.91	0.67
300	76	1.27	0.86	0.63
200	51	1.21	0.82	0.60
150	38	1.17	0.79	0.58
100	25	1.11	0.75	0.55
≤50	12	≤1.00	≤0.68	≤0.50

Conclusions

- Light is a critical signal to our biological system: take this along in our lighting codes, standards and designs
  → melanopic input → comfort & well-being
- Make indoor environments more sleep friendly: use 24 hr lighting cycles with enough bright light in daytime & sufficiently dark at night + (twilight) spectral transitions
- Lowering illuminances to 300 lux (energy savings) compromises visual acuity and comfort, especially in elder people. Elder people prefer to have >500 lux