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Trade Show and Conference

How Does Home Lighting Support Health and Well-being?

Mariana G. Figueiro, PhD

Mount Sinai Endowed Professor of Light and Health

Department of Population Health Science and Policy

Director, Light and Health Research Center

Icahn School of Medicine at Mount Sinai

New York, NY

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

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Learning Objectives

At the end of this course, participants will be able to:

1. Understand the human visual, perceptual, and circadian systems and the characteristics of lighting that affect each of these systems
2. Articulate the requirements of commonly used guidelines and recommended practices for the design of healthy lighting
3. Define the process to design lighting that supports human health and wellbeing in residential and commercial spaces

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Acknowledgements

Organizers of the event and…

- National Institute on Aging (R01AG072762, R01AG060716, R01AG062288, R01AG034157)
- National Institute of Diabetes and Digestive and Kidney Diseases (R01DK128972, MPI: Yechoor, Figueiro, Paul)
- National Cancer Institute (R21CA209419, PI: Redd, Co-I, Figueiro; 5R01CA260961, MPI: Valdimarsdottir, Figueiro)
- National Institute for Occupational Safety and Health (1R01OH012543, MPI: Rea, Figueiro)
- Army Research Office
- McClung Foundation
- Swedish Energy Agency
- Michael Richter Family
- General Services Administration
- Office of Naval Research
- U.S. Department of State
- Light for Human Health Partnership
- American Lighting Association
- Lighting Education Partnership

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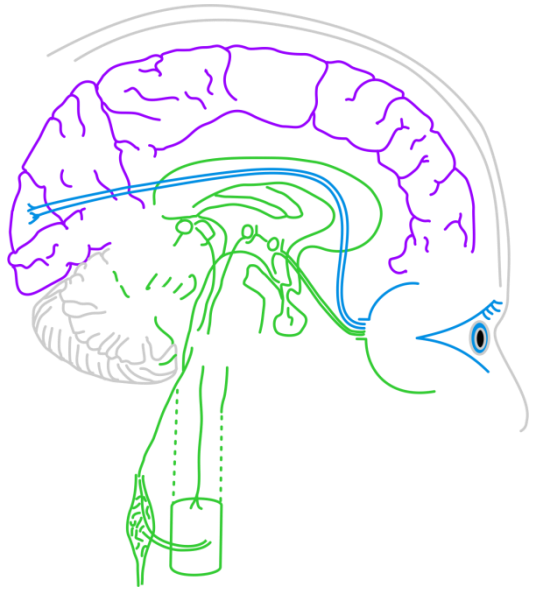
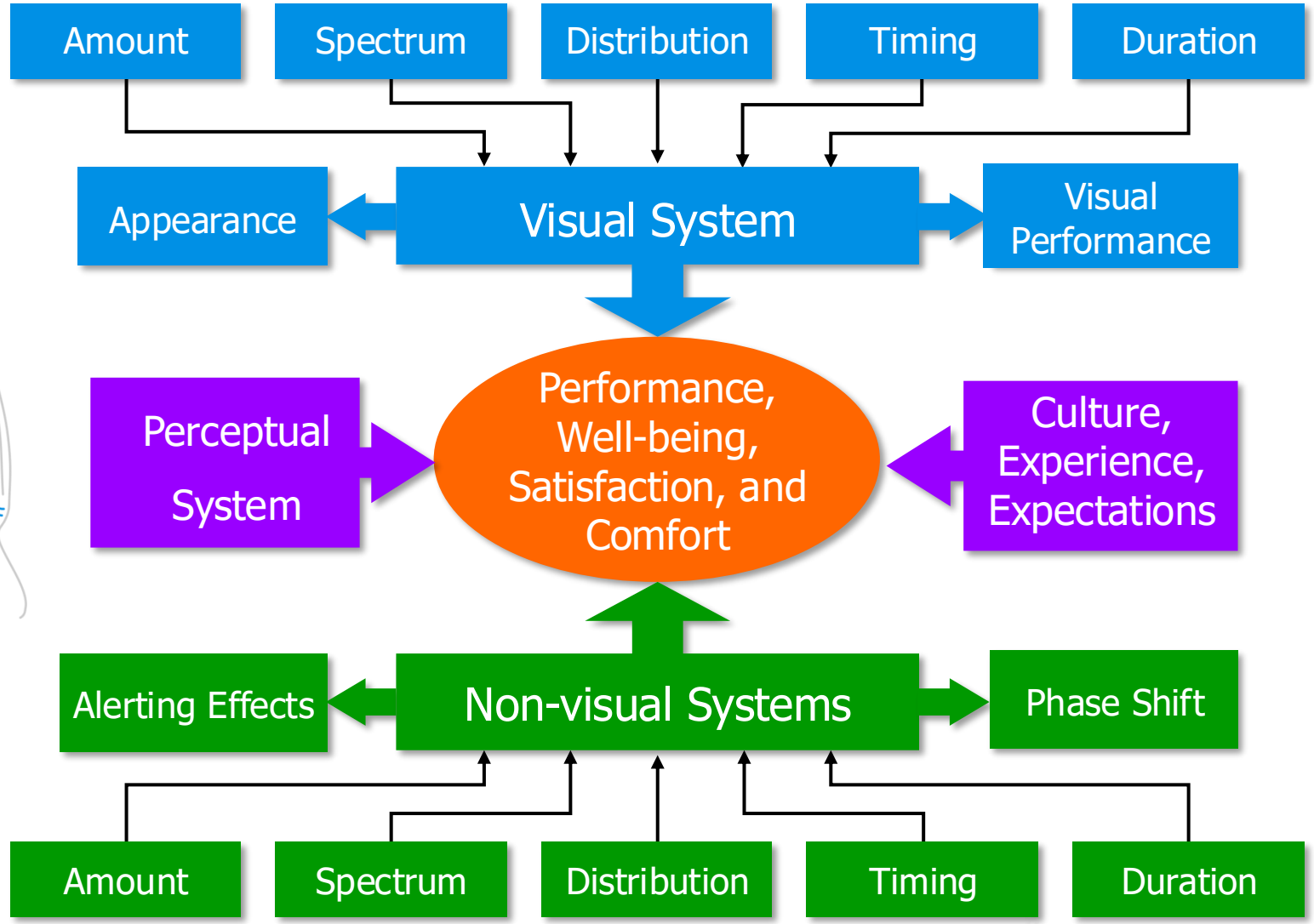
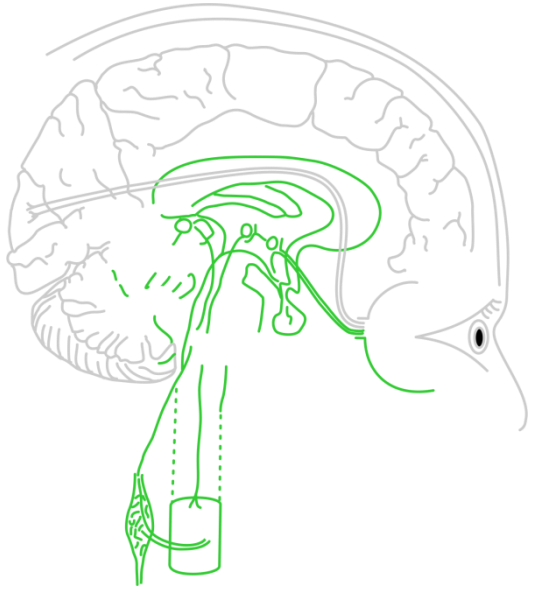
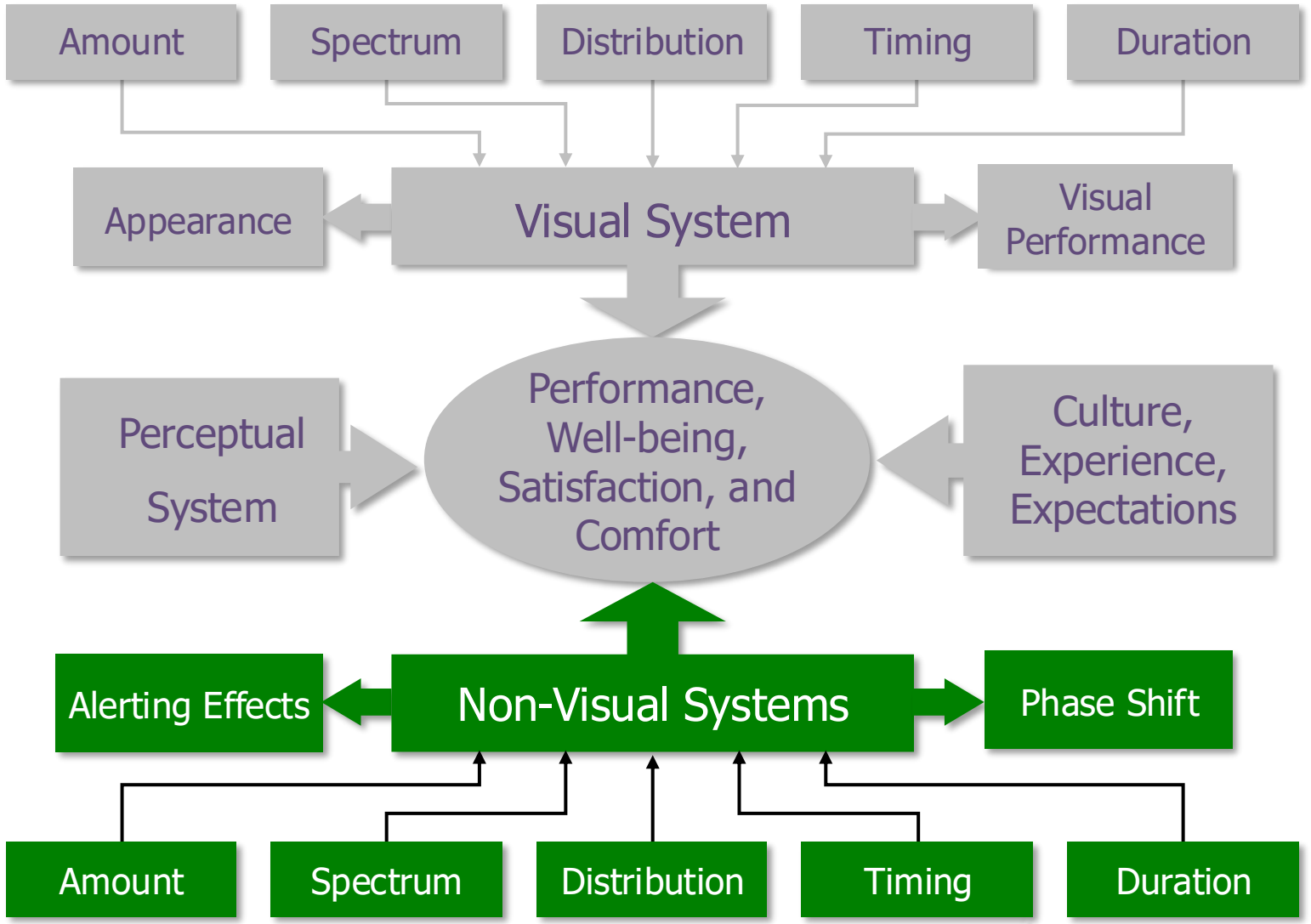
Lighting affects three systems: Visual + non-visual + message





Lighting affects three systems: Non-visual





Premise of our work

- Circadian rhythms are biological processes that display an endogenous (and entrainable) rhythm close to 24 h

  circa = approximately; dies = day

- Circadian rhythms are generated and regulated by a master biological clock in the brain
  - In humans, circadian rhythms free-run with a period slightly greater than 24 h

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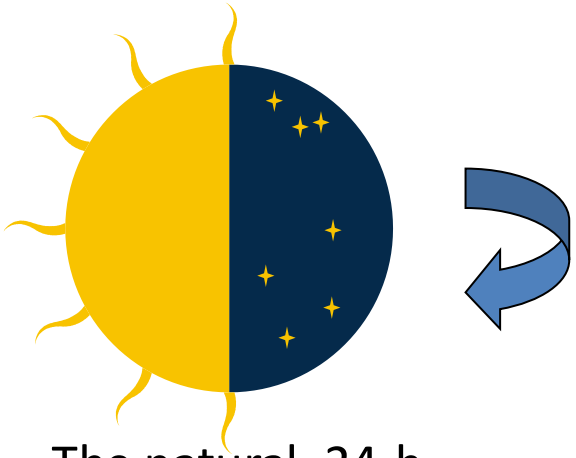
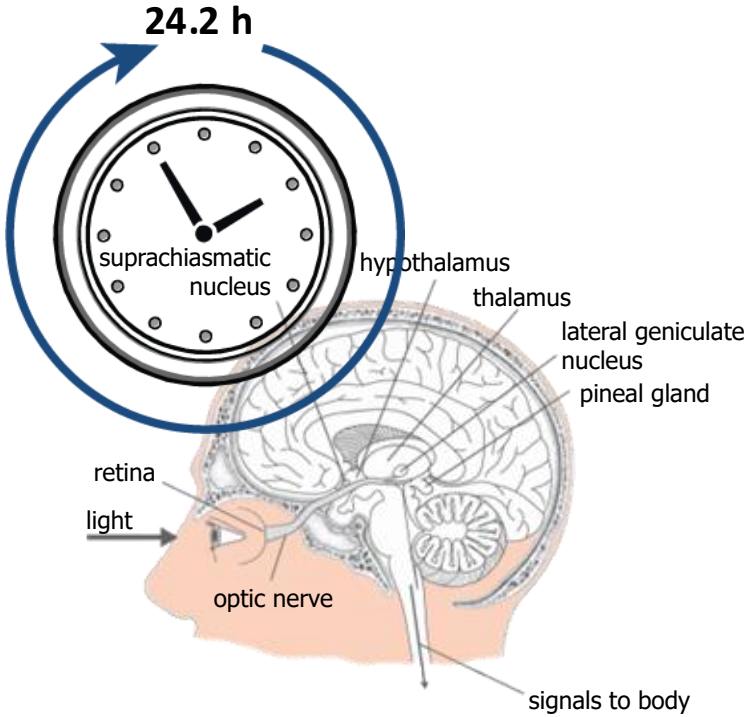
Light is the primary synchronizer of circadian rhythms to the local position on Earth



The natural, 24-h light-dark cycle



Adapted from National Library of Medicine, 2007 (public domain)

…also the major disruptor

Light is the primary synchronizer of circadian rhythms to our local position on Earth

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Circadian disruption

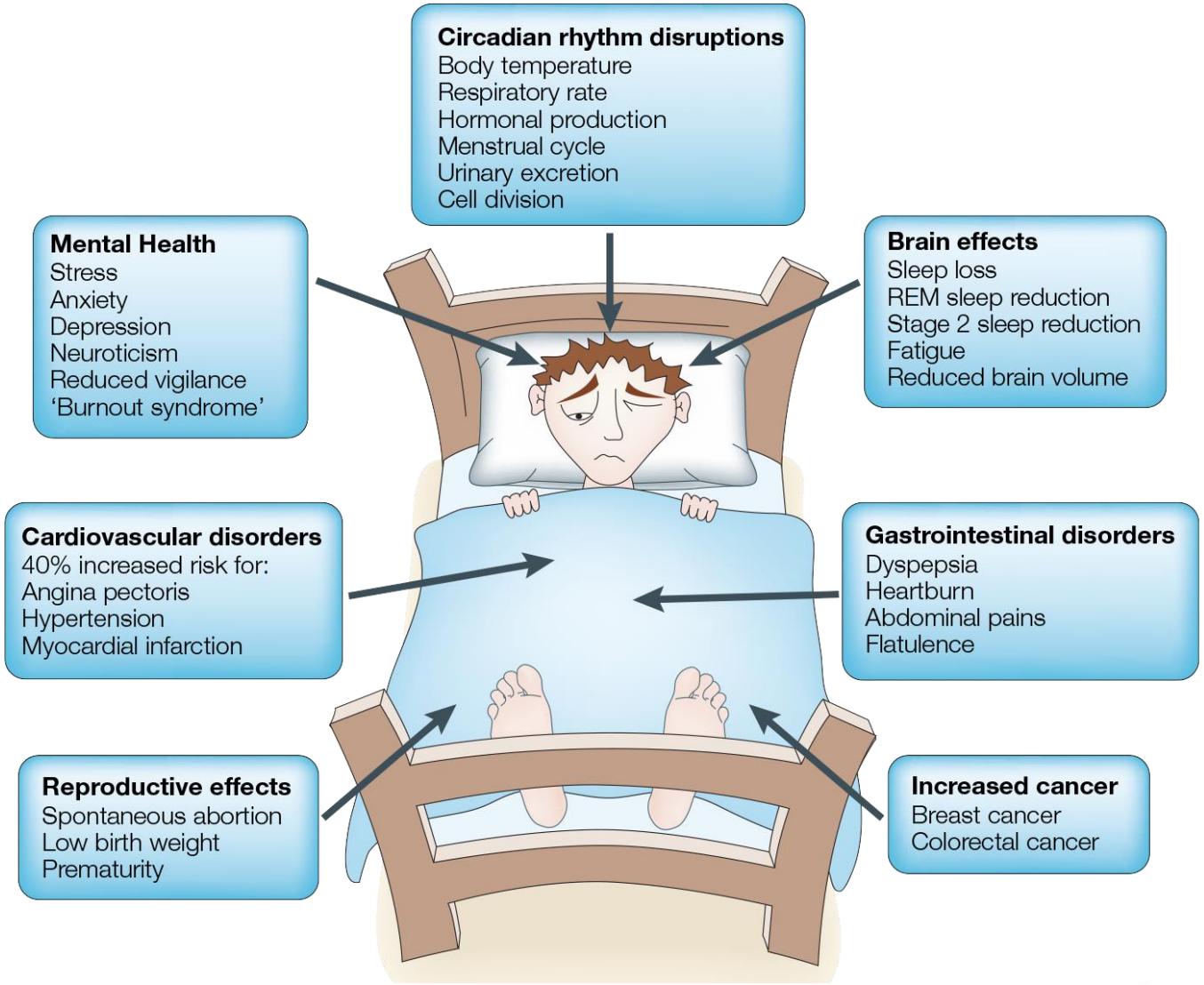

Image: Foster RG and Wulff K. The rhythm of rest and excess. *Nature Reviews Neuroscience*. 2005; 6: 407-414.

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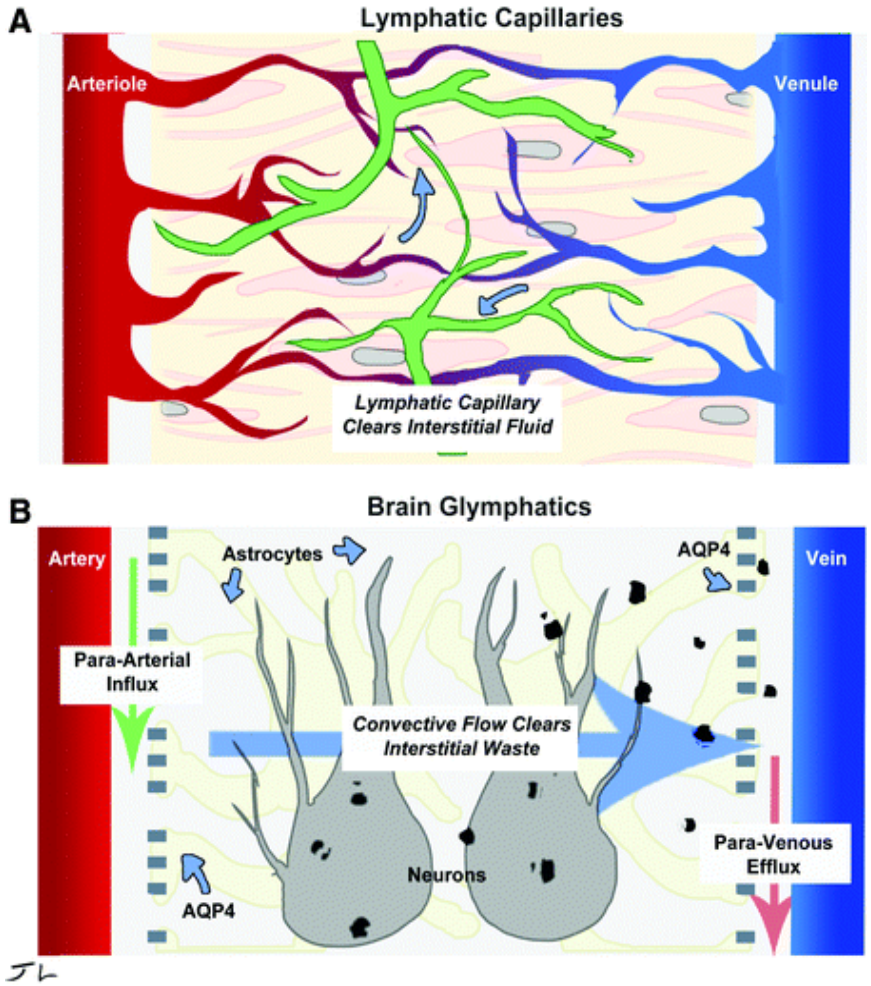
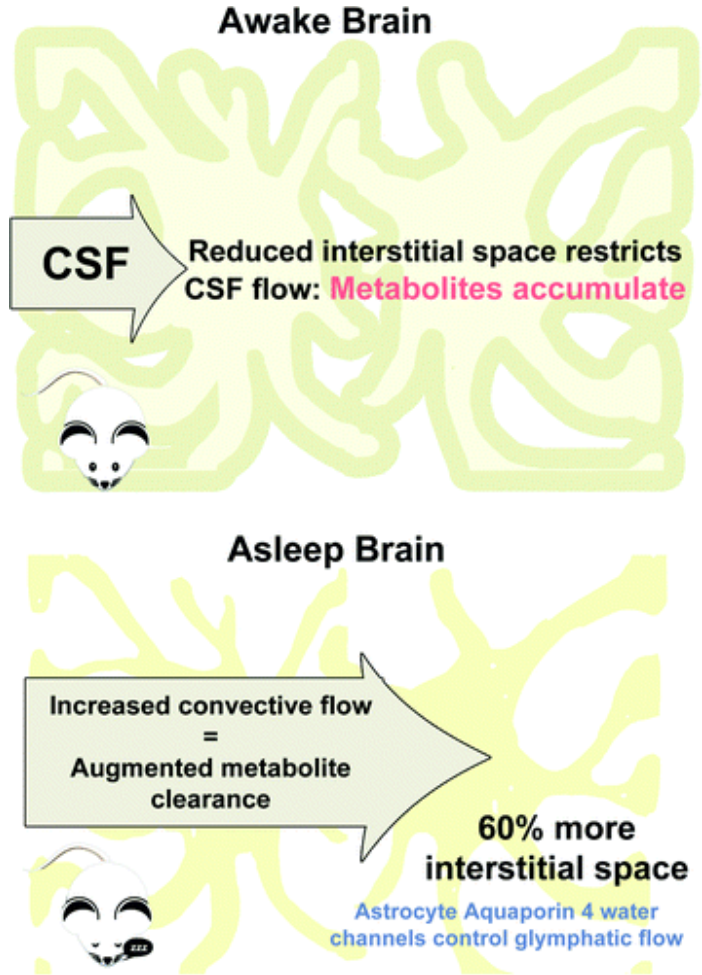
Why do we sleep?

- Sleep cleans up the debris in the brain that we accumulate during wakefulness
- Sleep promotes learning and consolidates memory
  - Different types of tasks are correlated with different sleep stages





(Left image): Walker MP, Stickgold R. Sleep-dependent learning and memory consolidation. *Neuron*. 2004;44(1):121–133.

(Right image): Jessen NA, Munk AS, Lundgaard I, Nedergaard M. The Glymphatic System: A Beginner's Guide. *Neurochemical Research*. 2015;40(12):2583–2599. doi:10.1007/s11064-015-1581-6

What is “light” for the circadian system?

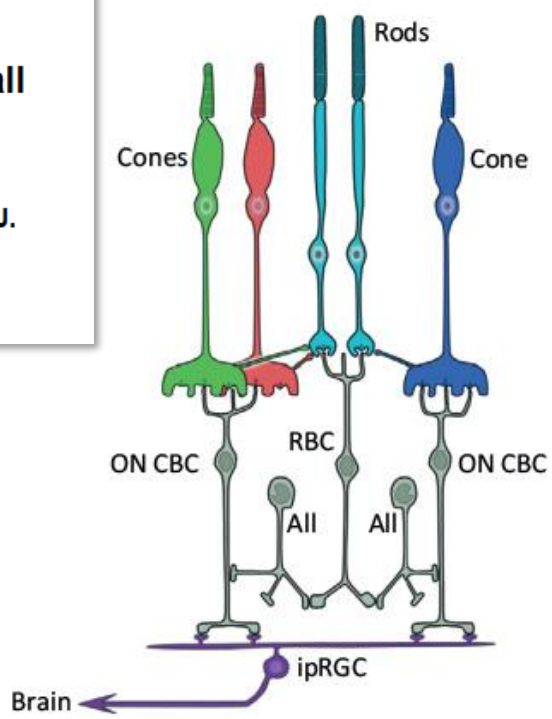
- All photoreceptors (rods, cones, and ipRGCs) participate in circadian phototransduction

Published in final edited form as:
Nature. 2003 July 3; 424(6944): 76–81. doi:10.1038/nature01761.

Melanopsin and rod–cone photoreceptive systems account for all major accessory visual functions in mice

S. Hattar[*], **R. J. Lucas**[†], **N. Mrosovsky**[‡], **S. Thompson**[†], **R. H. Douglas**[§], **M. W. Hankins**[†], **J. Lem**[‖], **M. Biel**[¶], **F. Hofmann**[#], **R. G. Foster**[†], and **K.-W. Yau**[*]

[*]Howard Hughes Medical Institute and Department of Neuroscience, Johns Hopkins University School of Medicine, Baltimore, Maryland 21205, USA



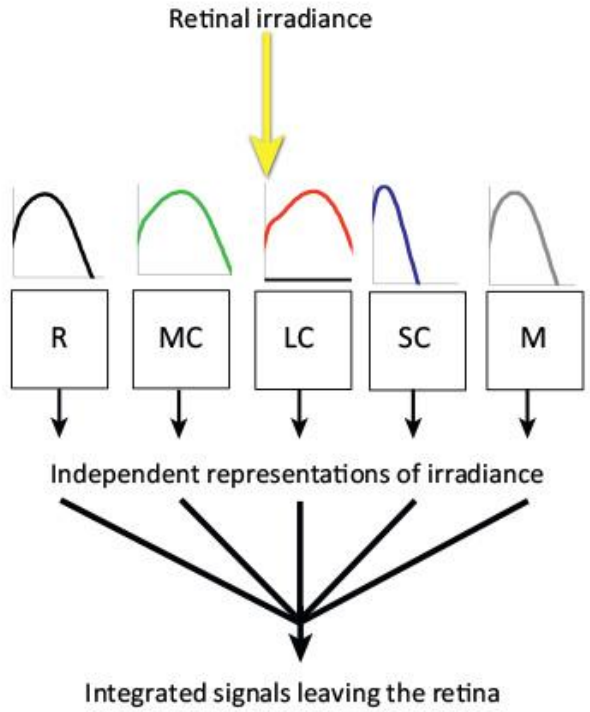


Image: Lucas et al. (2014). Measuring and using light in the melanopsin age. *Trends in Neurosciences,* 37(1): 1–9.

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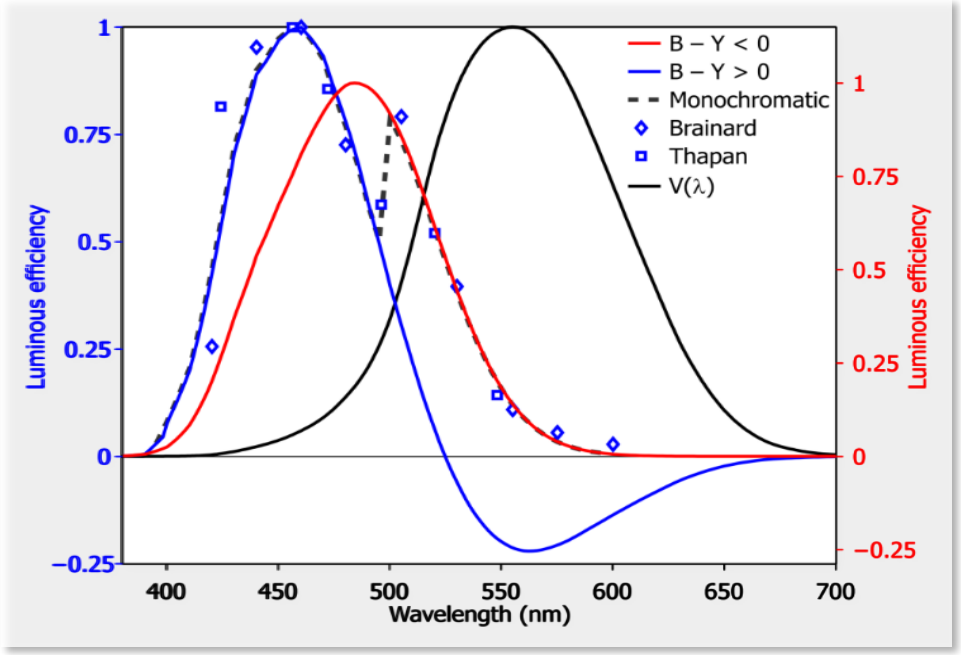
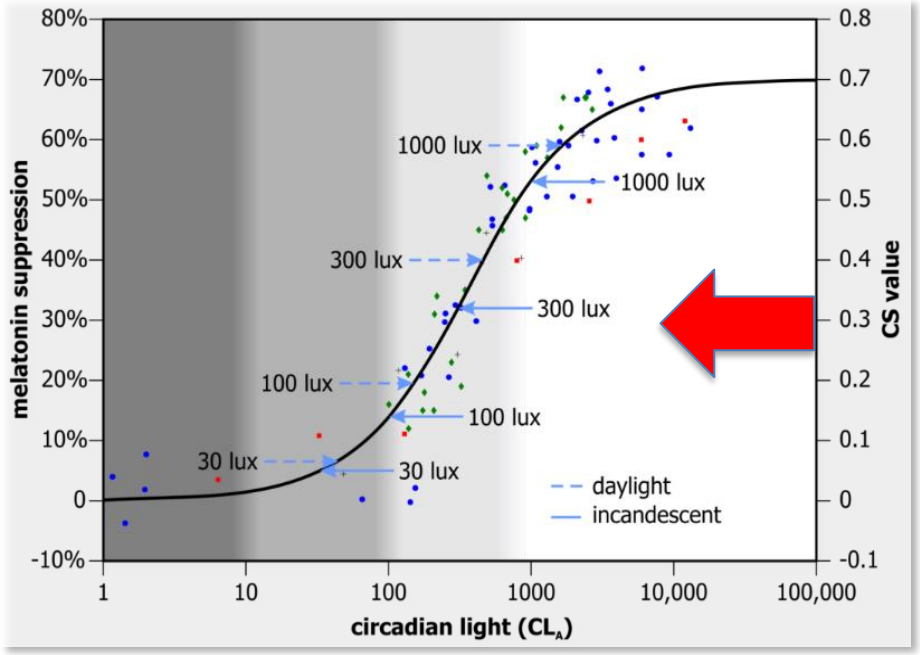
Circadian-effective light: How much and what color?

Spectral sensitivity



Absolute sensitivity



Rea MS, Figueiro MG, Bierman A, et al. (2012) Modelling the spectral sensitivity of the human circadian system. *Lighting Research & Technology* 44: 386-396.

Rea MS, Figueiro MG, Bullough JD, et al. (2005) A model of phototransduction by the human circadian system. *Brain Research Reviews* 50: 213-228.

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Circadian lighting practice recommendations

- **UL DG 24480**, Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People; advocates for use of Circadian Stimulus (CS) metric but proposes the other metrics too
  - CS = 0.3 for at least 2 h in the morning

https://www.shopulstandards.com/ProductDetail.aspx?productId=UL24480_1_D_20191219

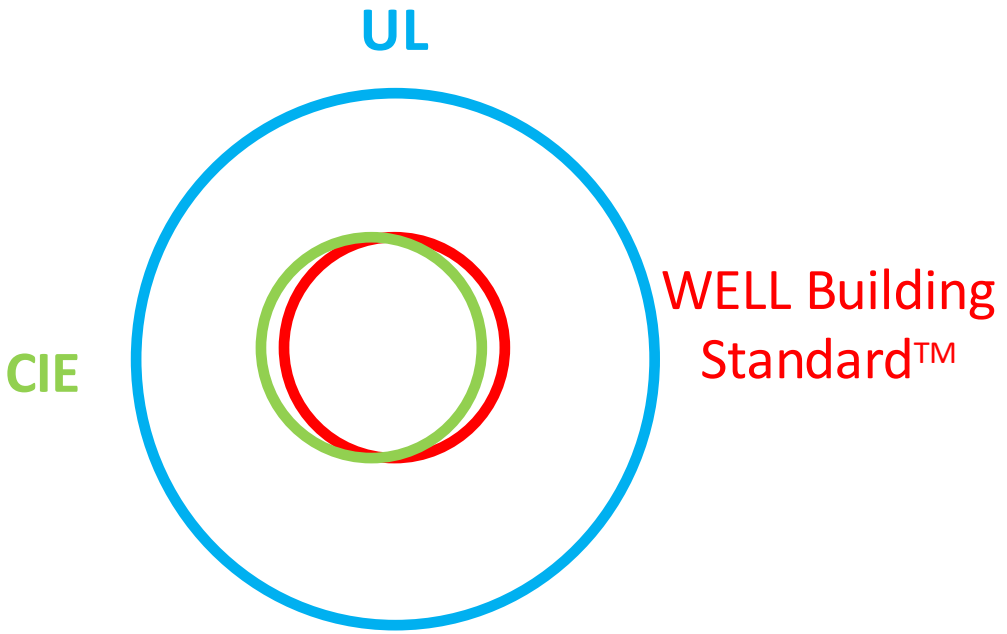
- **WELL Building Standard** advocates for Equivalent Melanopic Lux, or CS as an alternate compliance path
  - At least 150 EML [136 melanopic EDI] or at least 275 EML [250 melanopic EDI] for at least four hours (beginning by noon at the latest)

https://standard.wellcertified.com/light

- **CIE S 026:2018** proposes a toolbox to calculate alpha-optic action spectra, Melanopic Equivalent Daylight Index EDI
  - 250 melanopic EDI] during the day and less than 10 melanopic EDI] at night

https://www.youtube.com/watch?v=tXekFQuZo_s&t=367s

https://files.cie.co.at/CIE%20S%20026%20alpha-opic%20Toolbox%20User%20Guide.pdf



Overall, for day-active people in the office or at home:

- High light levels in the morning
- Low levels at evening

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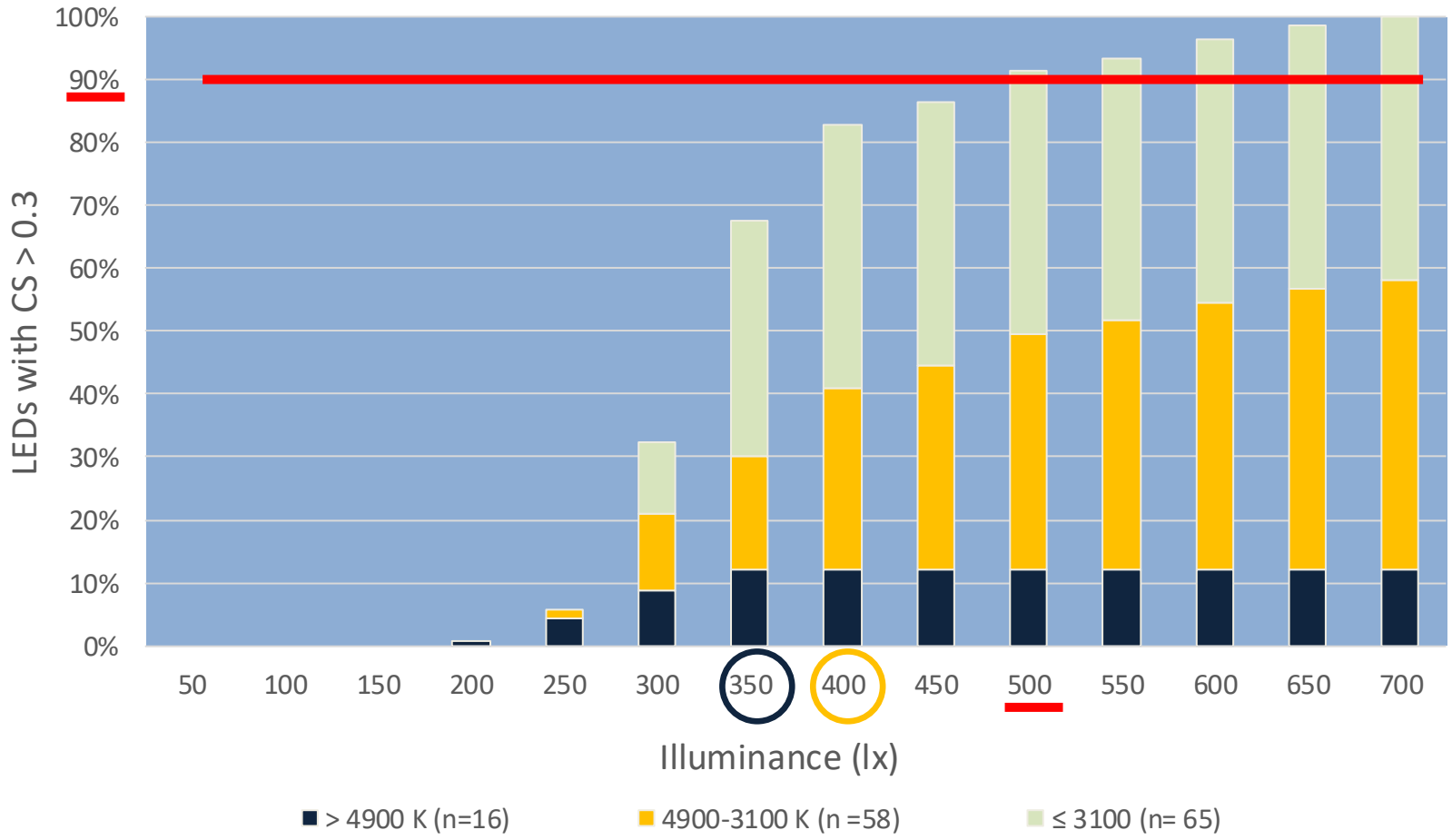
Vertical illuminance (E_V) at eye = 500 lx



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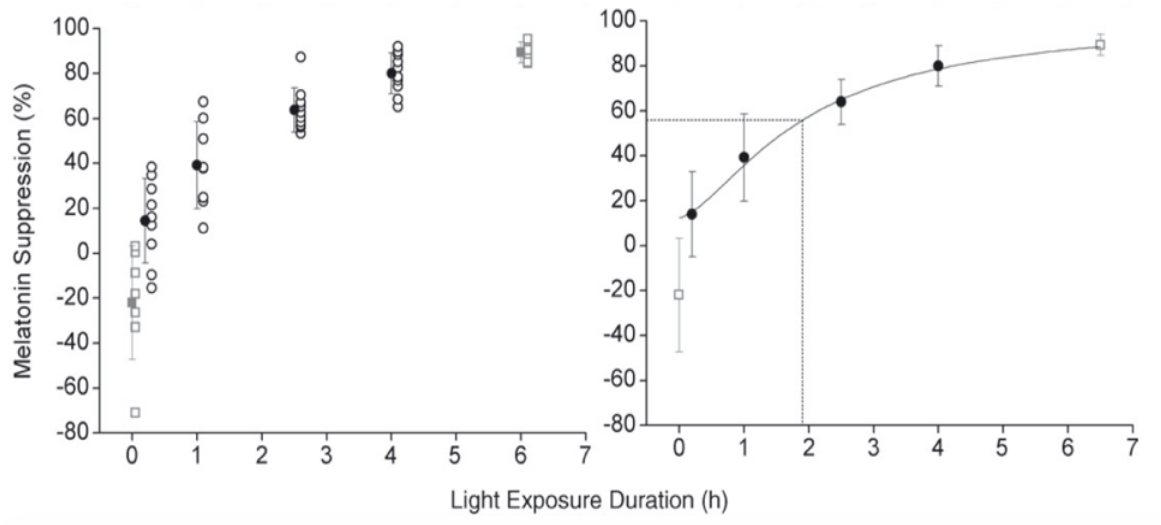
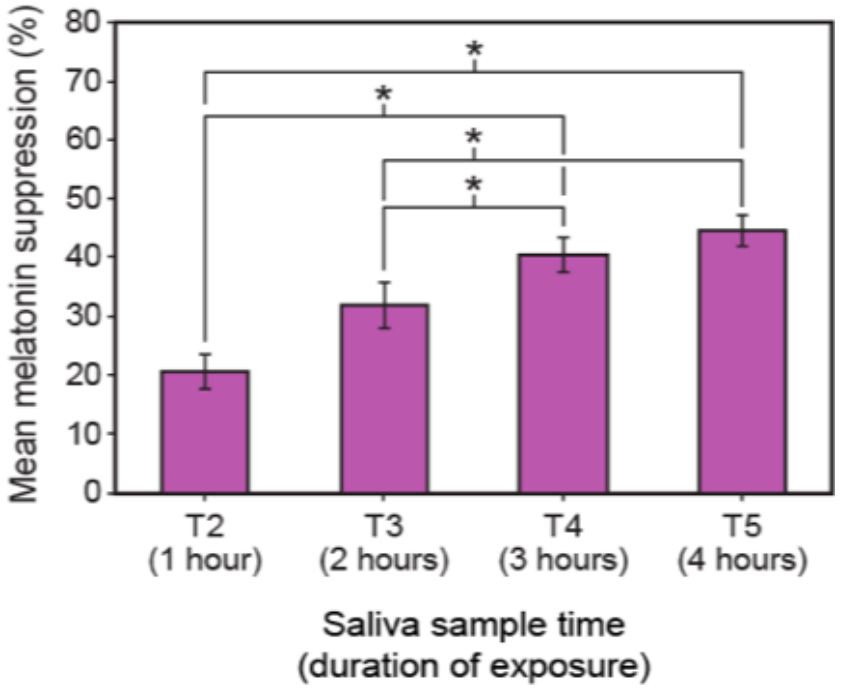
Circadian-effective light: how long?

- Varying light exposure duration affects the circadian pacemaker in a dose-dependent, non-linear manner



Chang AM, Santhi N, St Hilaire M, Gronfier C, Bradstreet DS, Duffy JF, et al. Human responses to bright light of different durations. *The Journal of Physiology* 2012; 590: 3103-3112.



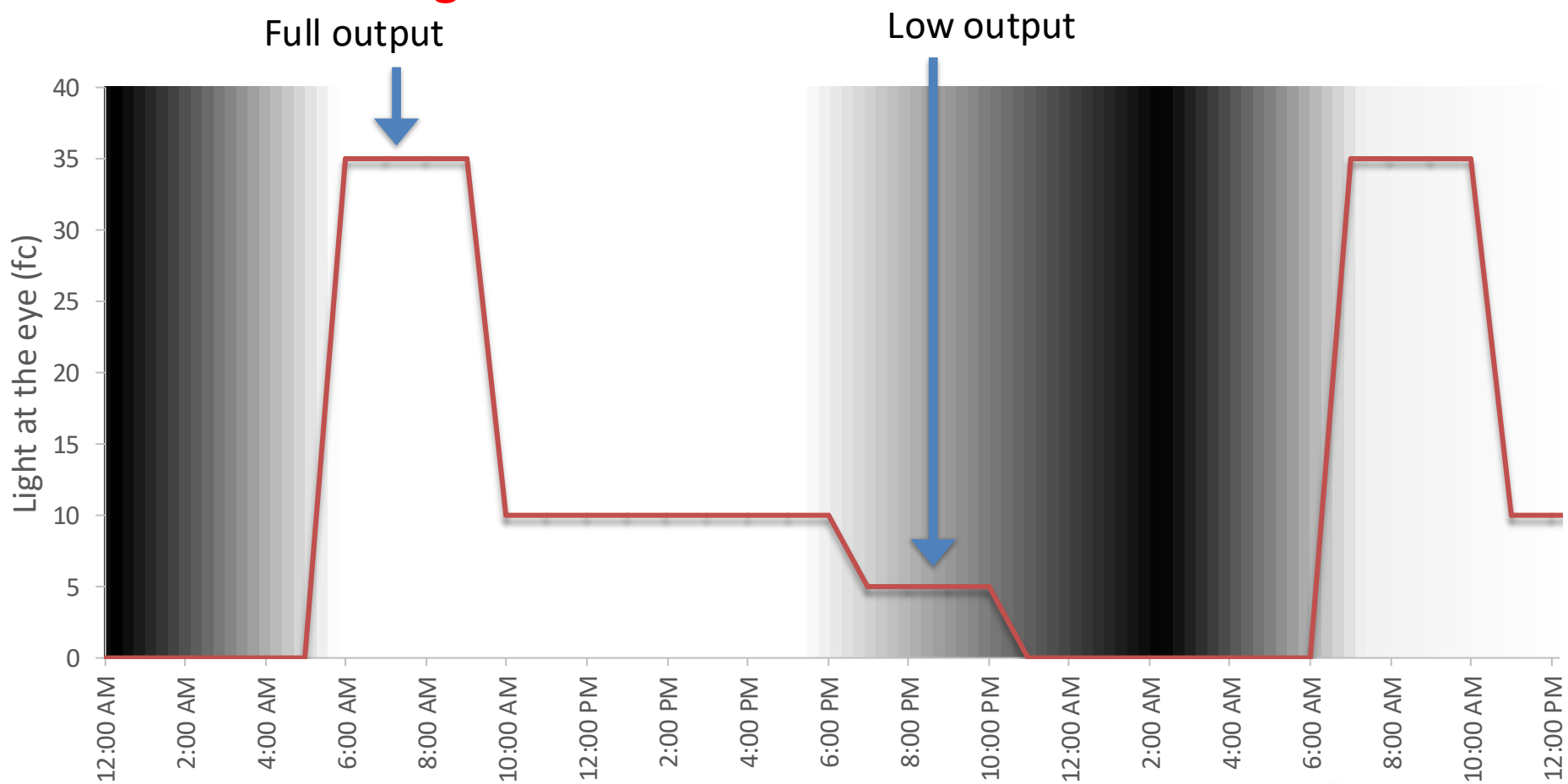
Nagare R, Plitnick B, Figueiro MG. Effect of exposure duration and light spectra on nighttime melatonin suppression in adolescents and adults. *Lighting Research and Technology* 2019; 51: 530-540.

Aoki et al. 1998, Beersma et al. 2009, Chang et al. 2012, Dewan et al. 2011, Gronfier et al. 2004, Hilaire et al. 2012, Rea et al. 2012, Rimmer et al. 2000, Zeitzer et al. 2000

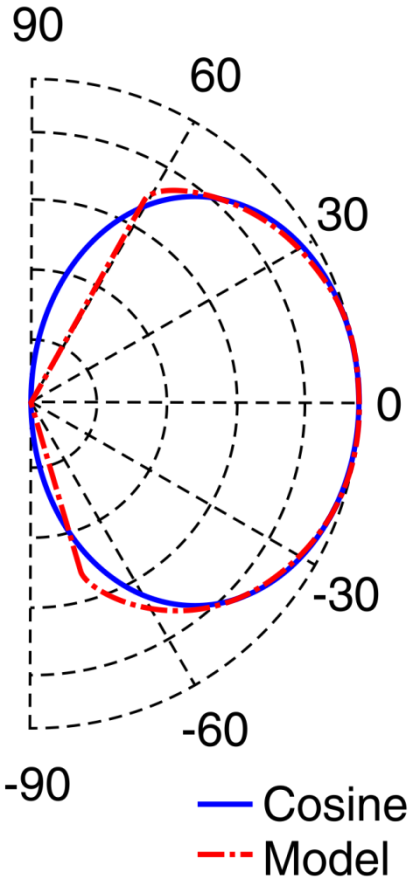
Circadian-effective light: How long and when?

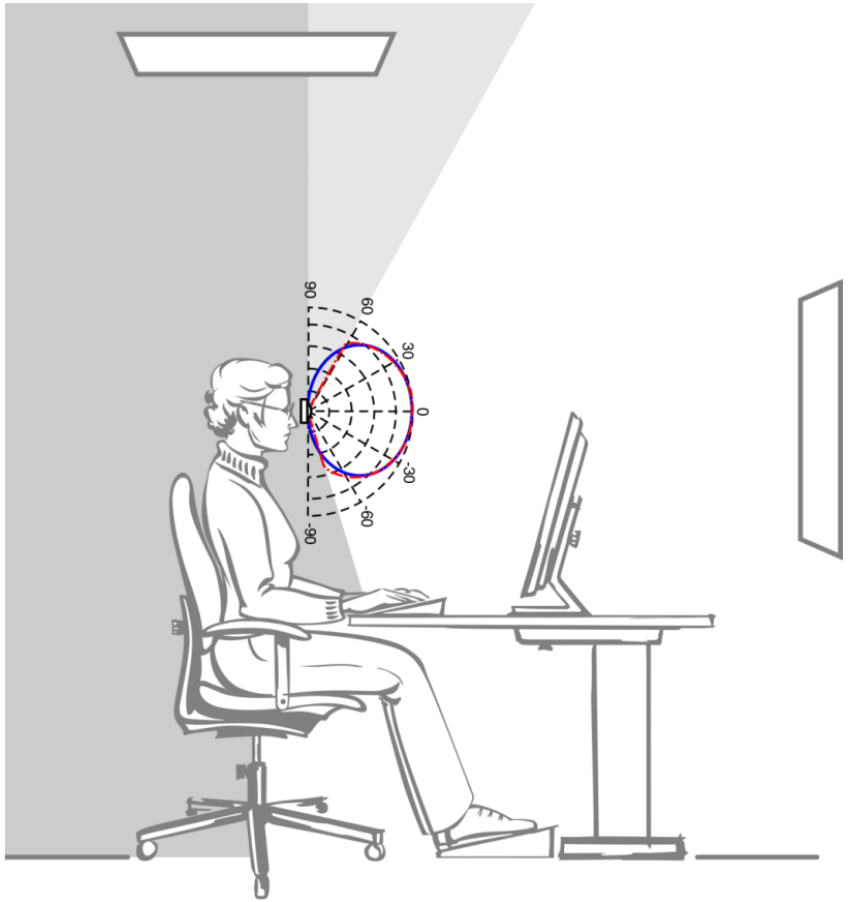
Min: 30 min
Pref: 1+ h within 2 h of waking

2 h before bedtime



Circadian-effective light: Where?





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Putting it all together, we need…

https://i.pinimg.com/originals/e1/3a/4d/e13a4d737425141353603f7a3edb73cd.jpg

When using electric lighting, we need……

- Regular pattern promotes healthy sleep
  - Bright mornings
    - > 35 fc at eye level (or CS>0.3)
    - 0.5-2 hours within 2 h of waking
  - Moderately lit daytimes
    - 10-20 fc at eye level (CS=0.2)
    - Up to 2 h prior to bedtimes
  - Dim evenings
    - < 3 fc at eye level (CS<0.1)
    - Starting 2 h prior to bedtimes
  - Dark nights
    - < 0.01 fc at eye level
    - Use nightlights to facilitate navigation

https://thehungryjpeg.com/

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What does the science show?

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Daytime light improves sleep in daytime workers

Sponsors: General Services Administration (GSA)
View Inc.

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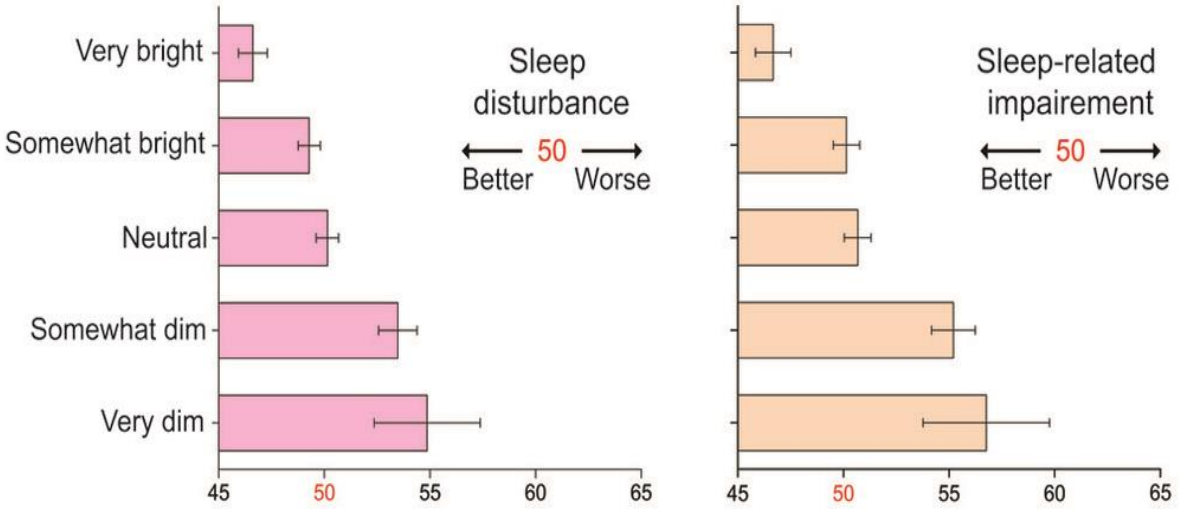
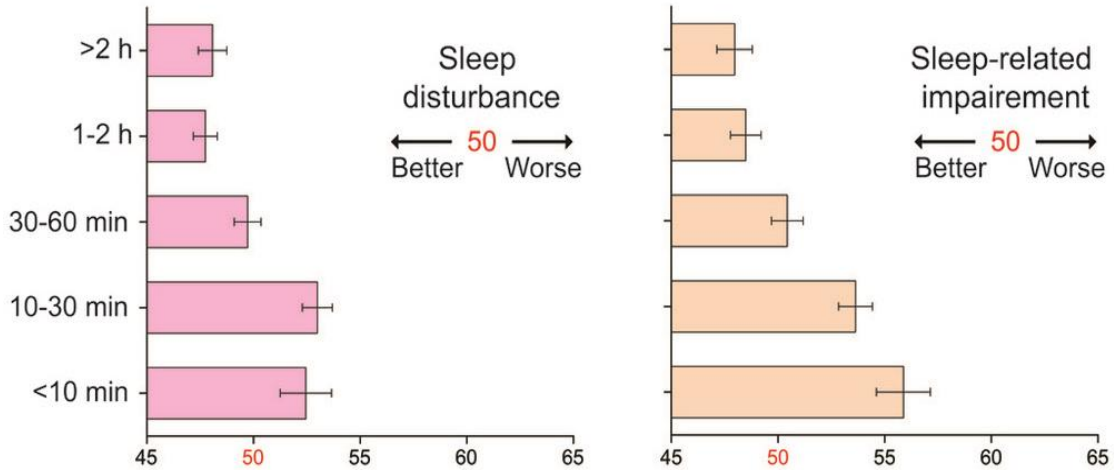
Light for better sleep during COVID-19 shutdown

At-home light exposure



Time spent outdoors



Figueiro M, Jarboe C, Sahin L. The sleep maths: A strong correlation between more daytime light and better night-time sleep. *Lighting Research & Technology*. 2021; 53: 423-435.

Light for better sleep in workers working from home

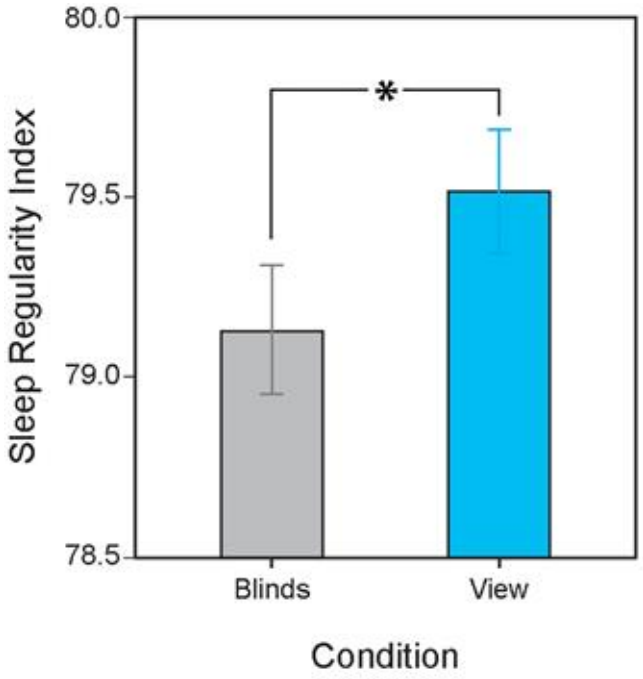
20
Residents

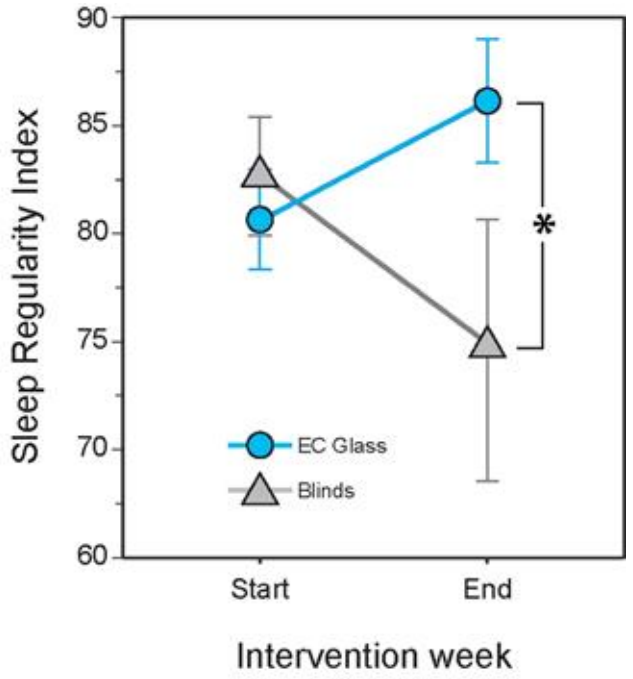
28 Days
in 2020

EXO Apartments
Reston, Virginia

Light for better sleep in workers working from home

- Sleep regularity, which has been associated with better health, increases with daytime light exposure





Sleep *Timing* Regularity (SRI) per Phillips AJK, Clerx WM, O'Brien CS, Sano A, Barger LK, Picard RW, Lockley SW, Klerman EB, Czeisler CA. Irregular sleep/wake patterns are associated with poorer academic performance and delayed circadian and sleep/wake timing. Sci Rep. 2017 Jun 12;7(1):3216. doi: 10.1038/s41598-017-03171-4.

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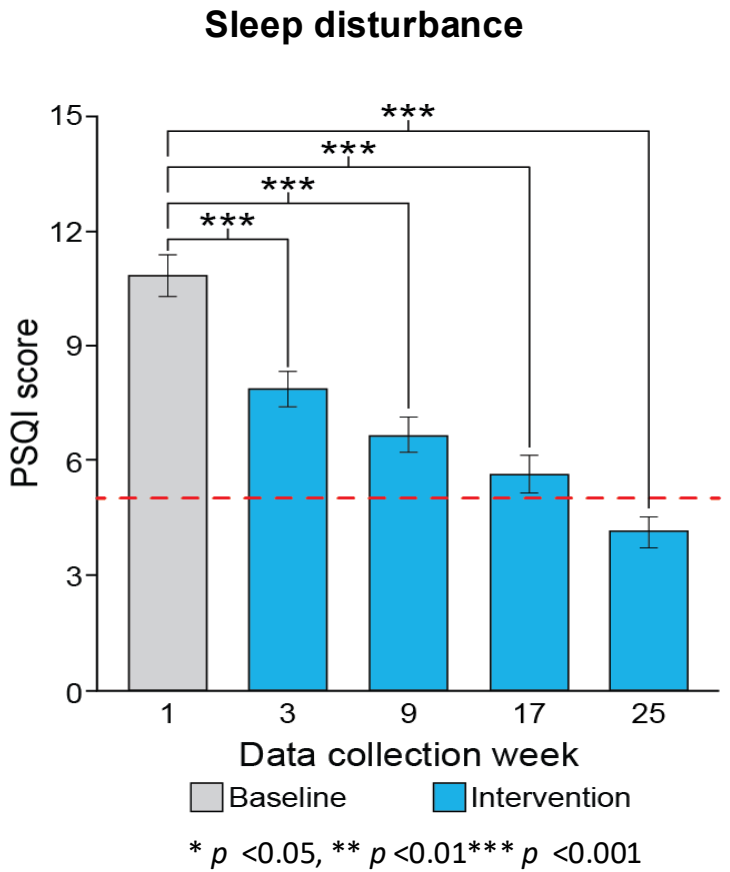
Daytime light improves sleep in persons with neurodegenerative diseases

Sponsors: National Institute on Aging, National Institute of Neurological Disorders and Stroke (PI: Pullman-Saunders)

Light for better sleep and mood in ADRD

Long-term study

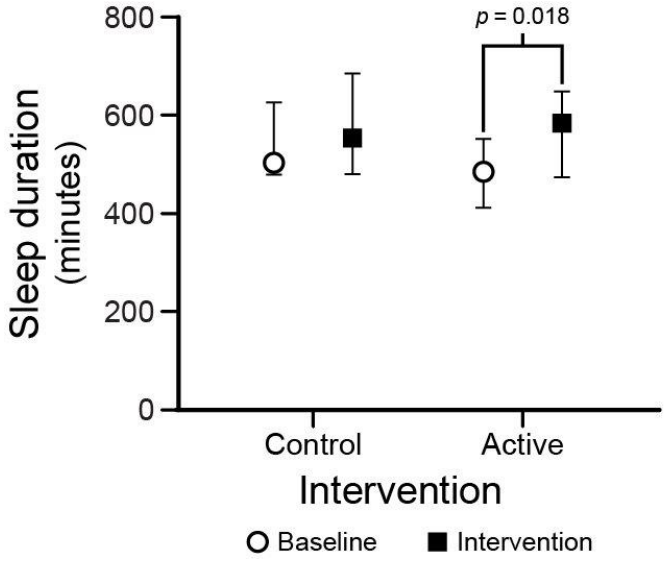
- Sleep disturbances (PSQI scores) continuously reduce over the course of 6 months

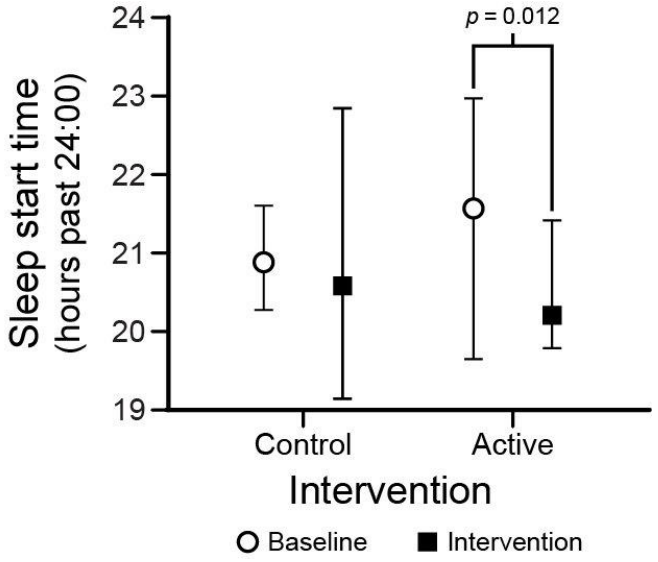


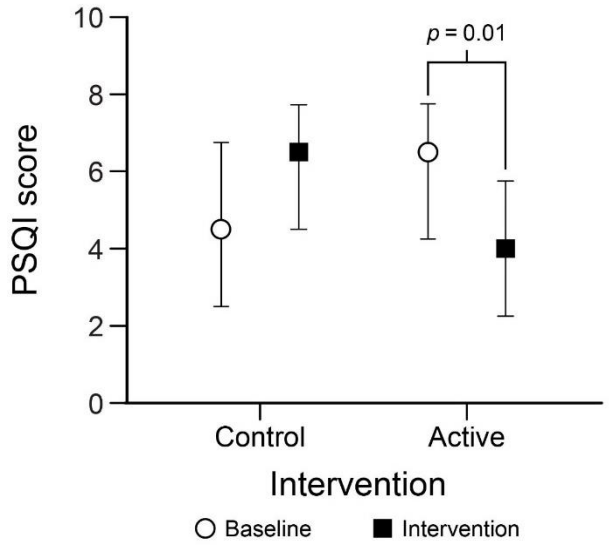
Sponsor: NIA

Light therapy for better sleep and mood in ADRD

- Active condition, after intervention compared to baseline:
- Sleep duration from actigraph significantly (p = 0.018) increased
- Sleep start time from actigraph significantly (p = 0.012) advanced
- Subjective sleep disturbances (PSQI) significantly (p = 0.01) decreases



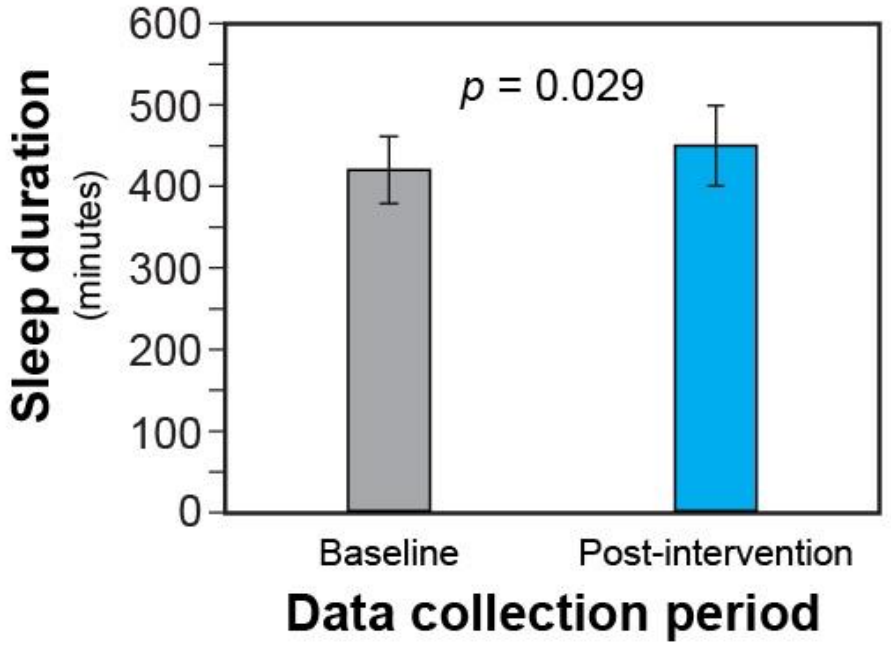




Sponsor: NIA (R01AG034157, 2R44AG060857)

Light for better sleep in Parkinson's disease

- Mean sleep duration significantly increased by 29 min (p = 0.029)



Sleep duration: Time in minutes between sleep start and sleep end

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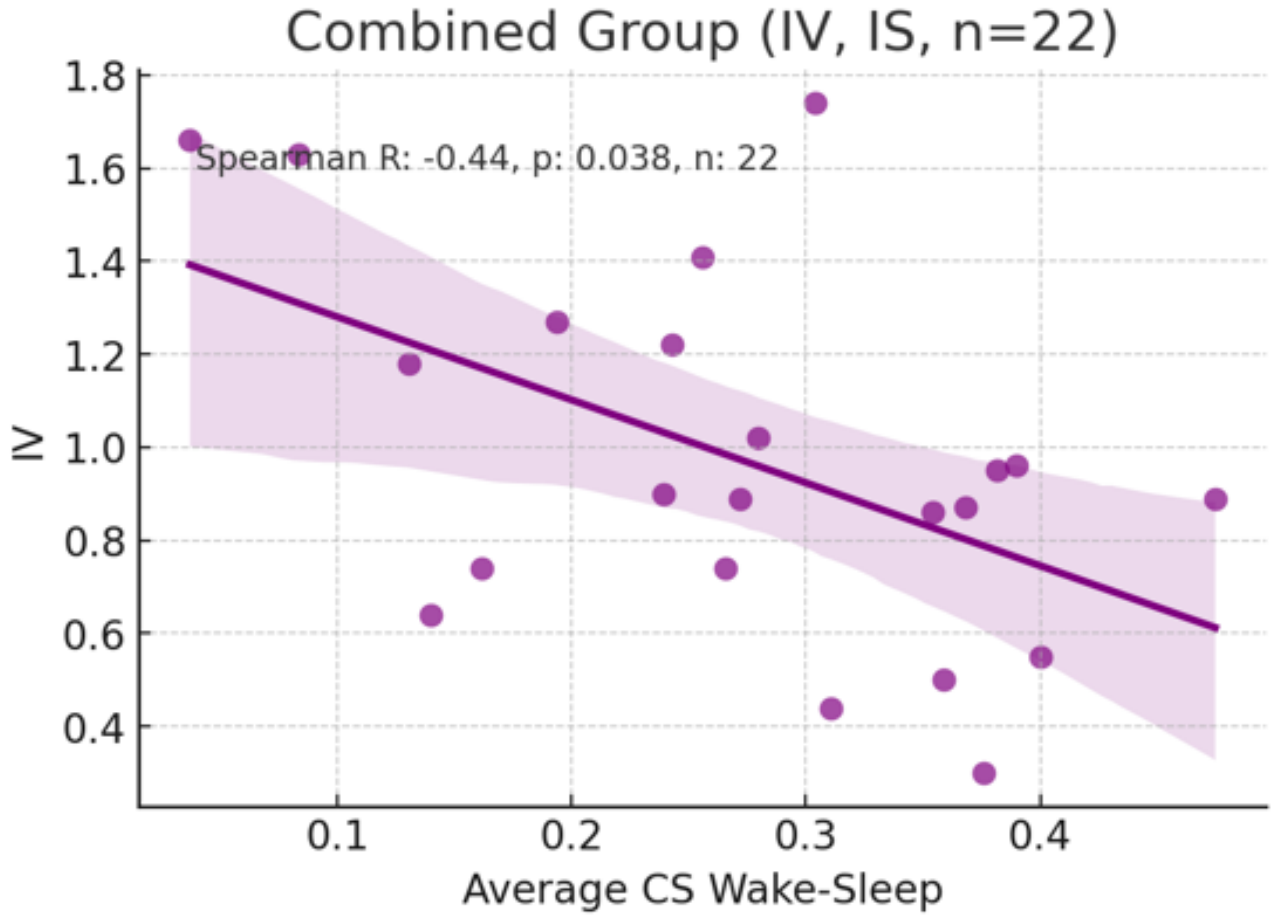
Circadian effective light and rest-activity fragmentation

- There was a negative correlation between daytime circadian effective light (CS) and IV (intradaily variability)

- **More daytime light = better entrainment**



Sleep Math: Brighter days = Better Nights

Figueiro M, Jarboe C, Sahin L. The sleep maths: A strong correlation between more daytime light and better night-time sleep. *Lighting Research & Technology*. 2021; 53: 423-435.

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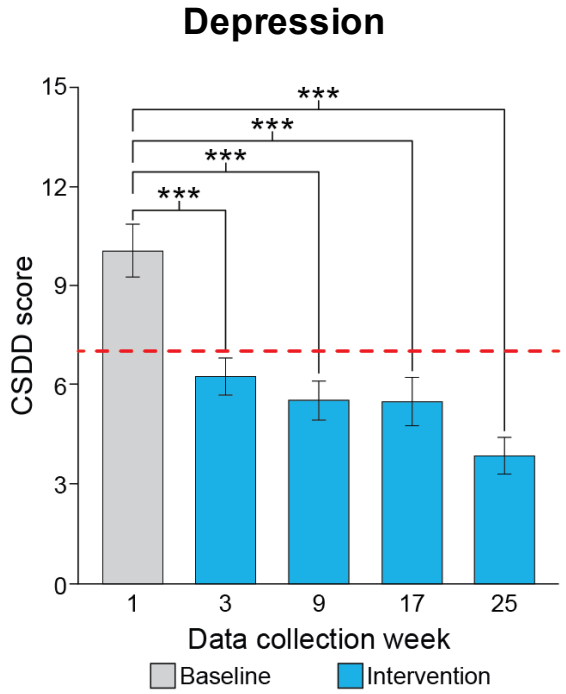
Daytime light improves mood in various populations

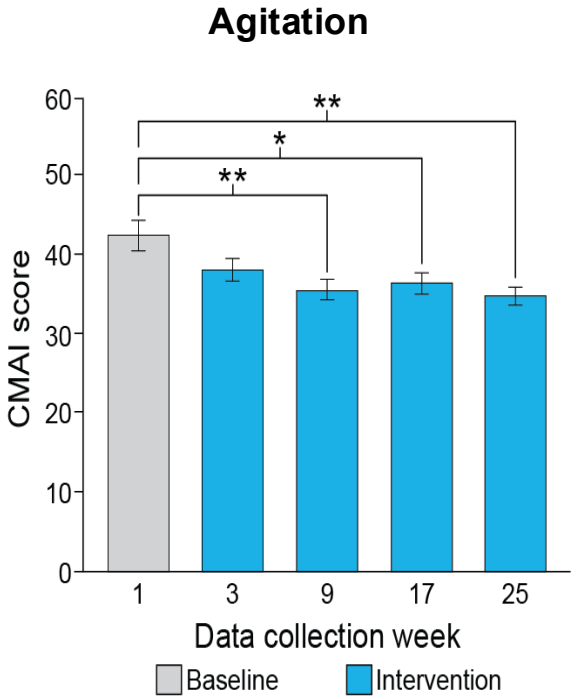
Sponsors: National Institute on Aging, National Institute of Neurological Disorders and Stroke (PI: Pullman-Saunders), National Cancer Institute, View, Inc.

Light for better mood and behavior in ADRD

Long-term study

- Fewer depression (CSDD) and agitation behavior symptoms (CMAI scores) during the tailored Lighting Intervention (TLI) compared to baseline





Sponsor: NIA

* p <0.05, ** p <0.01*** p <0.001

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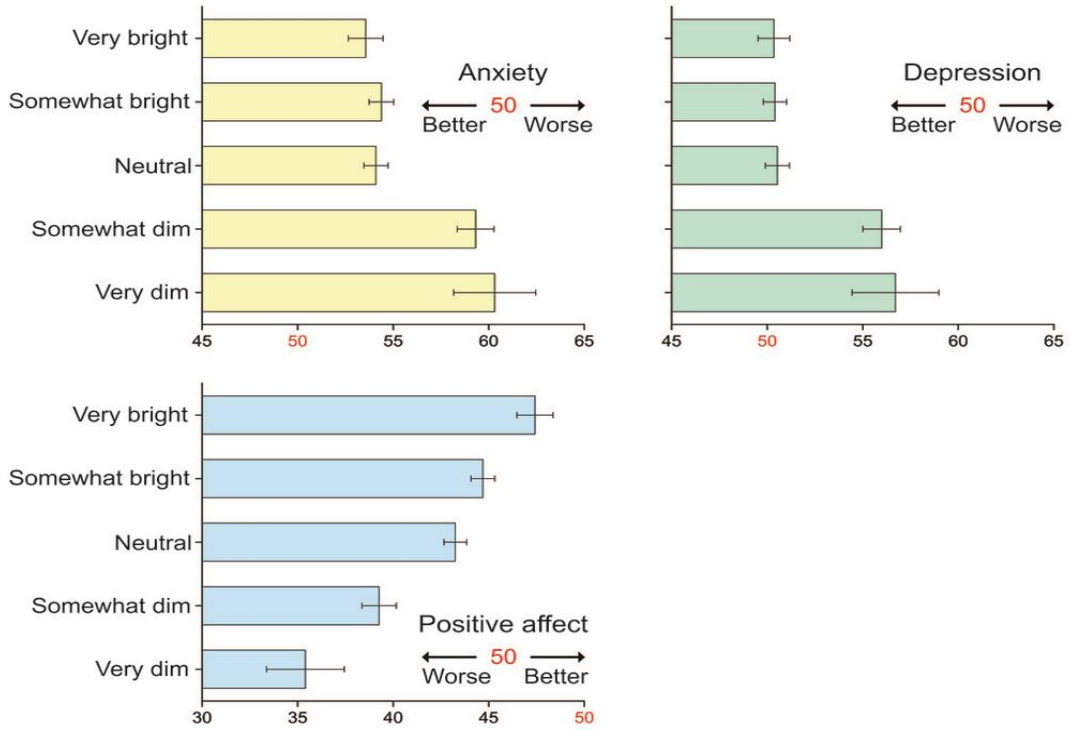
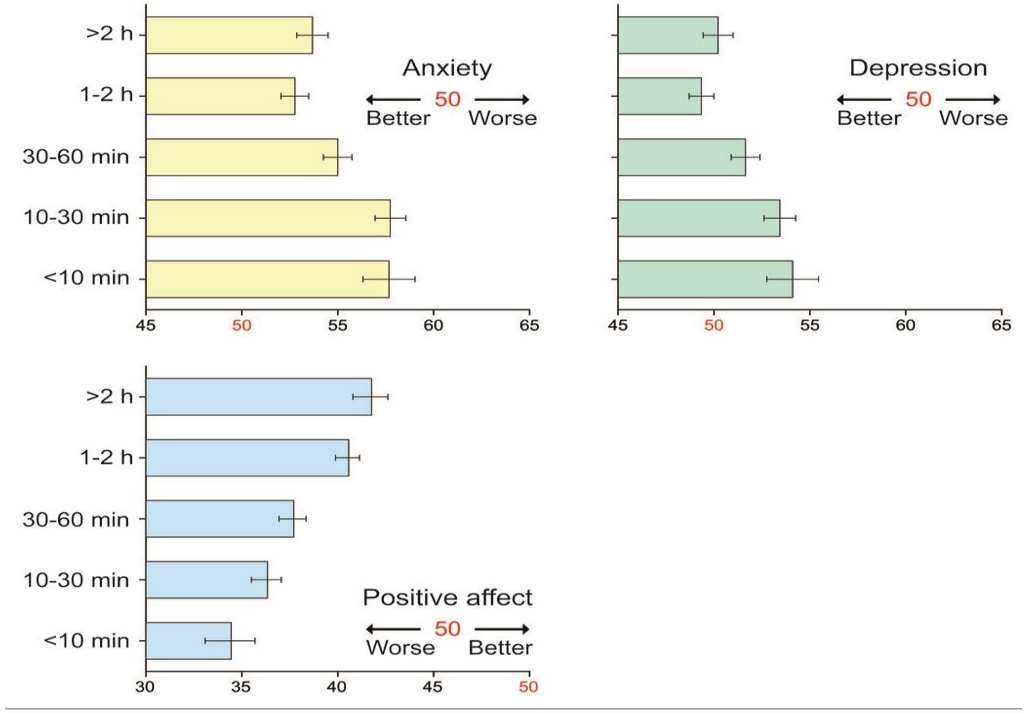
Light for better mood during COVID-19 shutdown

At-home light exposure

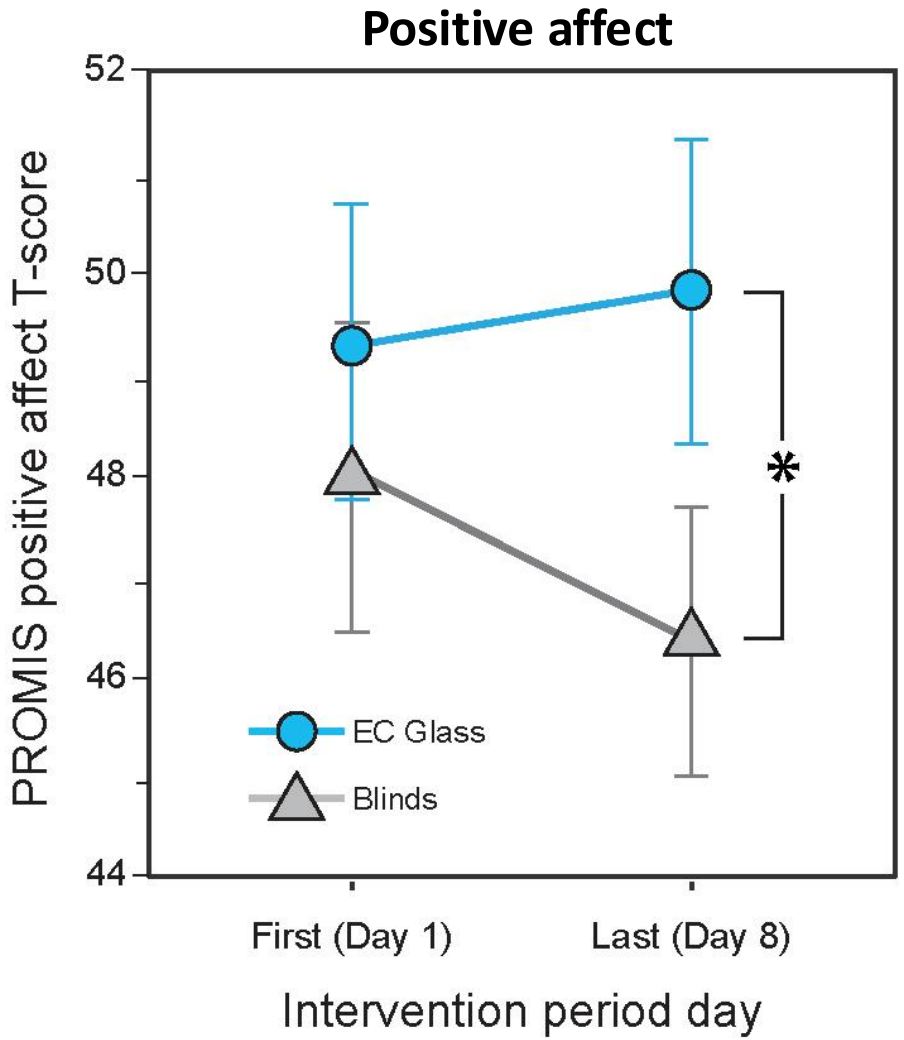


Time spent outdoors



Figueiro M, Jarboe C, Sahin L. The sleep maths: A strong correlation between more daytime light and better night-time sleep. *Lighting Research & Technology*. 2021; 53: 423-435.

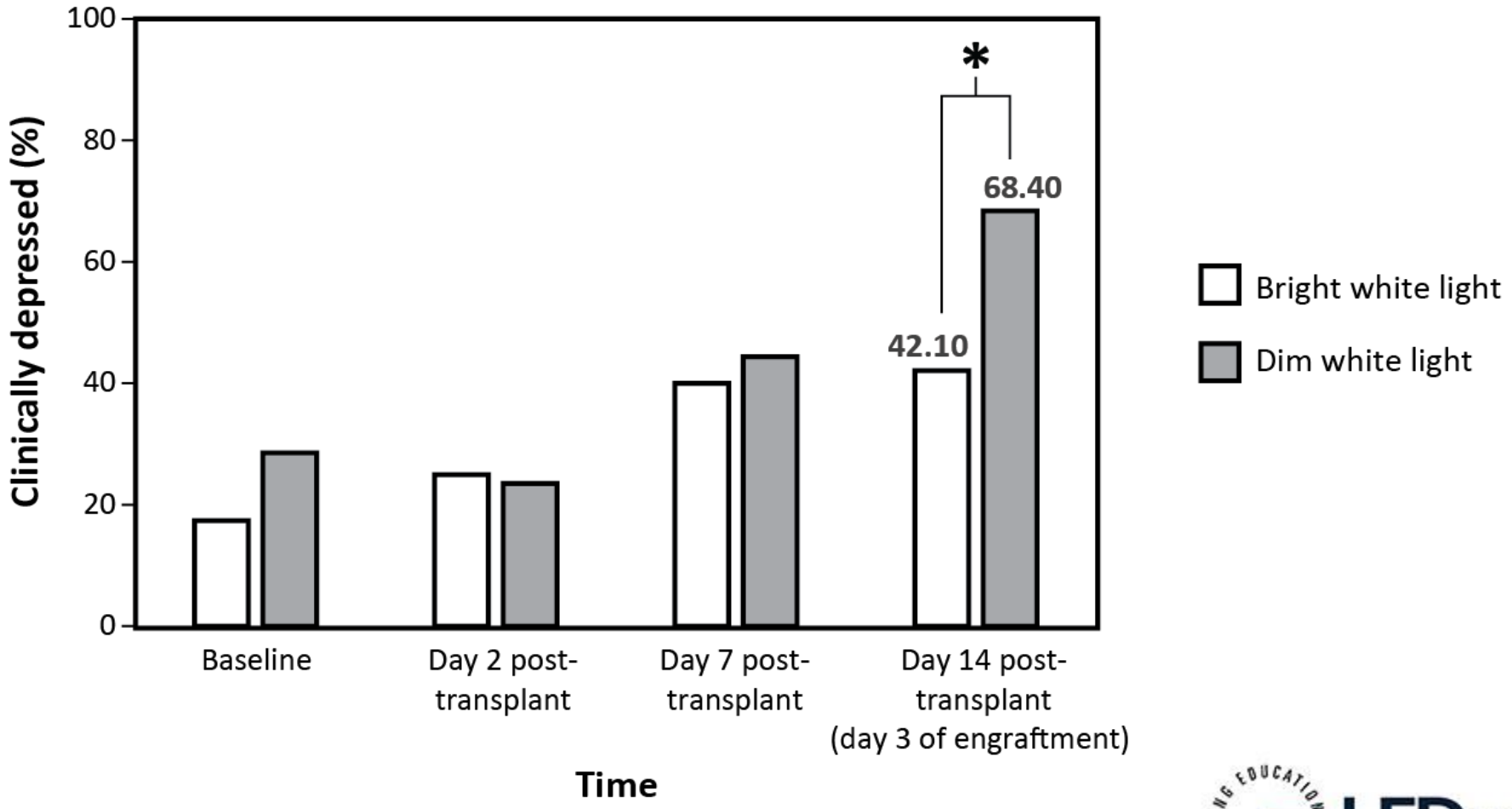
Light for better mood in workers working from home



T-test (End of week)
p=0.093

Within-subject (End of week)
+3.7 points or +7%
p=0.035

Light for better mood in myeloma transplant patients



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Daytime light improves cognition in individuals with mild cognitive impairment (MCI)

Sponsor: National Institute on Aging

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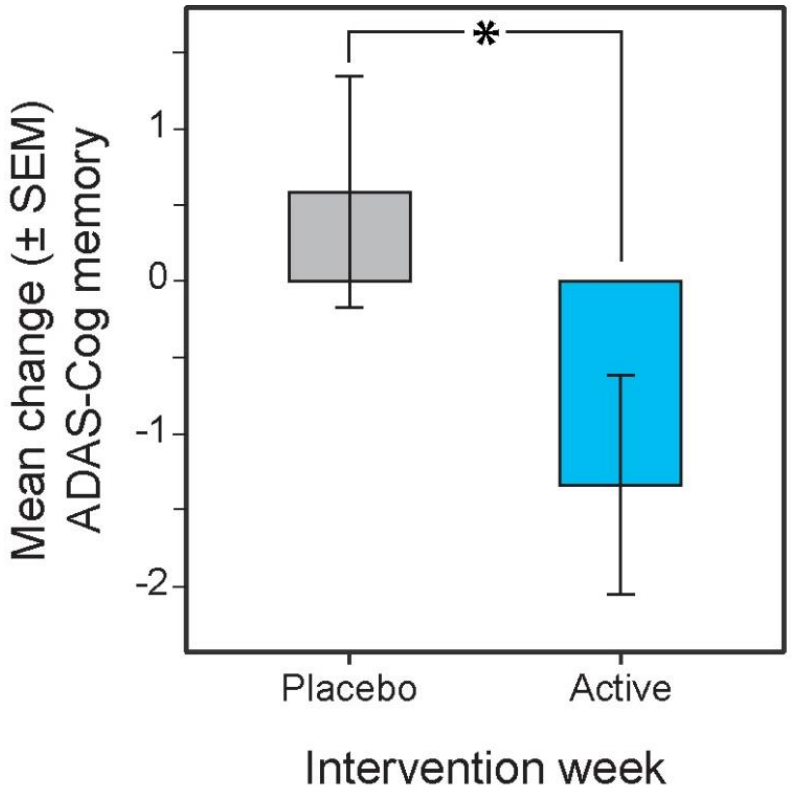
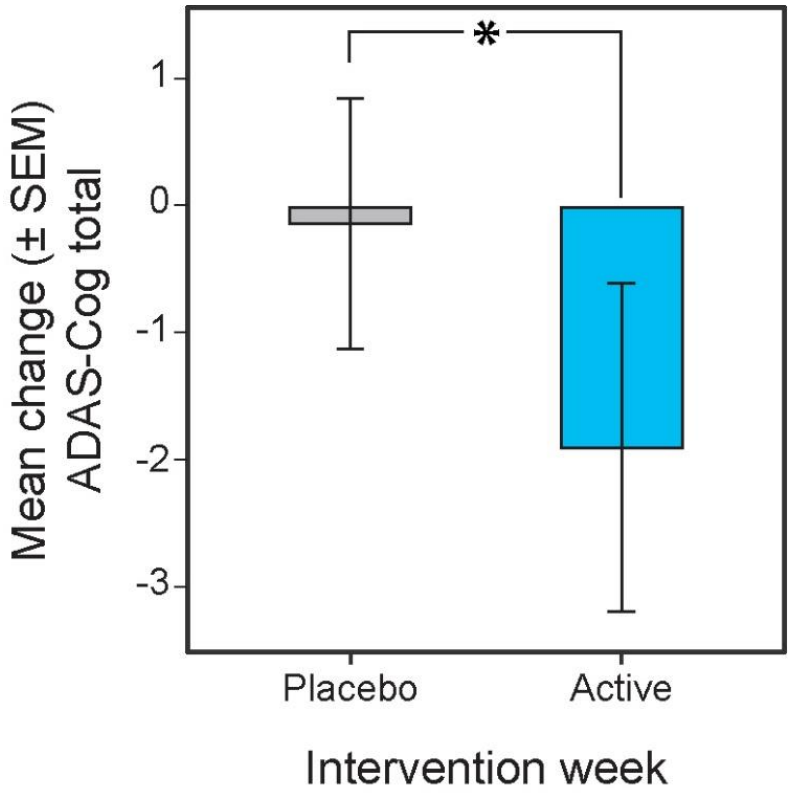
Light for better cognition in MCI patients





Negative values indicate improvement in cognitive performance

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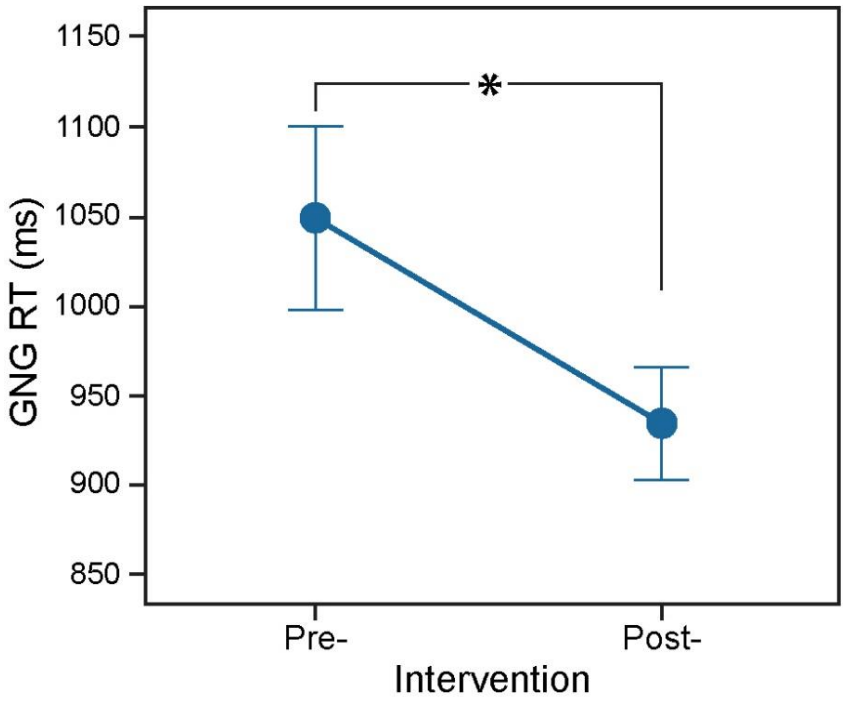
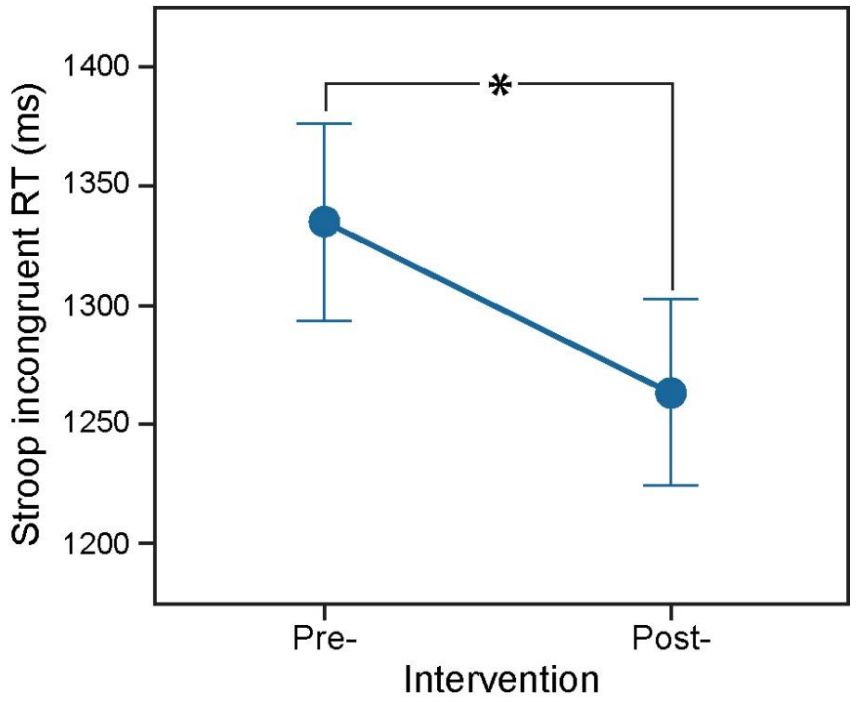
Light for better cognition in the World Trade Center rescue and recovery workers

Go/no-go task



Stroop task



Lower values indicate faster reaction times (better performance)

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Daytime light reduces inflammation (preliminary results from our studies)

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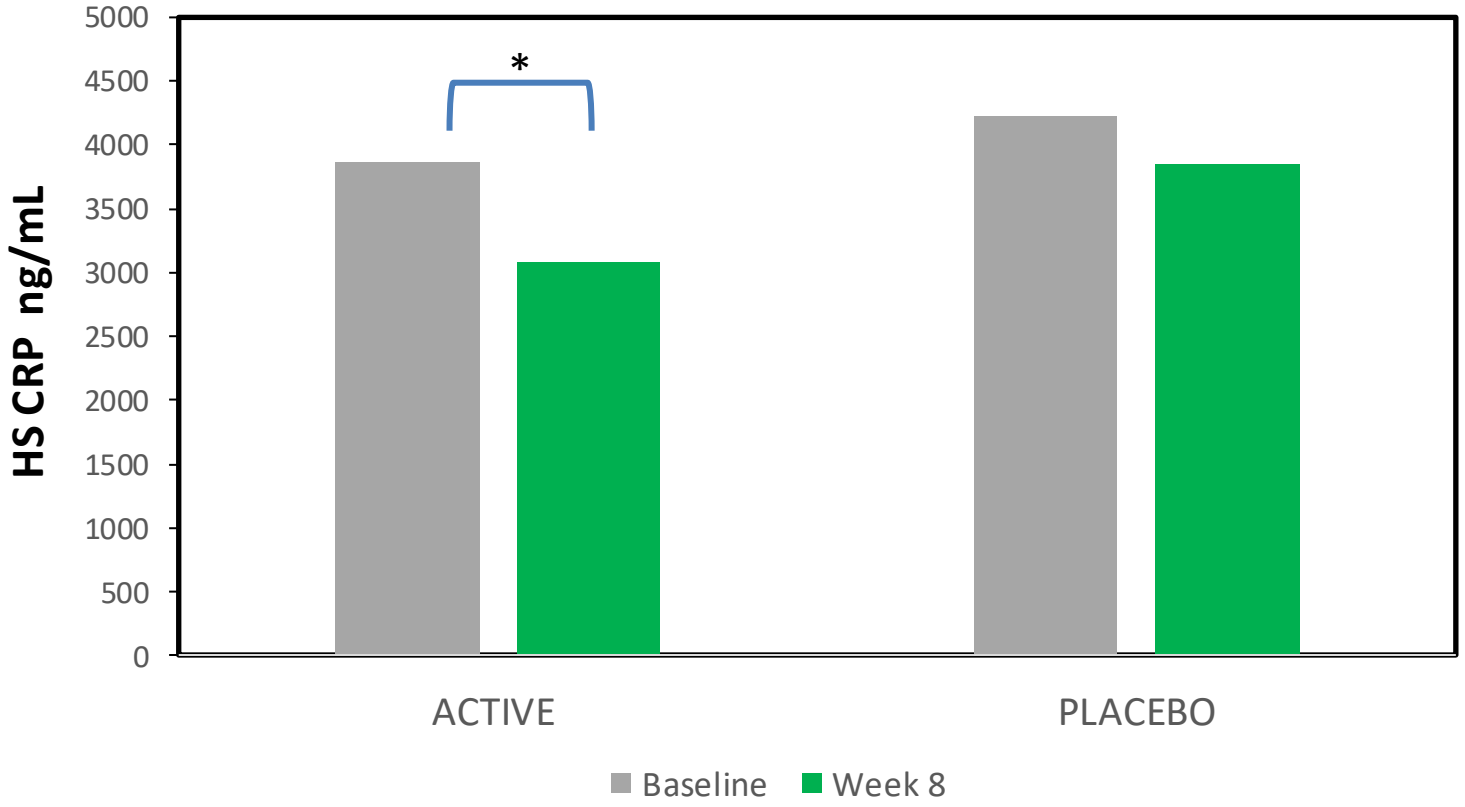
Light to promote entrainment and reduce inflammation in MCI patients



20% reduction in high-sensitivity C-reactive protein in the active light (n=8) and 9% reduction in the placebo light (n=8)

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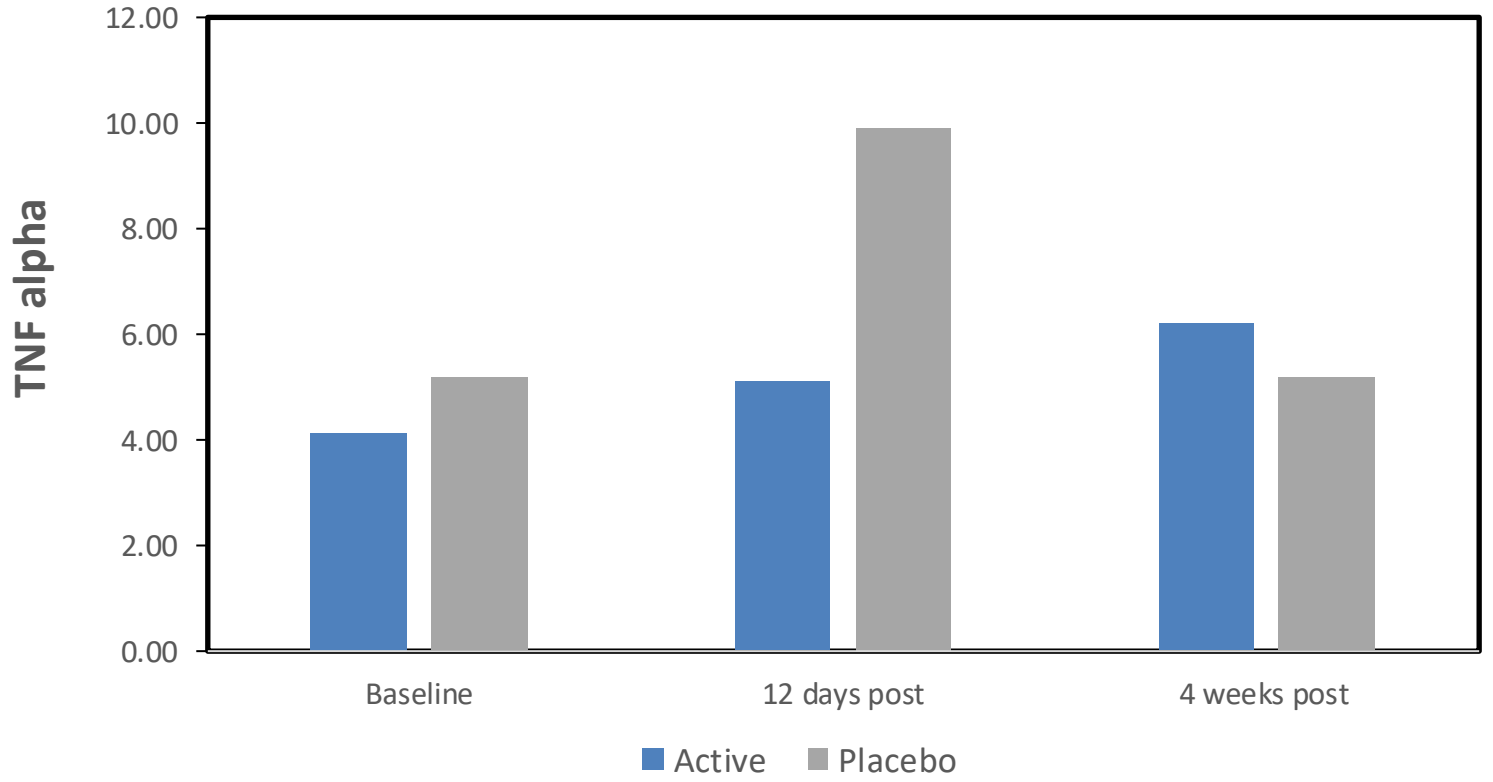
Light to promote entrainment and reduce inflammation in myeloma transplant patients



Active n=6 and placebo n=9

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How to implement these concepts in the various spaces

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When using electric lighting, we need……

- Regular pattern promotes healthy sleep
  - Bright mornings
    - > 35 fc at eye level (or CS>0.3)
    - 0.5-2 hours within 2 h of waking
  - Moderately lit daytimes
    - 10-20 fc at eye level (CS=0.2)
    - Up to 2 h prior to bedtimes
  - Dim evenings
    - < 3 fc at eye level (CS<0.1)
    - Starting 2 h prior to bedtimes
  - Dark nights
    - < 0.01 fc at eye level
    - Use nightlights to facilitate navigation

https://thehungryjpeg.com/

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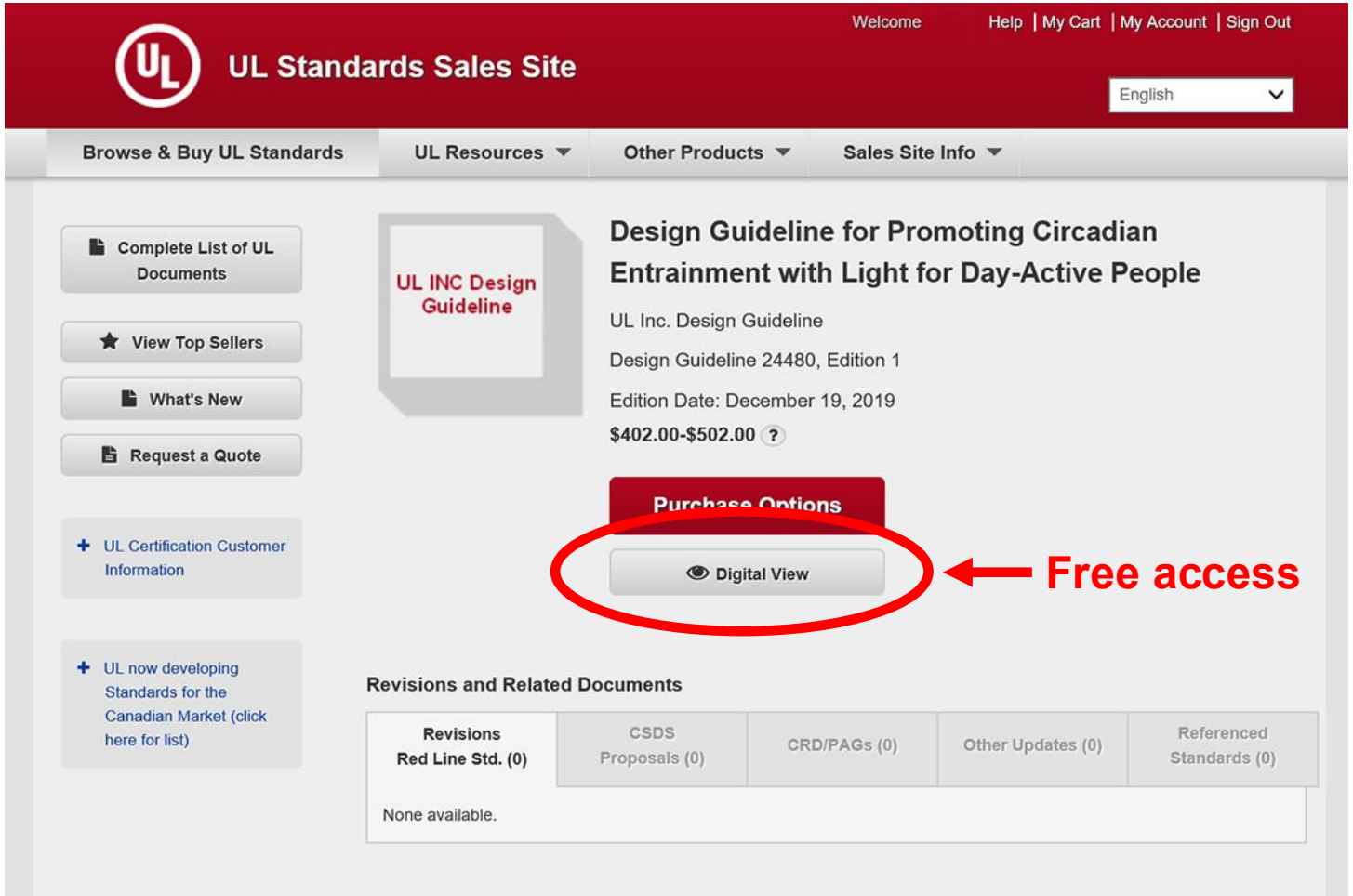
UL Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People (DG) 24480

- *The goal is to provide a more natural cycle of bright light during the day (and dim light at night) in the built environment*



https://www.shopulstandards.com/

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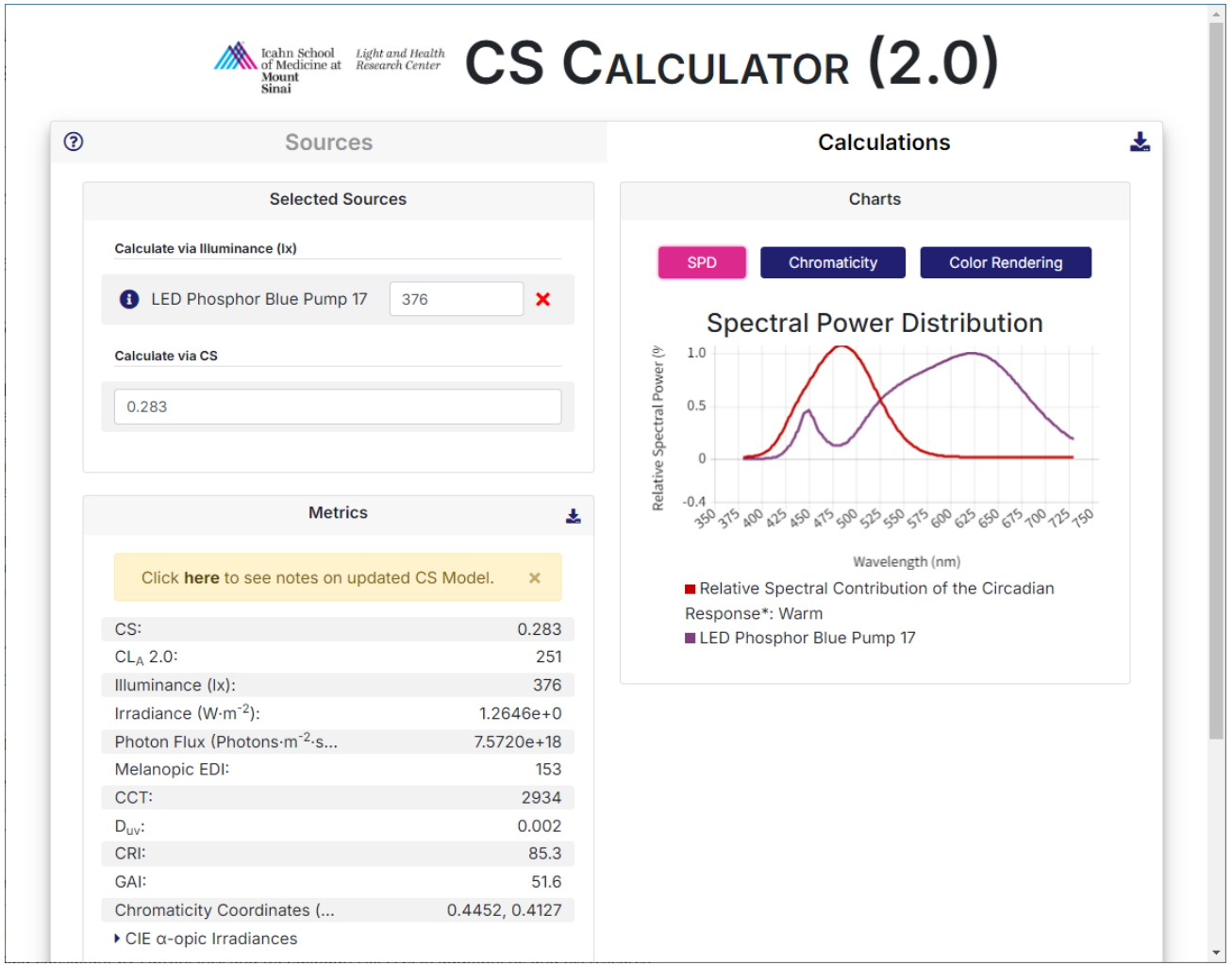
Quick guide from UL-DG 24480

- Step 1: Establish a circadian-effective lighting design criterion (e.g., CS = 0.30)
- Step 2: Select a luminaire type (e.g., direct/indirect)
- Step 3: Select a light source (e.g., 3000 K LED)
- Step 4: Perform photometrically realistic software (e.g., AGi32) calculations for the building space
- Step 5: Calculate CS from the vertical illuminance at the eye (E_V) and the light source's spectral power distribution (SPD)
- Step 6: Determine whether the lighting system meets the circadian-effective lighting design criterion; repeat steps 2–6 if necessary

Circadian Stimulus Calculator

- Input vertical illuminance (E_V) calculations
- Input tabular SPD values
- Calculate CS
  - Or EML, m-EDI
- Also includes calculations of:
  - CIE α-opic irradiances
  - Color characteristics (CCT, CRI, GAI, chromaticity)
- Allows blending of sources

https://cscalc.light-health.org/



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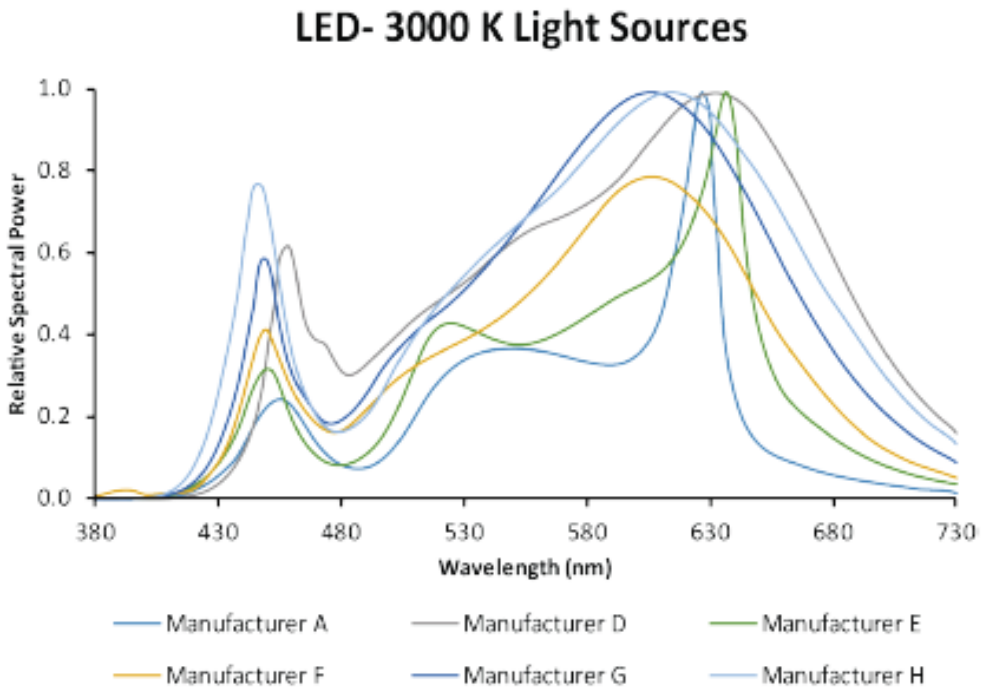
Important considerations: Spectral power distribution (SPD)

Horizontal Illuminance (lux)	Manufacturer					
	A	D	E	F	G	H
300	0.23	0.26	0.24	0.24	0.23	0.12
325	0.25	0.27	0.25	0.25	0.25	0.13
350	0.26	0.29	0.26	0.27	0.26	0.14
375	0.27	**0.30**	0.28	0.28	0.27	0.14
400	0.29	**0.31**	0.29	0.29	0.28	0.15
425	**0.30**	**0.33**	**0.30**	**0.30**	**0.30**	0.16
450	**0.31**	**0.34**	**0.31**	**0.31**	**0.31**	0.17
475	**0.32**	**0.35**	**0.32**	**0.32**	**0.32**	0.18
500	**0.33**	**0.36**	**0.33**	**0.33**	**0.33**	0.19



It is important to request the SPD from the manufacturer for luminaires under consideration, as SPDs can vary for any given CCT

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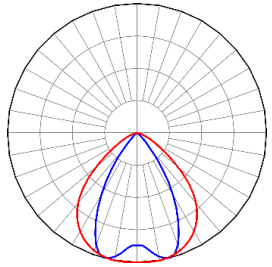
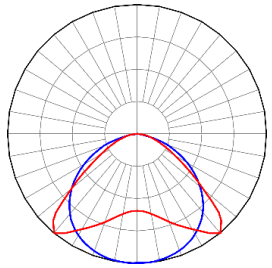
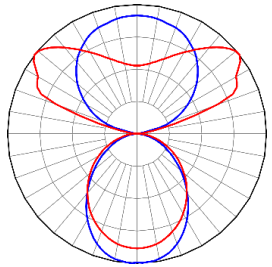
Important considerations: Intensity distribution

- Lighting designs for commercial architecture typically have to meet horizontal illuminance (E_H) requirements on the floor/ground or workplane
- When designing for circadian health, <u>vertical</u> illuminance (E_V) at the eye becomes the primary target
- The E_V/E_H ratio becomes important when considering the optic of a luminaire
  - A ratio ≥ 0.65 is recommended


Downlight


Troffer


D/I Pendant

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Minimize discomfort glare

- Discomfort or inability to see due to excessive light or contrast
- Minimize luminance (<8500 cd/m^2)
  - When viewed in typical application
  - Similar to the blue sky
- Hide bulbs/sources with diffusers
  - Avoid bare bulbs
- Large, diffuse light source
  - Avoid tiny points/lines of light
- Primarily high output (daytime) concern

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Why is residential lighting so important to health?

- We start our day at home
- We spend our evenings at home
- We may work from home
- We have control over our home lighting
  - Including daylighting

https://www.istockphoto.com/vector/day-and-night-house-illustration-gm512908192-8737645 7

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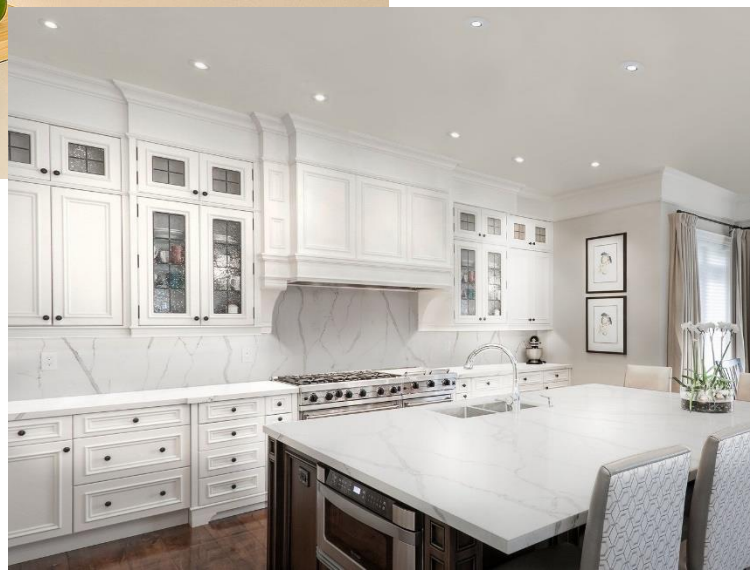
Residential Kitchen



Some tips:

- Add task lighting
- Light finishes
- Use layers of light
- Attention to direct and reflected glare

CONTINUING EDUCATION AIA LEDucation.org

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Residential Kitchen

- Dim general lighting
- Task lighting
  - But direct away from eyes to avoid discomfort glare
- Coves, soffits
- Toe kick, island, etc. to allow for nighttime navigation

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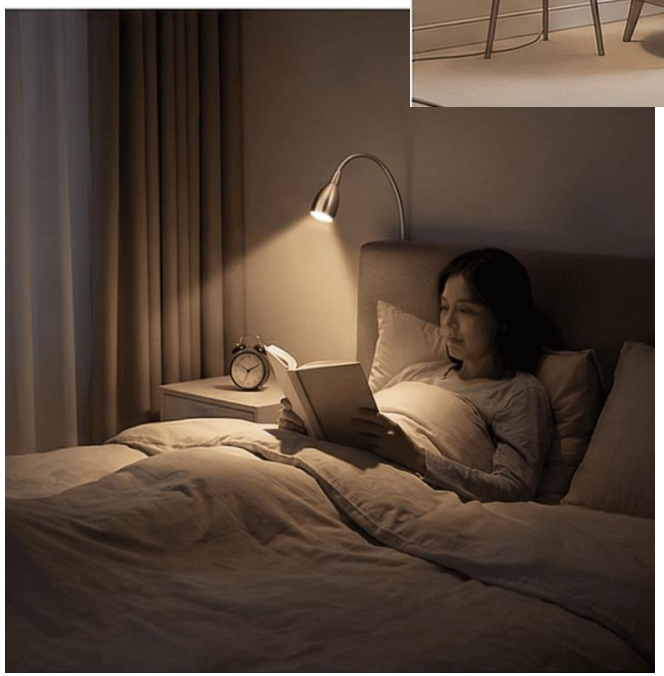
Bedrooms



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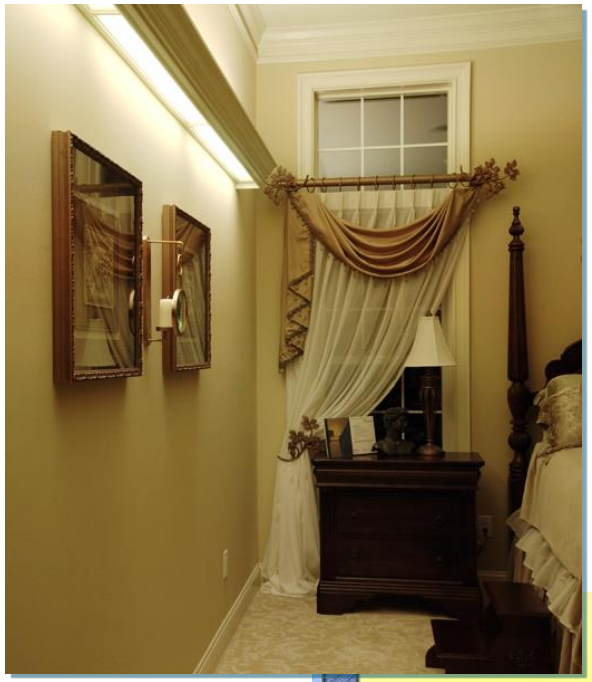
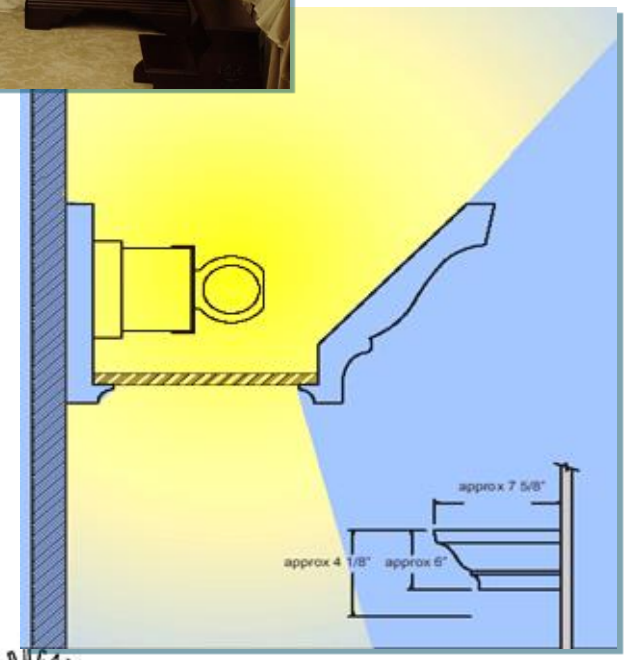
Bedrooms





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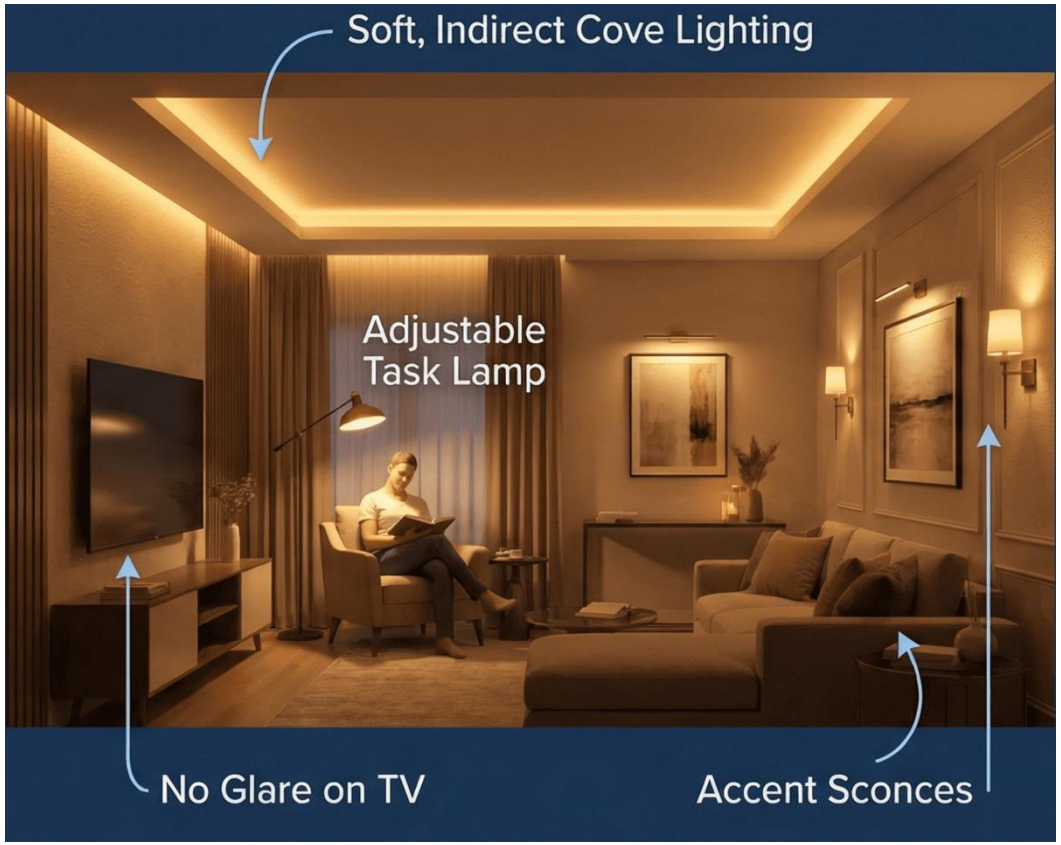
Living room



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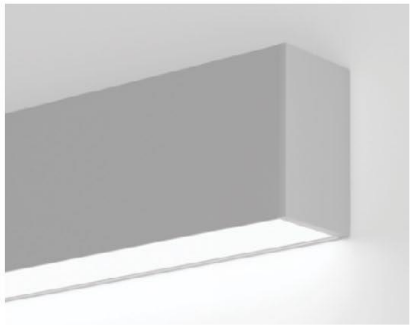
Memory Care Facility, Boston, MA

- Common dining areas
- Lighting redesign
  - Supplement existing lighting with direct/indirect pendants
  - Add wall-mounted direct/indirect linear fixtures
- CS Schedule:

Time	CS
7:00 am - 5:00 pm	0.4
5:00 pm - 6:00 pm	0.4 → 0.1
6:00 pm - Bed	< 0.1



Hospital Room Concept

- High CS (0.3-0.4) in the morning (300-400 lux at eye)
- Medium CS (0.2) in the afternoon (200 lux at eye)
- Low CS (≤0.1) at night (≤ 30 lux at eye)



Note: light levels in lux will change depending on light source spectra. This is why we use CS instead, because it accounts for absolute and spectral sensitivity of the circadian system

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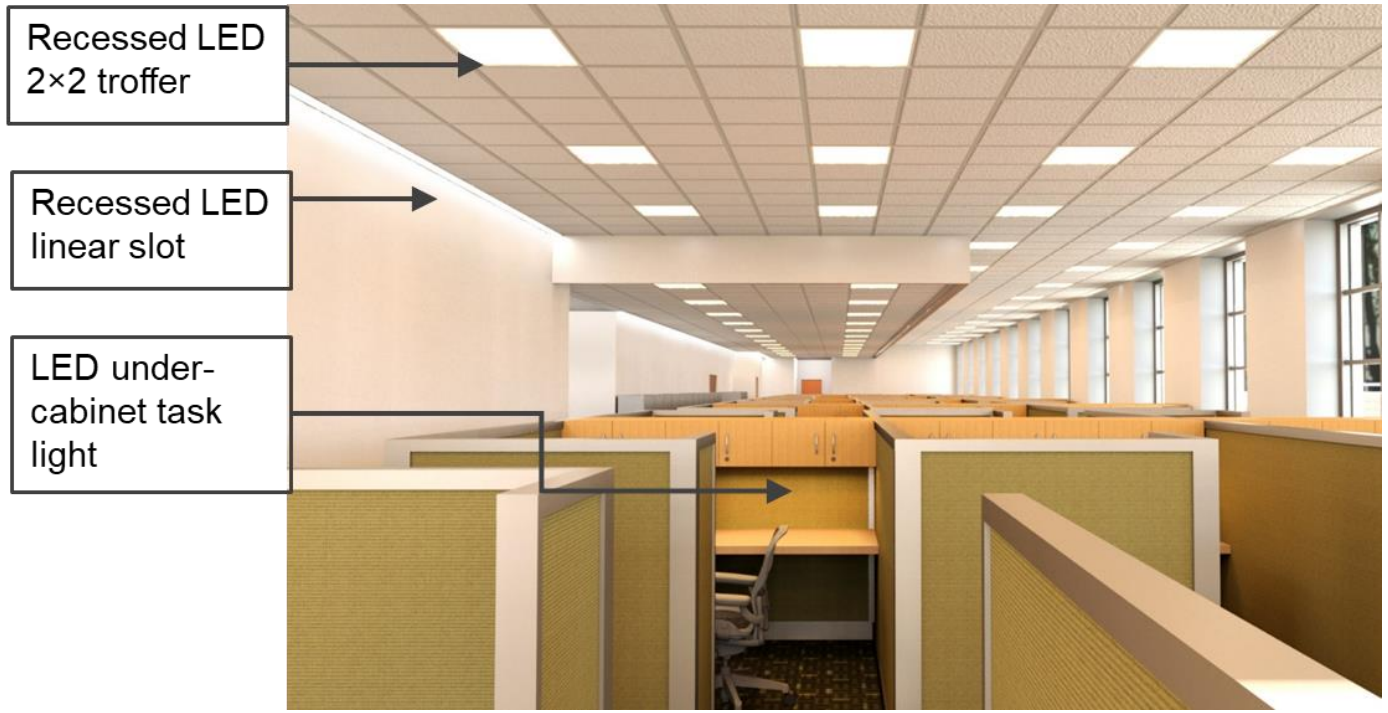
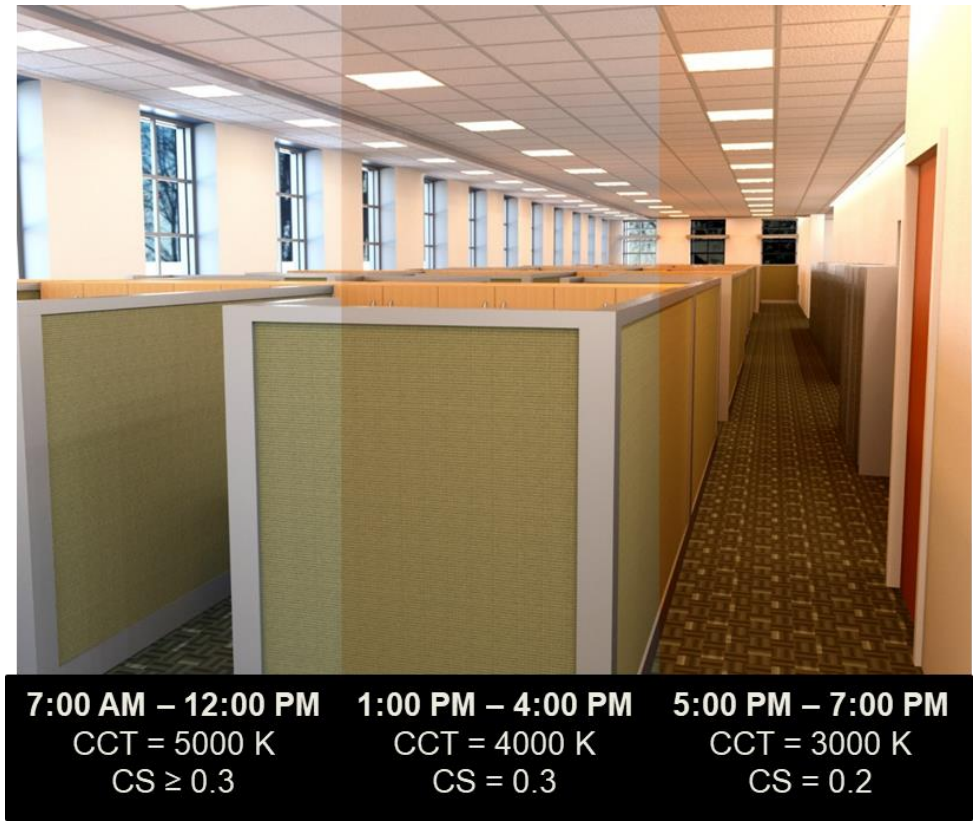
US Embassy, Riga Latvia

- Two alternative circadian effective lighting design strategies
- Static lighting
- CCT changing





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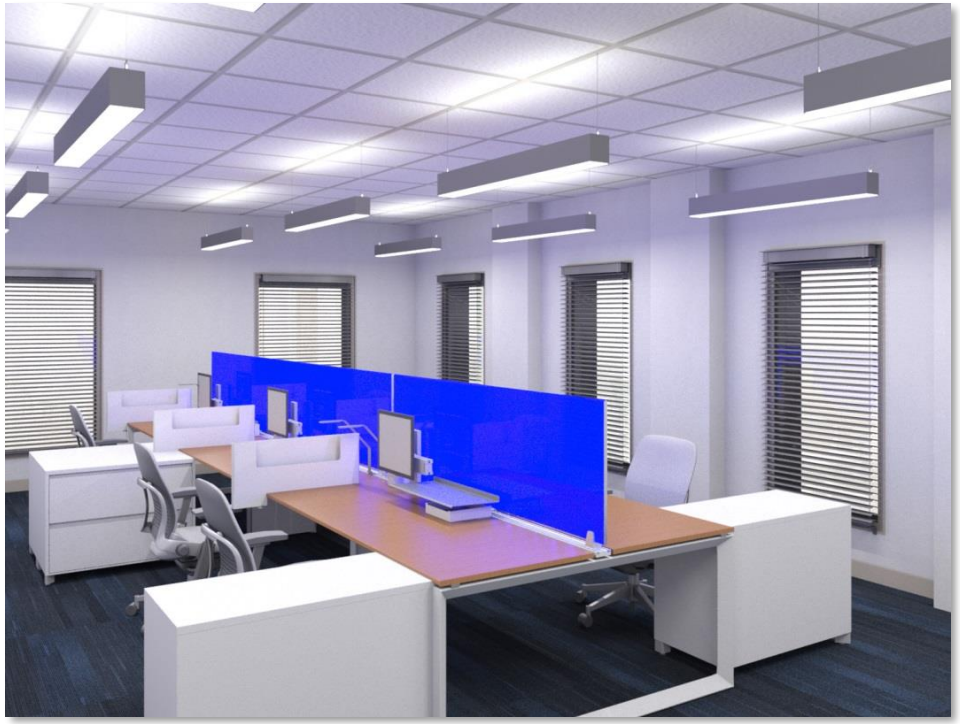
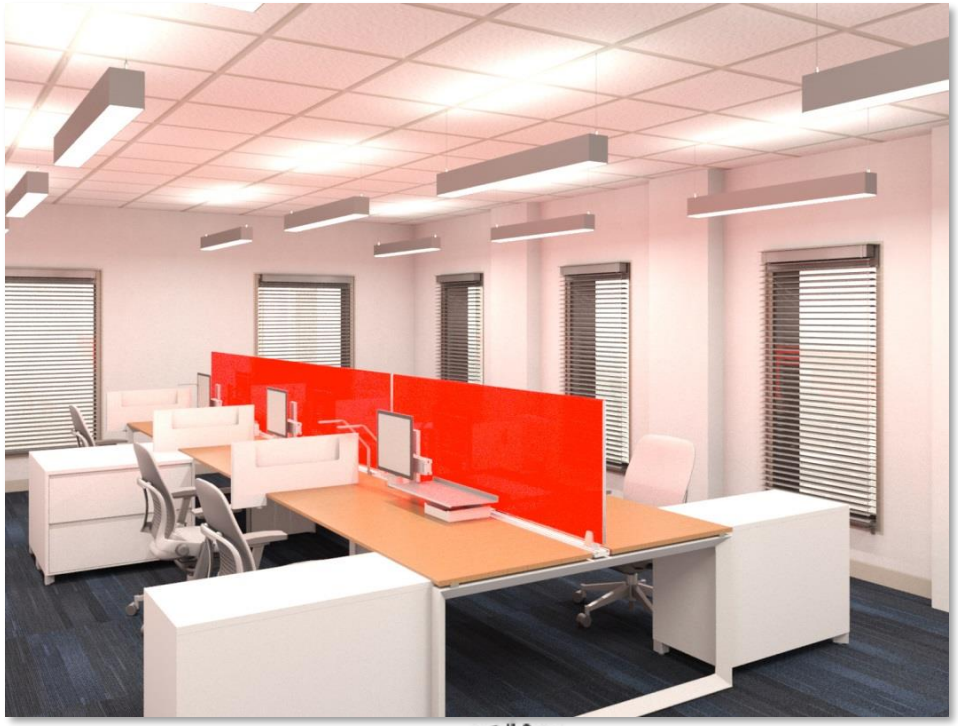
Office Lighting Concept

- Morning – bright or high CCT ambient lighting with blue light at desk level to help promote circadian entrainment



- Afternoon – dim or lower CCT ambient lighting with red light at desk level to promote alertness but not disrupt circadian entrainment



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School Classroom Concept

- Existing design (left) provides inadequate CS whereas the redesign employing direct/indirect linear pendants (right) provided adjustable CS throughout the day while improving student/teacher visibility and the classroom's aesthetic appeal

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School Classroom/Lecture Hall Concept

- Add layers of saturated blue light (470 nm light) to increase daytime CS

In conclusion

- Light *and* dark can and should be used as a non-pharmacological intervention to improve circadian sleep disorders
  - Need to appropriately specify and measure the stimulus
  - Light is just as important as darkness
- The future
  - Every person may have an app and a lighting system in their homes, hospitals, schools, offices that will deliver individualized lighting solutions
    - Precision medicine with light?
  - Light can also aid in improving postural control and stability

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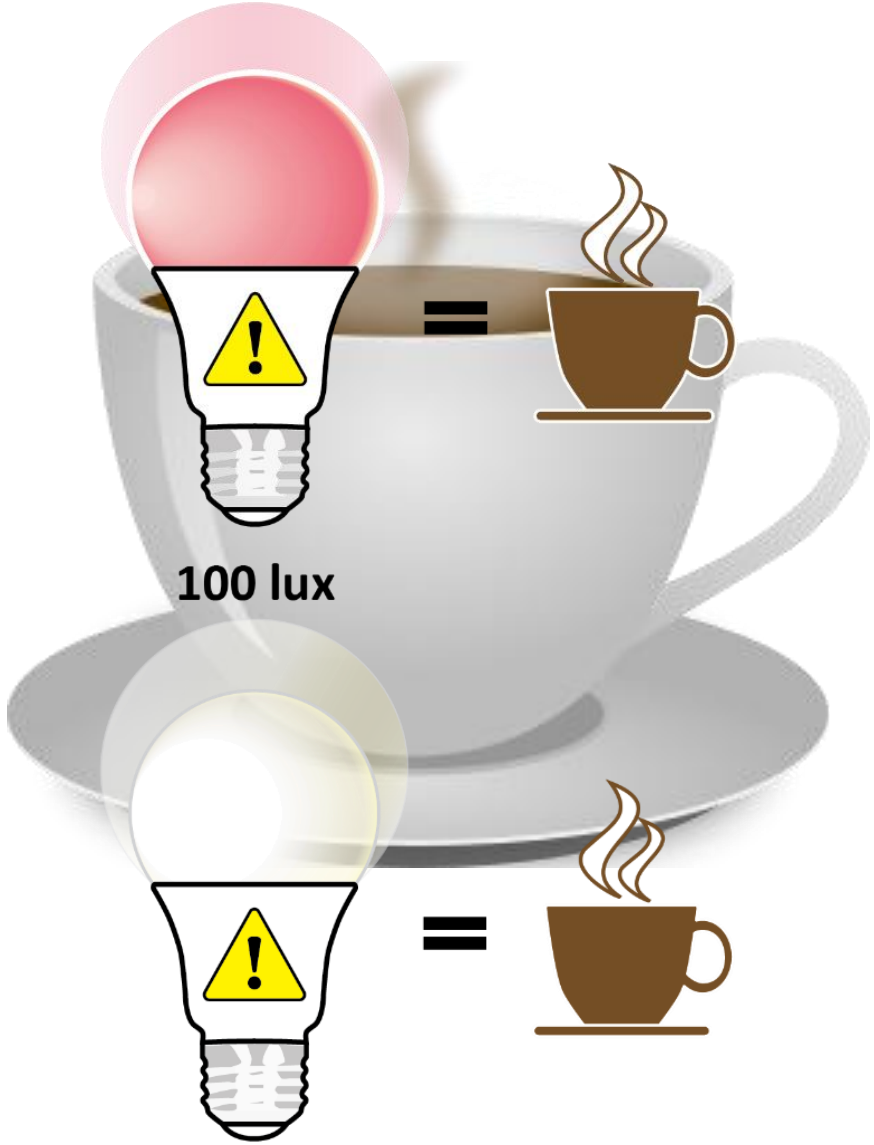
Light and alertness

- But… Don't forget that light can also increase alertness, like a **cup of coffee**
  - Lighting characteristics for alertness are different than those for circadian entrainment
- Studies have shown that red light can have an acute alerting effect without suppressing melatonin or affecting circadian phase
  - Consider using red light as a way to boost alertness for occupants, especially shift workers



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Stay in touch

For research updates from the Mount Sinai Light and Health Research Center:

https://www.linkedin.com/company/light-and-health-research-center-mount-sinai

https://icahn.mssm.edu/research/light-health

https://www.facebook.com/Light.and.Health.Research.Center.Mount.Sinai

Bi-monthly Newsletter:
https://www.light-health.org/

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Thank you!

Email contact:
mariana.figueiro@mountsinai.org

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This concludes The American Institute of Architects Continuing Education Systems Course