Designers Lighting Forum

Sleep Math:
Better daytime light = better nighttime sleep

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

Learning Objectives

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

1. Understand the importance of sleep on wellbeing and chronic health conditions
2. Describe the impact of light and daylight on sleep and occupant health
3. List three design strategies in multi-family residential that improve occupant health
4. Explain how health-centric design and amenities impact tenant attraction and retention

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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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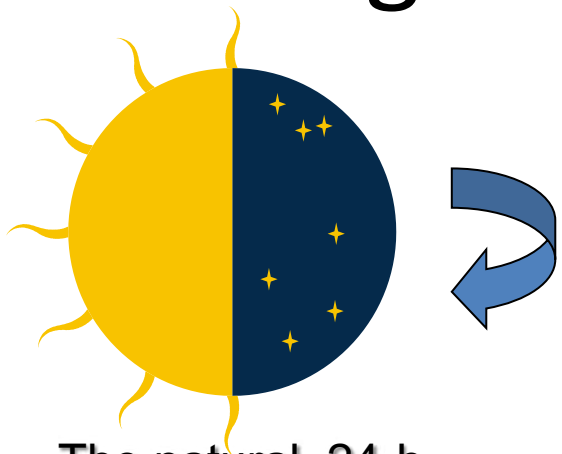
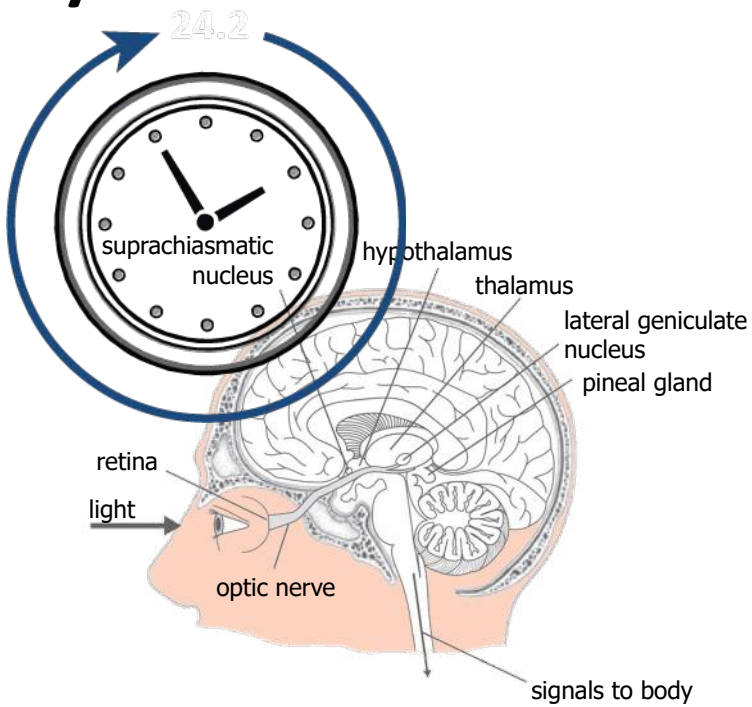
Light and the circadian system



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

Circadian system disruption

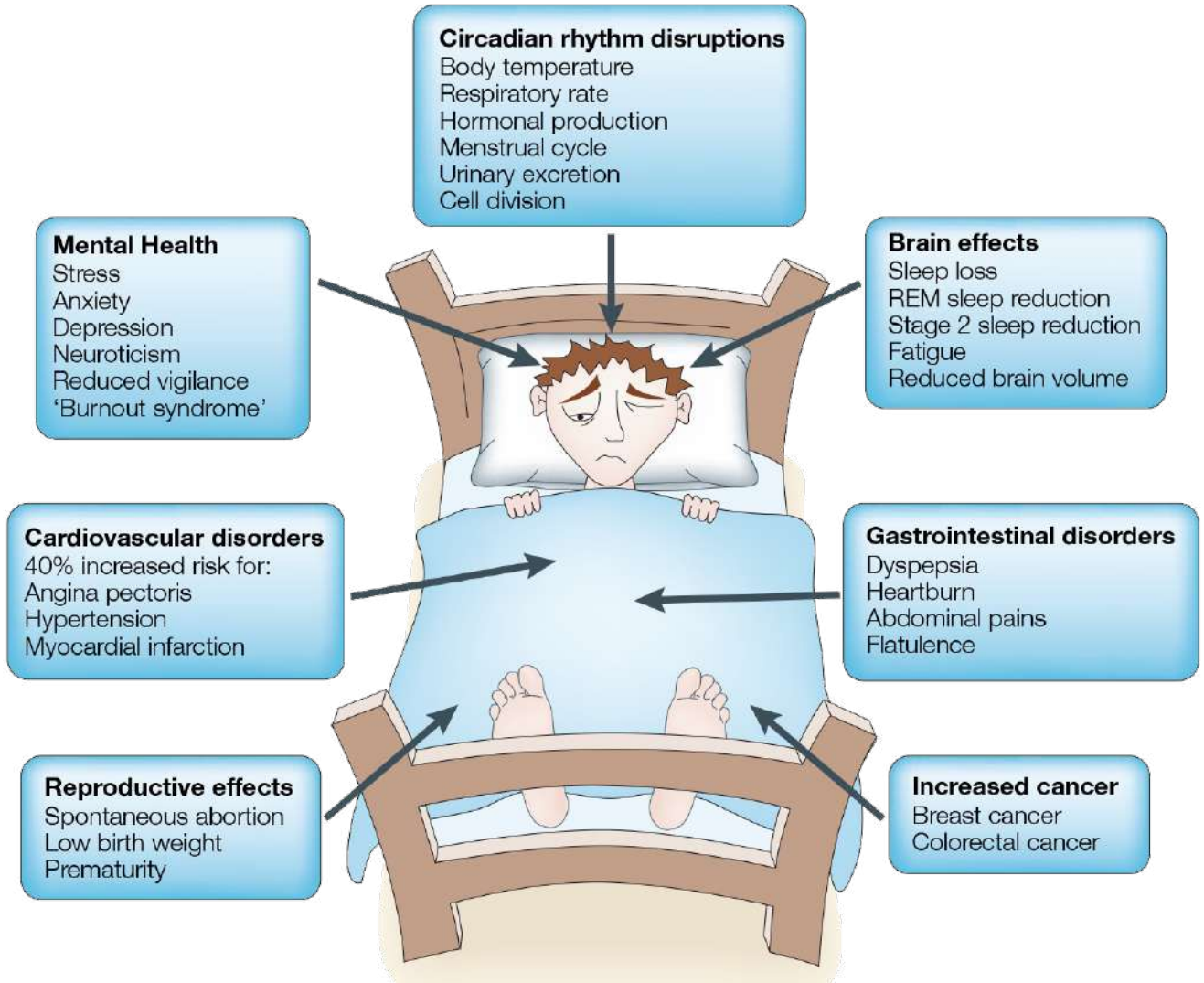


Image: Foster RG and Wulff K. The rhythm of rest and excess. *Nature Reviews Neuroscience*. 2005; 6: 407-414.

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Sleep – wake cycle

Two-process model

- Circadian (C)
- Homeostatic (S)
  - The suprachiasmatic nuclei (SCN) maintain wakefulness, counterbalancing the "homeostatic sleep drive"
  - In both humans and monkeys, the circadian timing system promotes and maintains wakefulness across the subjective day and opposes the accumulating homeostatic sleep drive

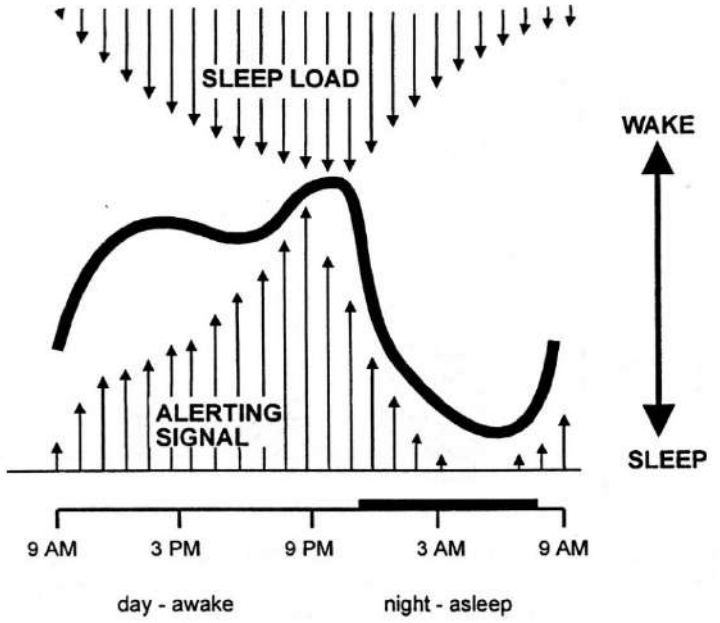

Figure 5 Schematic of the "opponent processes" mediating physiological sleepiness as a function of time of day. Sleep drive increases in response to wakefulness imposed and/or maintained by the suprachiasmatic pacemaker. Increasing levels of SCN-dependent alerting over the subjective day opposes homeostatic sleep drive, both of which peak shortly before the habitual sleep phase. (From Ref. 66.)

Dijk DJ, Edgar DM. Circadian and homeostatic control of wakefulness and sleep. In: Turek FW, Zee PC, editors. *Regulation of Sleep and Circadian Rhythms*. New York: Marcel Dekker Inc; 1999. pp. 111–147.

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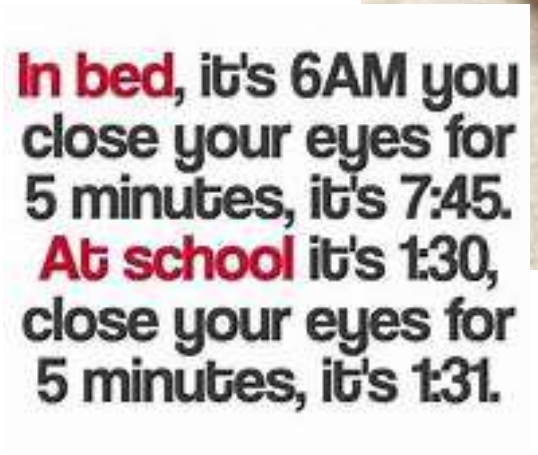
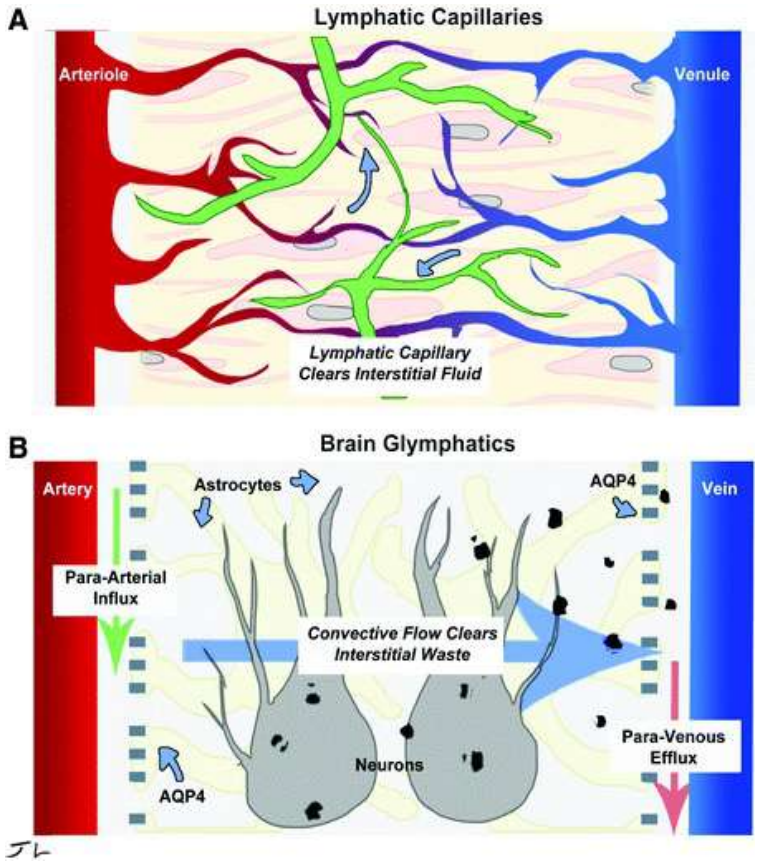
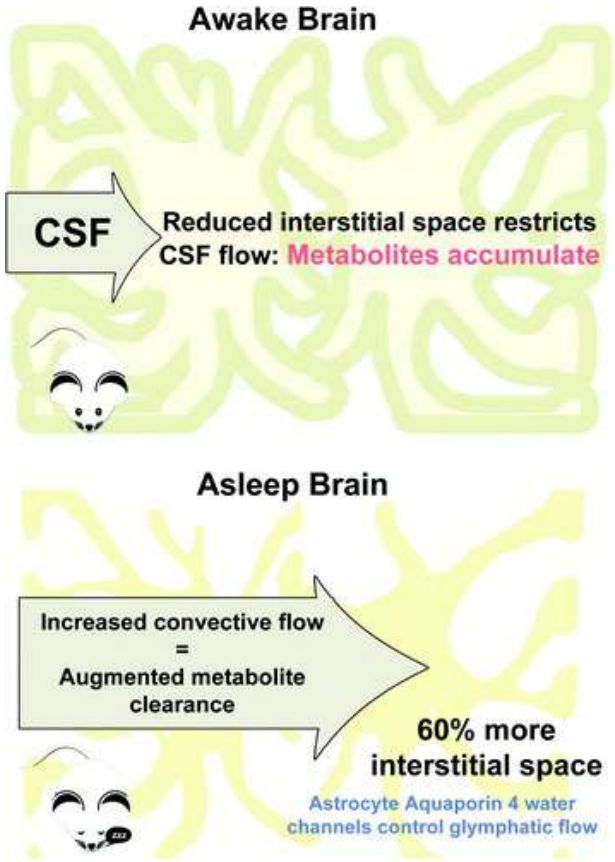
Why do we sleep?



Why do we sleep?

- Sleep cleans up the debris in the brain that we accumulate during wakefulness





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

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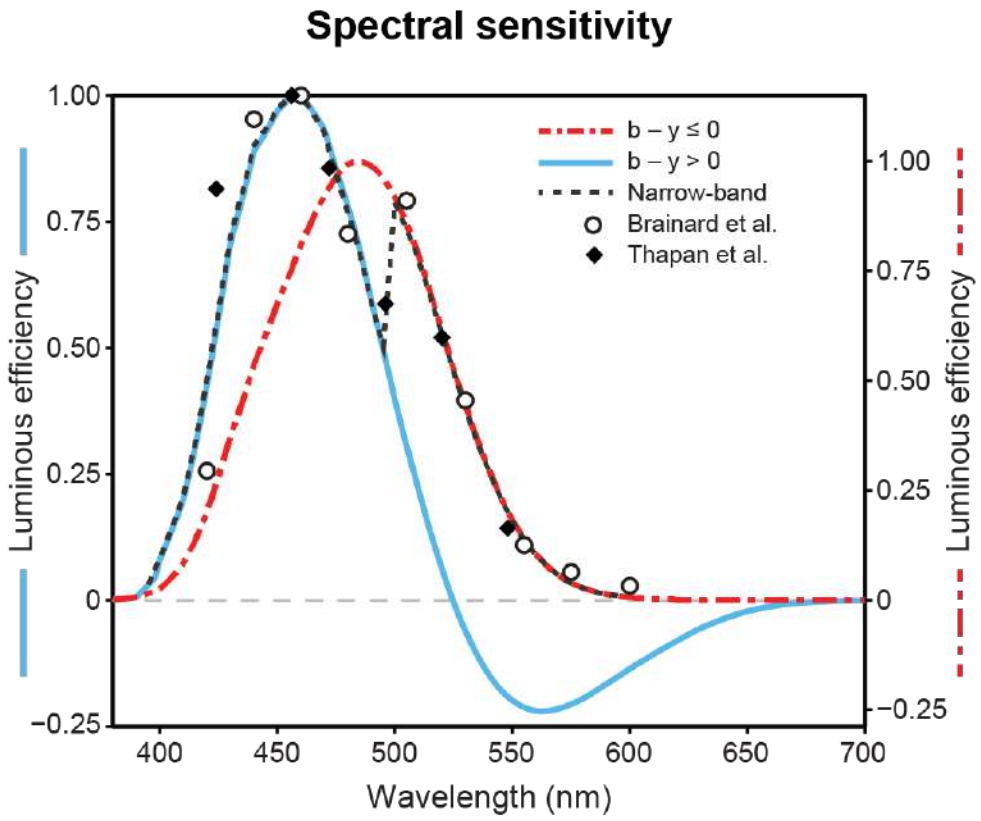
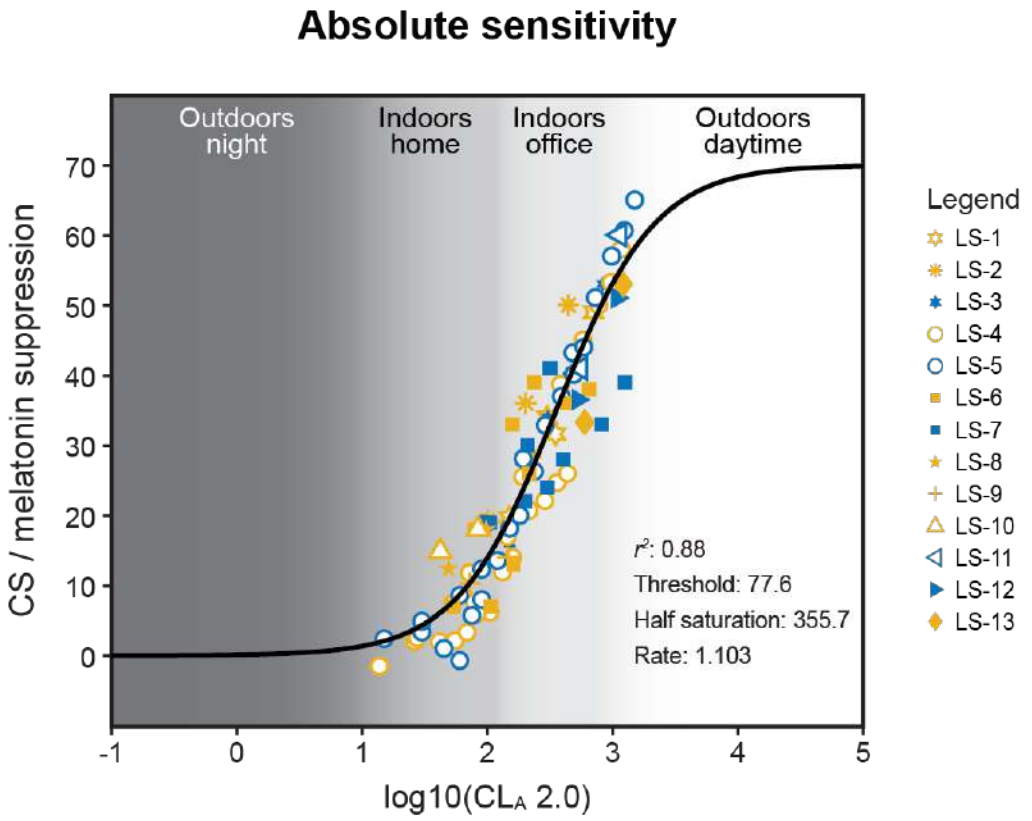
What metric to use?

Specification of the stimulus: Humans

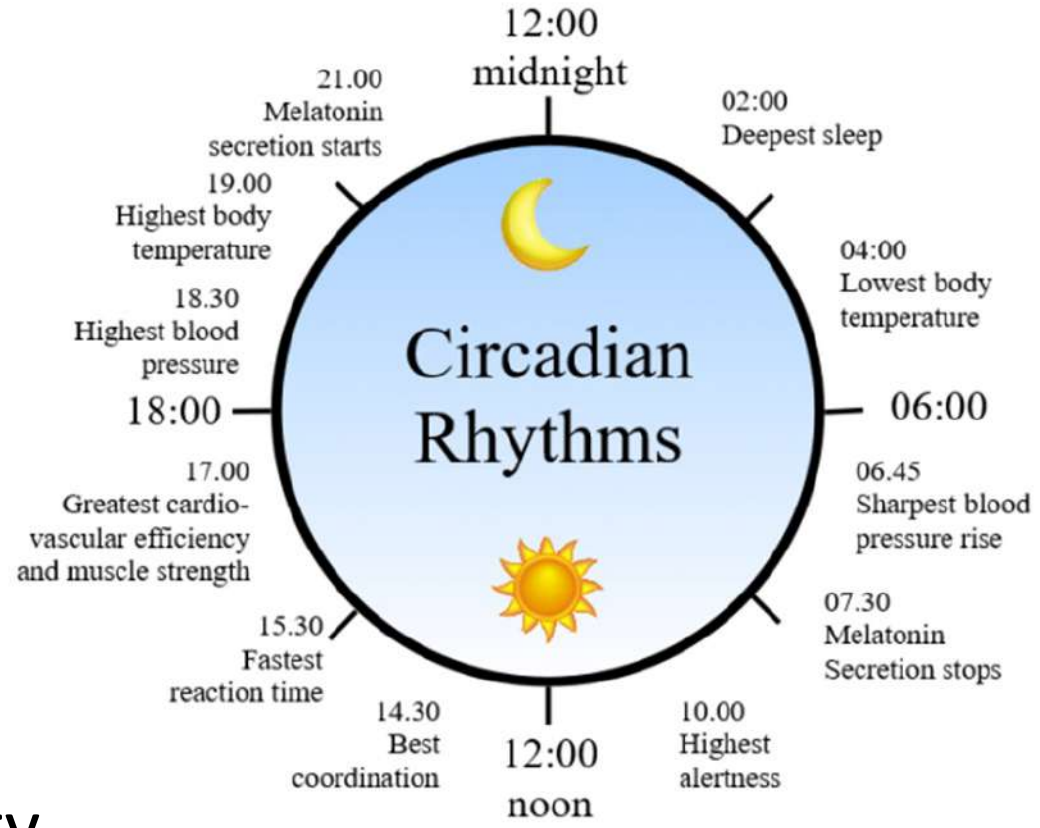




Rea MS, Figueiro MG, Bullough JD, Bierman A. A model of phototransduction by the human circadian system. *Brain Research Reviews*. 2005; 50: 213-228.
Rea MS, Figueiro MG, Bierman A, Hamner R. Modelling the spectral sensitivity of the human circadian system. *Lighting Research & Technology*. 2012; 44: 386-396.
Rea MS, Nagare R, Figueiro MG. Modeling circadian phototransduction: Retinal neurophysiology and neuroanatomy. *Frontiers in Neuroscience*. 2021; 14: 1467.
Rea MS, Nagare R, Figueiro MG. Modeling circadian phototransduction: Quantitative predictions of psychophysical data. *Frontiers in Neuroscience*. 2021; 15: 44.

UL 24480 Design Guideline

- This document is intended for use by those who design and specify lighting in buildings and wish to provide light for vision and for circadian entrainment for typical day-active and night-inactive people
- Provide a light measurement and lighting specification methodology as well as a method for verification of effect



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Recommended Practice and Design Guideline

- The amount of light equivalent to that, after 1 h of exposure, capable of suppressing the production of melatonin at night by at least 30% (CS ≥ 0.30) should be continuously available at the occupant's eyes for a minimum of 2 h during the daytime

Alternative method: WELL recommendations (versions 1 and 2)

Light source	Metric	Equivalent melanopic lux (EML)		
		150	200	240
Blackbody (5000 K)	CS	0.22	0.28	**0.31**
	E_V (E_H)	161 (230)	214 (349)	257 (368)
LED 107	CS	0.21	0.27	**0.30**
	E_V (E_H)	230 (329)	307 (439)	368 (526)
LED 21	CS	0.21	0.26	**0.29**
	E_V (E_H)	239 (342)	318 (454)	382 (546)
D65	CS	0.25	**0.3**	**0.34**
	E_V (E_H)	136 (194)	181 (259)	218 (312)

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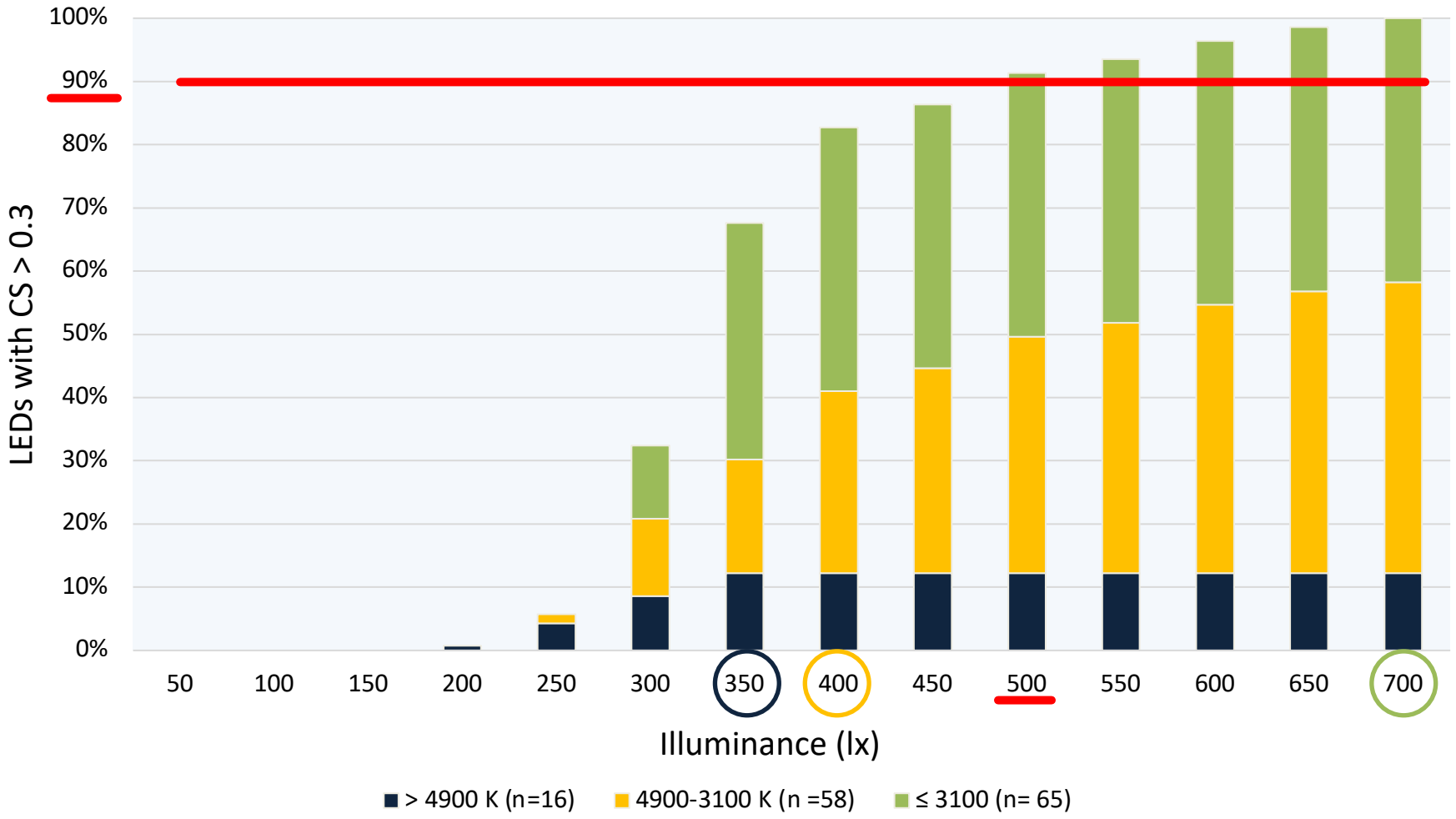
Alternative method: Vertical illuminance at eye (E_V = 500 lx)



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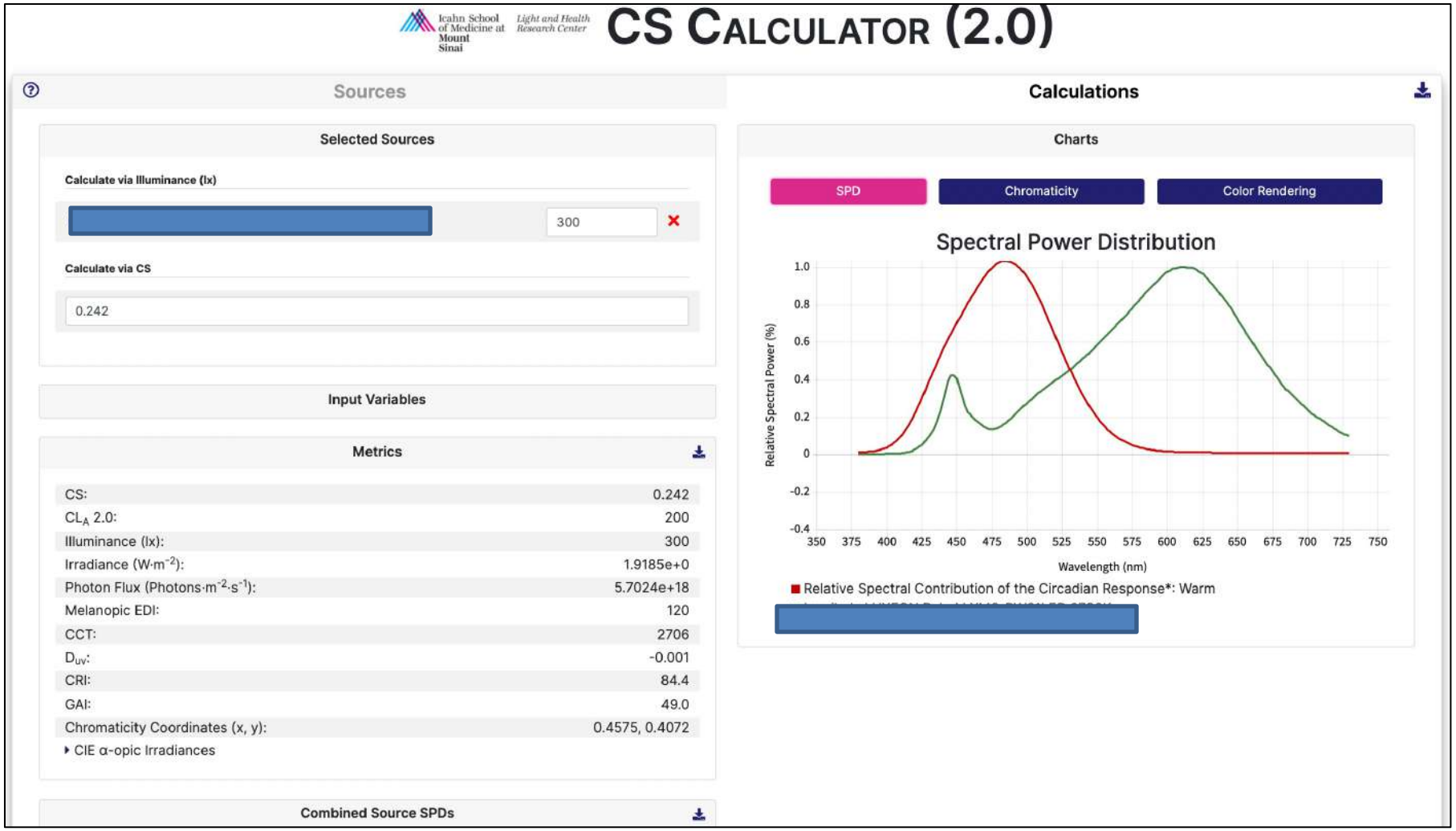
Quick Guide

- Step 1: Establish a circadian-effective light design criterion (e.g., CS = 0.3)
- 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 calculations for the building space (e.g., AGi32)
- Step 5: Calculate CS from the vertical illuminance at the eye (E_V) and the spectral power distribution (SPD)
- Step 6: Determine if the selected lighting system meets the circadian-effective lighting design criterion; repeat steps 2 – 6 if necessary

CS Calculator 2.0

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



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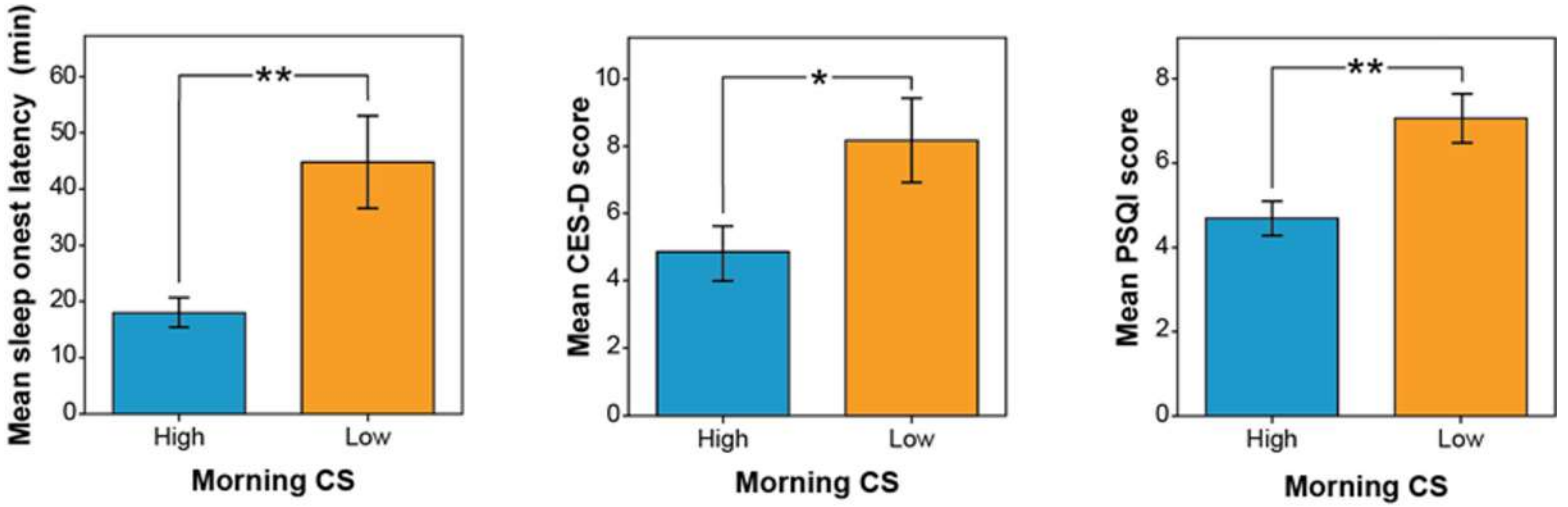
Specific Notes on Calculation Tools

- CS Calculator 2.0
  - Web-based tool; can save calculation result on local device
  - Relative or absolute spectral calculations
  - Single or multiple/combined SPDs in any/irregular wavelength intervals including non-integers
  - Forty-six in-built sample SPDs
  - CS value can be linked to nocturnal melatonin suppression under specific conditions
  - Reverse calculation: Identify photopic illuminance required to achieve a specific CS value (e.g., as specified by UL 24480, *Design Guideline for Promoting Circadian Entrainment with Light for Day-Active People*)

What does the research say?

Light and sleep in office workers

- Those exposed to higher morning (08:00 to noon) CS (CS > 0.3) fell asleep faster (less sleep onset latency) and reported better sleep and feeling less depressed than those exposed to low morning CS (CS < 0.15)



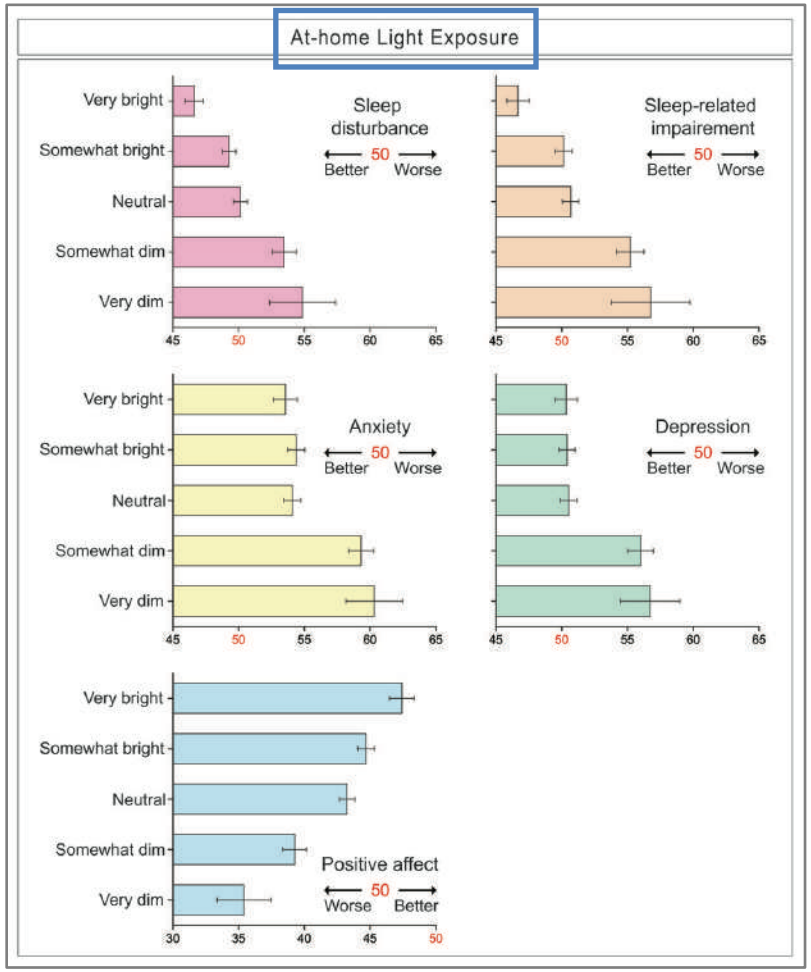
(** = $p < .01$; * = $p < 0.05$)

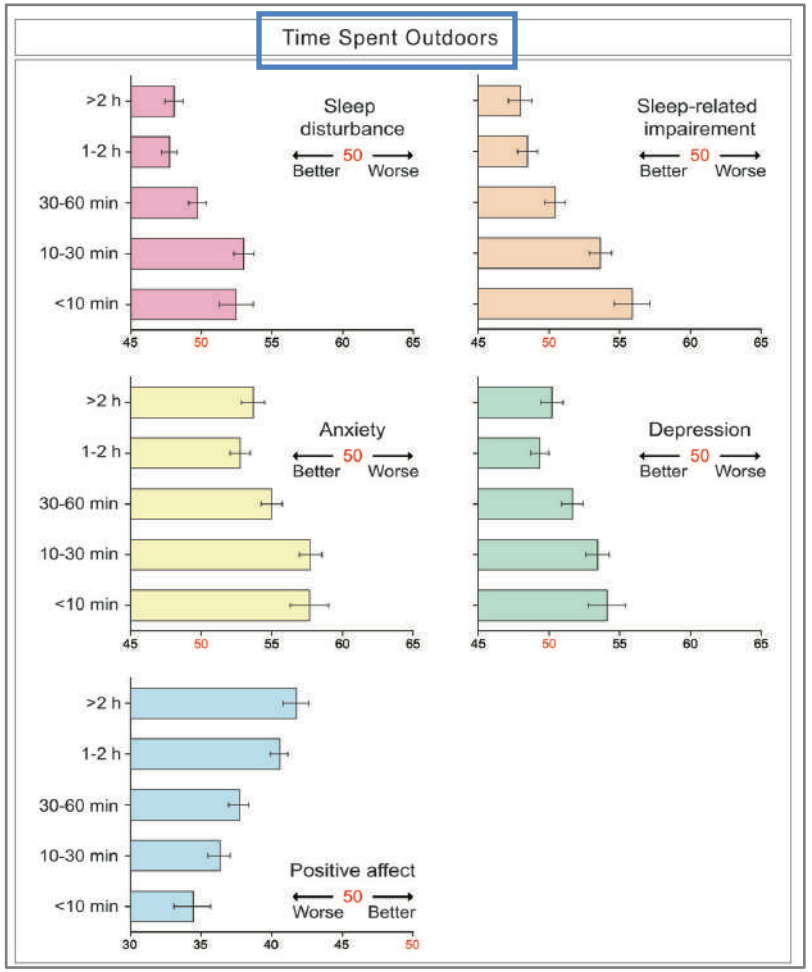
Figueiro M.G., Steverson B., Heerwagen J., Kampschroer K., Hunter C.M., Gonzales K., Rea, M.S. (2017). The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health*; 3(3):204-215.

Light and sleep survey during COVID-19 shutdown

- The LHRC sent out a survey probing people's light exposures (indoors and outdoors) and how that impacted measures of sleep, mood, and anxiety
- **Hypothesis:**
  More light during the day = better sleep and mood
- Over 700 responses
- Included in the analyses are those who are employed but working at home or unemployed and staying home

Light and sleep survey during COVID-19 shutdown





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REVOLV Study 1

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Study design

20 total participants

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
n = 10	Baseline						View								Baseline						Blinds							
n = 10	Baseline						Blinds								Baseline						View							

Environmental monitoring

Sleep tracking

Surveys

Personal Light

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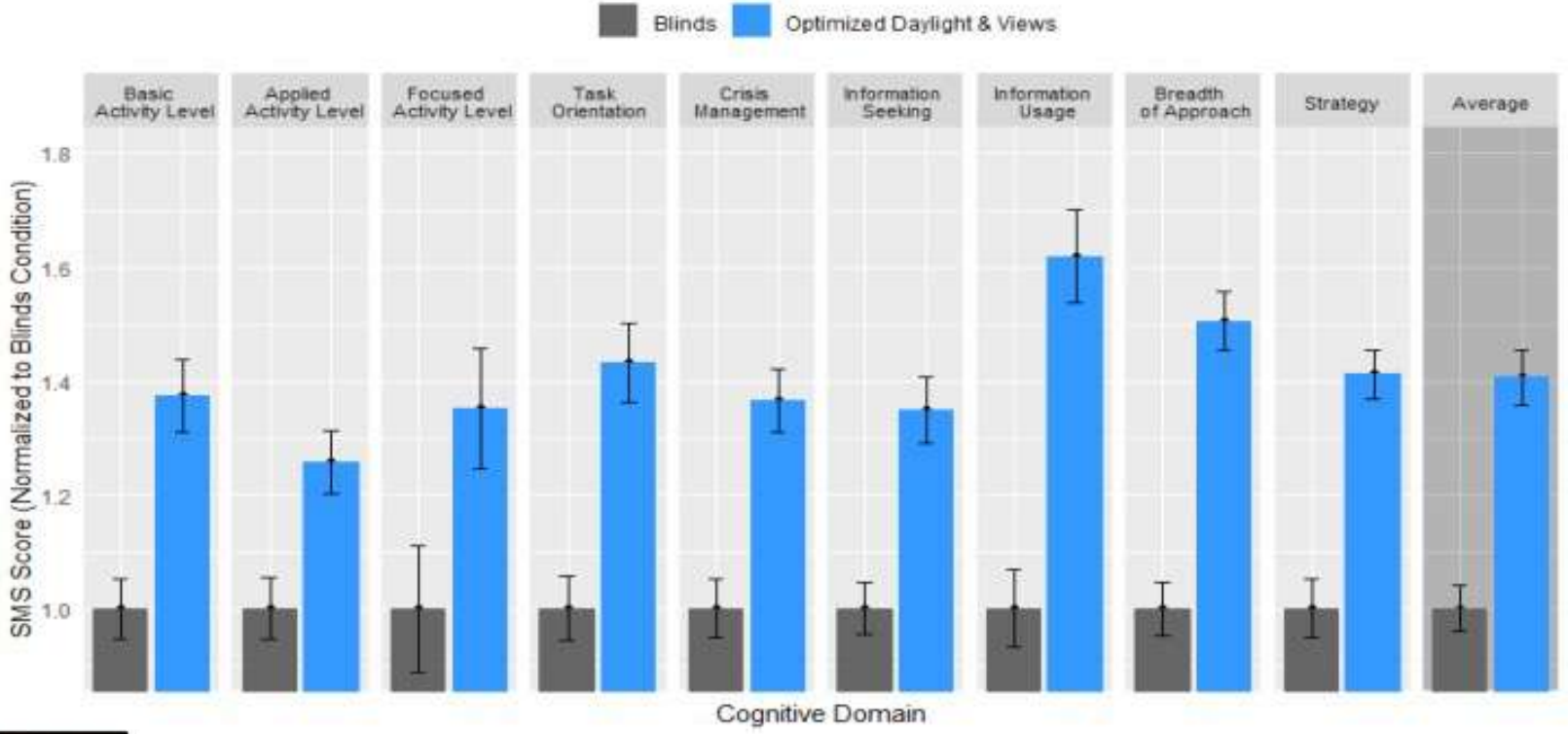
Quality sleep improves mental health and productivity

30 participants spent one week working in two office environments – electrochromic glass or traditional blinds



Boubekri M, Lee J, MacNaughton P, Woo M, Schuyler L, Tinianov B, et al. The impact of optimized daylight and views on the sleep duration and cognitive performance of office workers. International Journal of Environmental Research and Public Health. 2020; 17: 3219

REVOLV Study 2

Icahn School of Medicine at Mount Sinai

Light and Health Research Center

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20
Residents

28 Days
in 2020

EXO Apartments
Reston, Virginia

Demographics

Demographics

		No. (%)
Gender	Female	11 (55%)
	Male	8 (40%)
	Non-binary	1 (5%)
Age	Average age	35 years old
Race	Asian	2 (10%)
	Black	3 (15%)
	Multiracial	3 (15%)
	White	9 (45%)
	Hispanic/Latino/Spanish in Origin	3 (15%)
Employment	No	5 (25%)
	Yes	15 (75%)
General Health	Poor	0 (0%)
	Fair	1 (5%)
	Good	4 (20%)
	Very Good	11 (55%)
	Excellent	4 (20%)
Sleep Chronotype	Average nightly sleep duration	8.2 hours
	Slight early	2 (10%)
	Normal	3 (15%)
	Slight late	7 (35%)
	Moderate late	8 (40%)

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PARTICIPANTS	WEEK 1	WEEK 2	WEEK 3	WEEK 4
10	BASELINE	SMART WINDOWS 	BASELINE	BLINDS 
10	BASELINE	BLINDS 	BASELINE	SMART WINDOWS 

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PARTICIPANTS	WEEK 1	WEEK 2	WEEK 3	WEEK 4
10	BASELINE	SMART WINDOWS	BASELINE	BLINDS
10	BASELINE	BLINDS	BASELINE	SMART WINDOWS

ENVIRONMENTAL MONITORING

SLEEP TRACKING

SURVEYS

PERSONAL LIGHT

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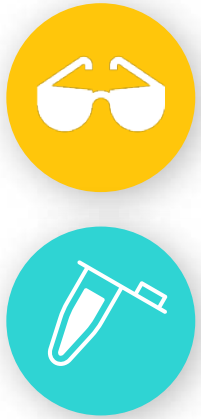
PARTICIPANTS	WEEK 1	WEEK 2	WEEK 3	WEEK 4
10	BASELINE	SMART WINDOWS	BASELINE	BLINDS
10	BASELINE	BLINDS	BASELINE	SMART WINDOWS

VITALITY SURVEY

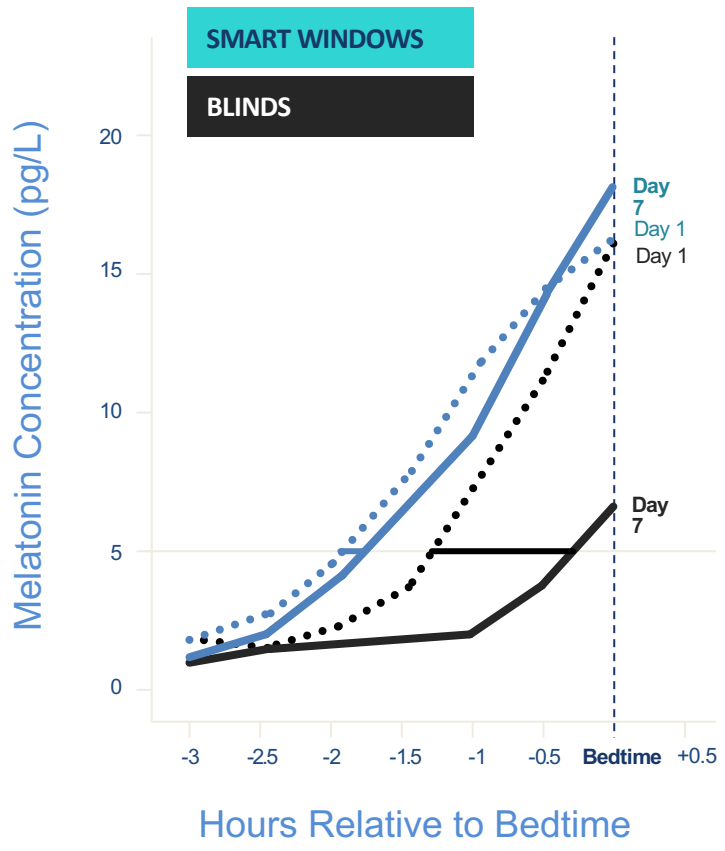
- 7:00 am
- 11:00 am
- 3:00 pm
- 7:00 pm
- 11:00 pm

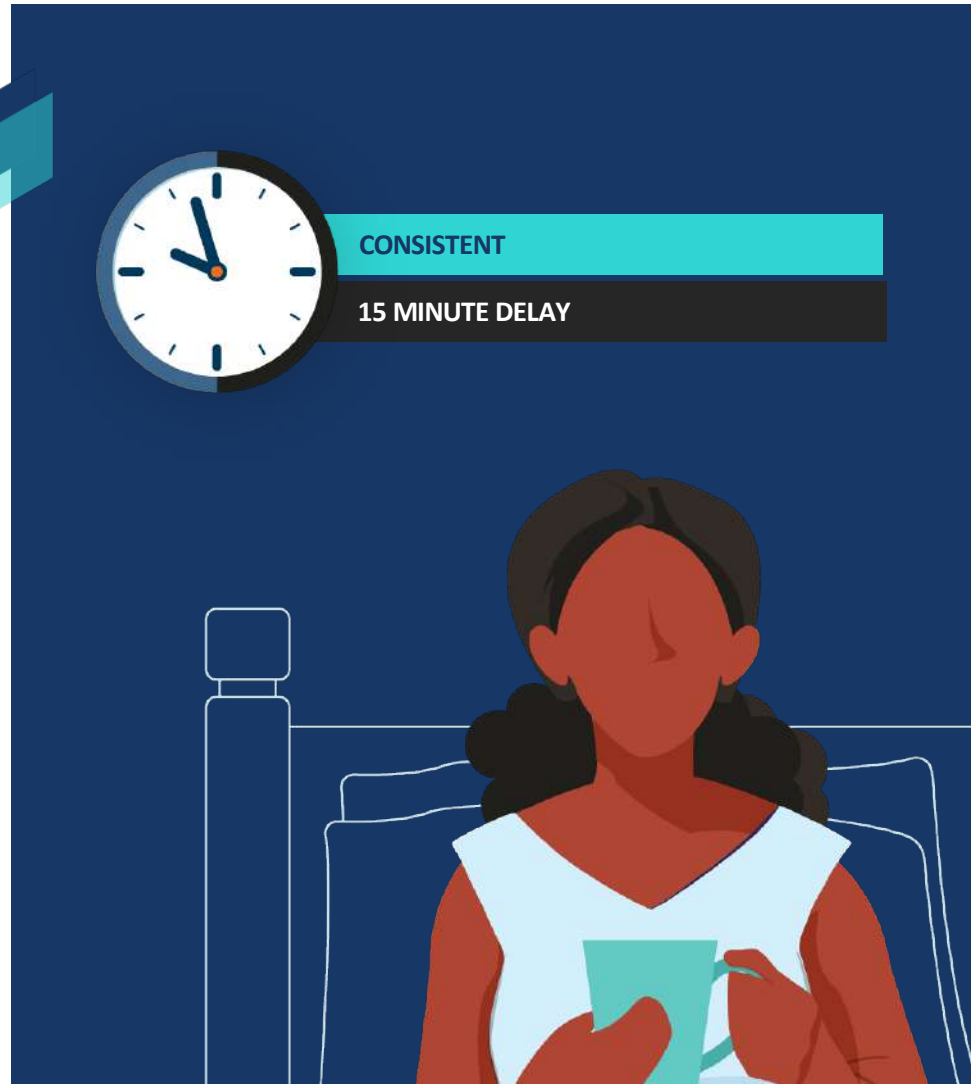
SALIVA TESTS

- 7:30 pm
- 8:00 pm
- 8:30 pm
- 9:00 pm
- 9:30 pm
- 10:00 pm
- 10:30 pm
- 11:00 pm
- 11:30 pm
- 12:00 am

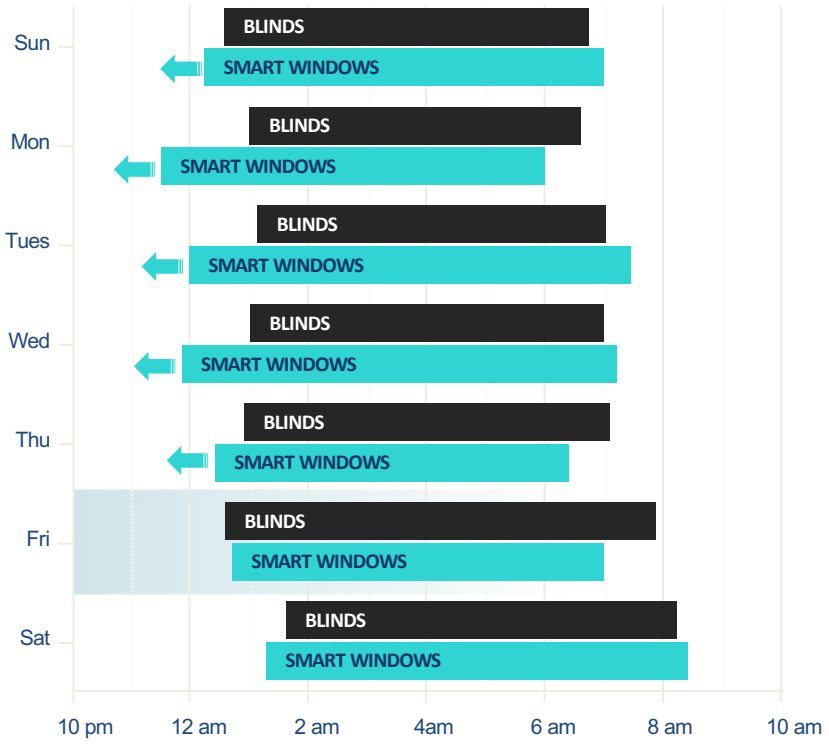


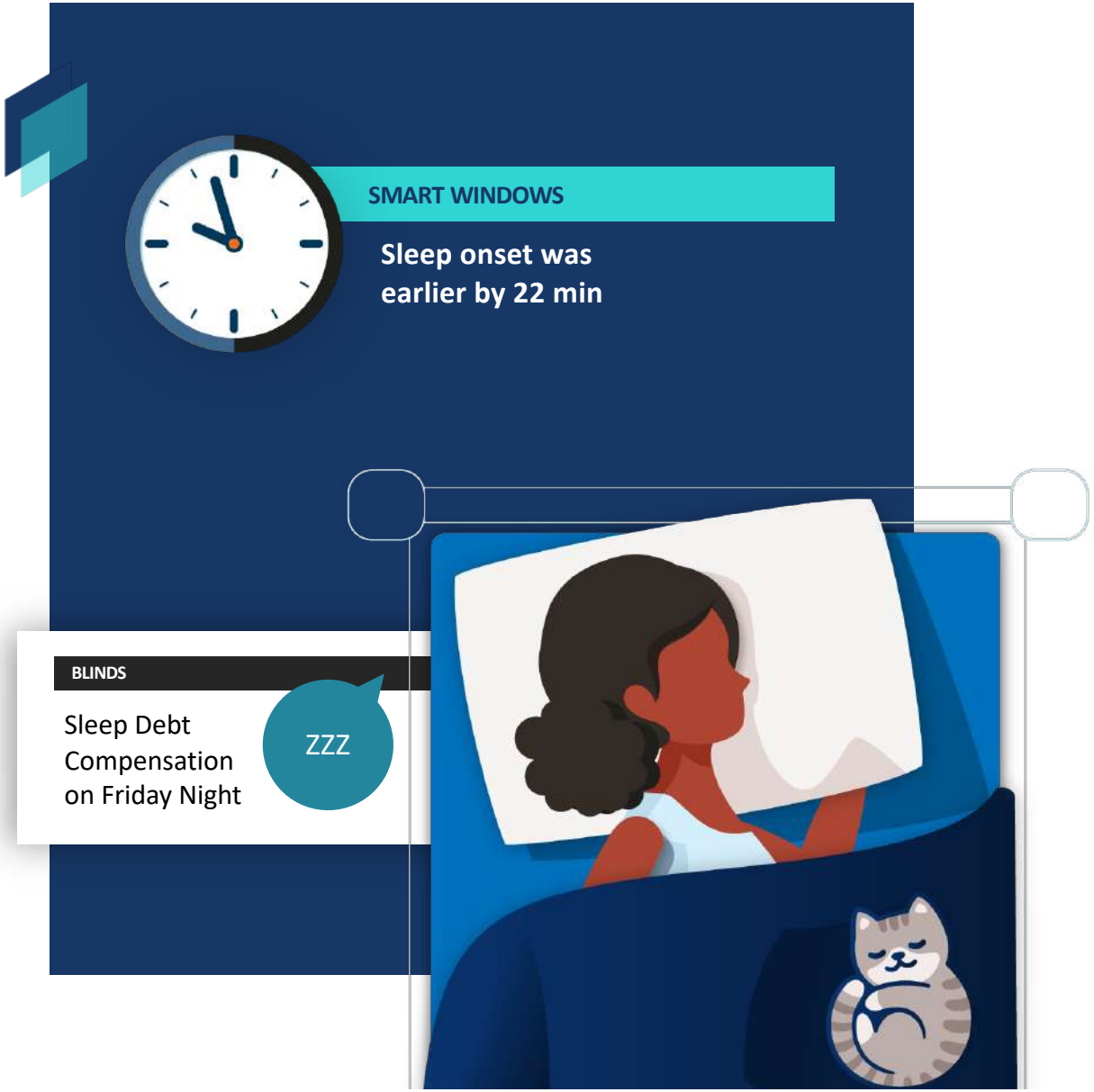
Melatonin


SMART WINDOWS
BLINDS
Melatonin Concentration (pg/L)
20
15
10
5
0
Day 7
Day 1
Day 1
Day 7
-3
-2.5
-2
-1.5
-1
-0.5
Bedtime
+0.5
Hours Relative to Bedtime


CONSISTENT
15 MINUTE DELAY

Sleep





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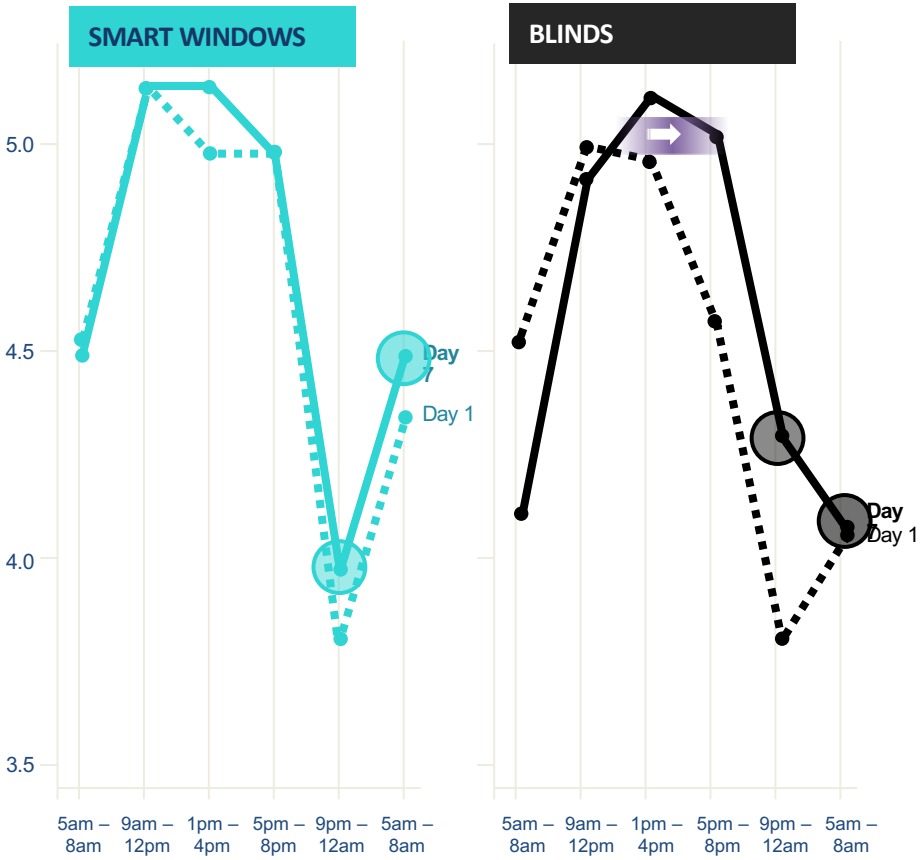
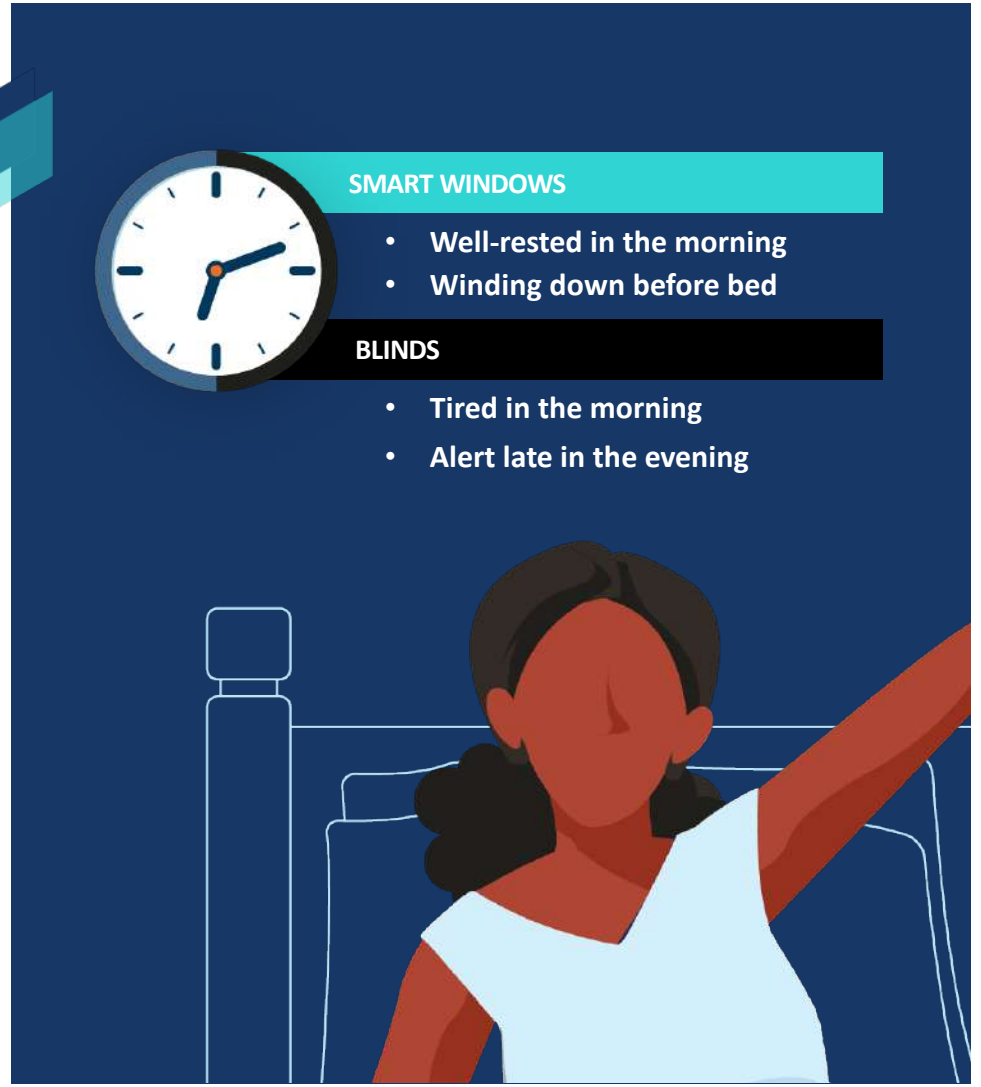
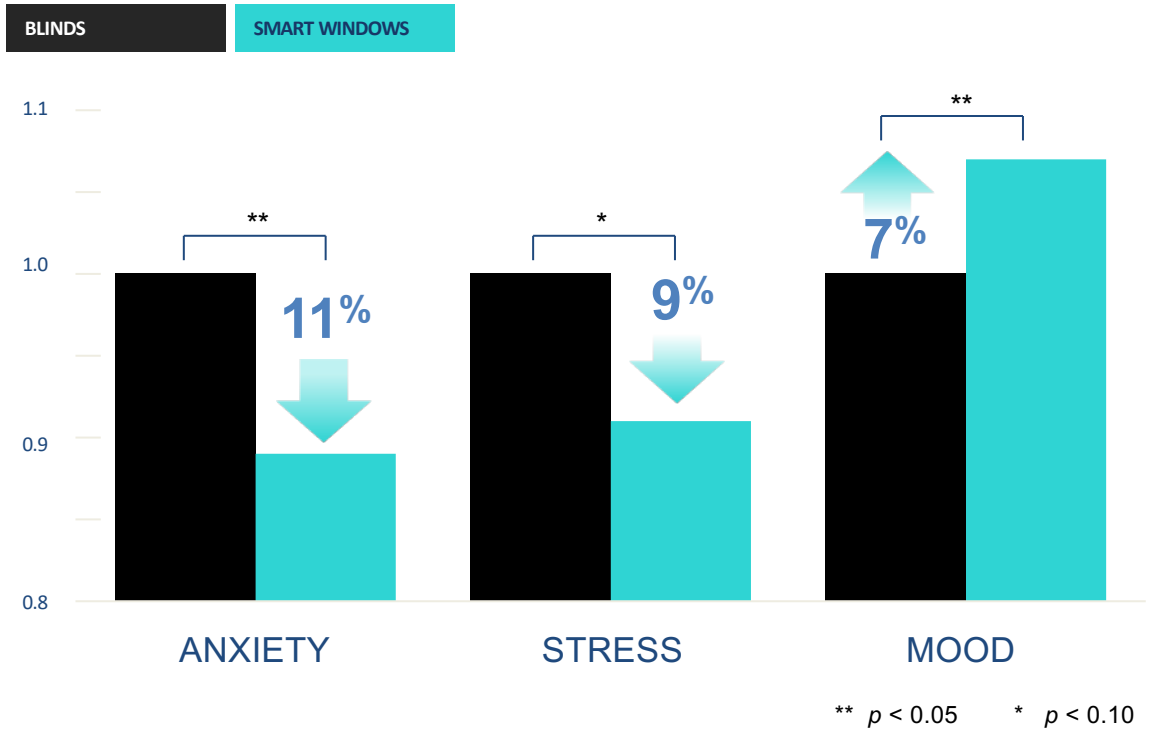
Vitality

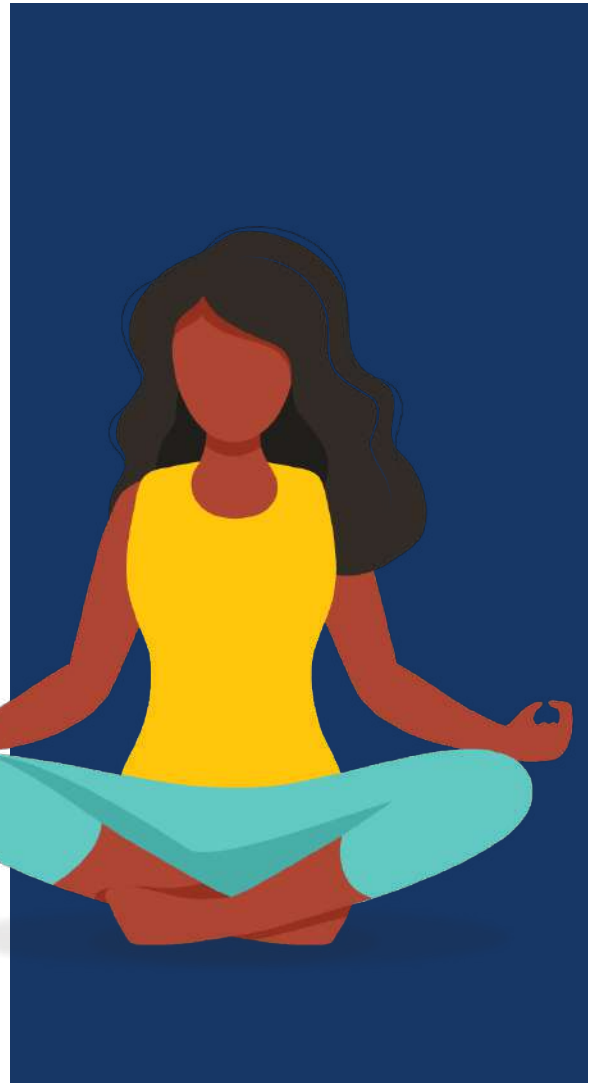

SMART WINDOWS
BLINDS
5.0
4.5
4.0
3.5
Day 7
Day 1
Day 7
Day 1
5am – 8am
9am – 12pm
1pm – 4pm
5pm – 8pm
9pm – 12am
5am – 8am


SMART WINDOWS
• Well-rested in the morning
• Winding down before bed
BLINDS
• Tired in the morning
• Alert late in the evening

Quality Sleep Improves Mental Health



** $p < 0.05$ * $p < 0.10$



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Daylight Maintains A Healthy Circadian Rhythm

Smart windows provide a home environment that optimizes circadian health:
From our hormones to how we sleep at night and function during the day.

Melatonin

Sleep

Vitality

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	SMART WINDOWS	BLINDS
Melatonin	Consistent melatonin onset	15 minutes delay over the course of the week
Sleep	Earlier sleep onset by 22 min	Sleep debt compensation on Friday night
Vitality	Consistent cycle of vitality with high morning and daytime energy levels	Delayed peak vitality, high nighttime energy levels and low morning vitality

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Ambient light therapy to promote entrainment in cancer patients

Sponsors: National Cancer Institute

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Sponsors: National Cancer Institute and

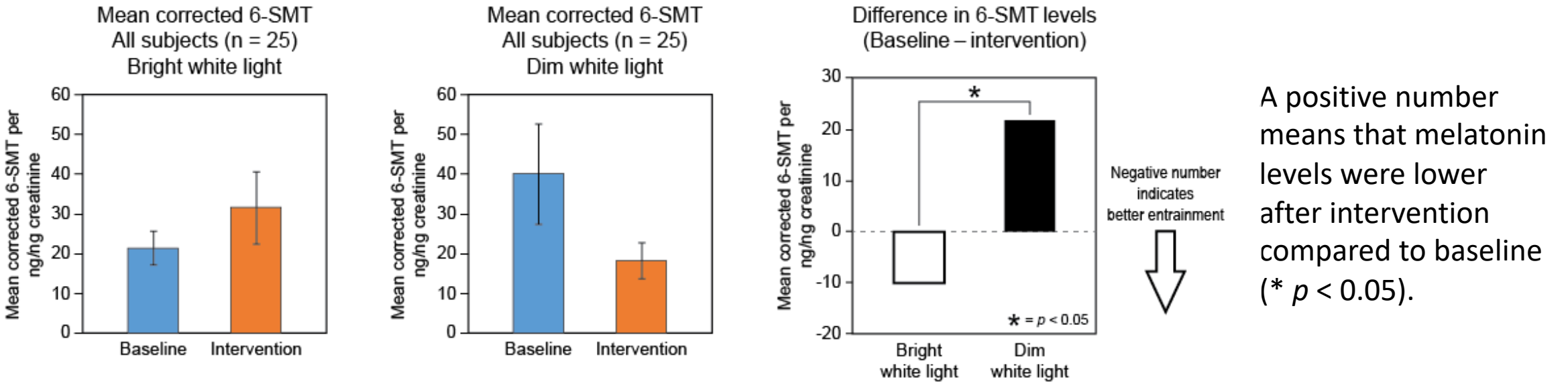
Light therapy and melatonin in myeloma transplant patients

- Our team investigated the impact of a CS of 0.3 (1000 lx at pillow, 3000 K light source) between 07:00 and 10:00 on:
  - Symptom burden (i.e., depression)
  - Melatonin levels (circadian entrainment)
  - Inflammation (IL-6) and neutropenic fever

Sponsors: National Cancer Institute and

Light therapy and melatonin in myeloma transplant patients

- Urinary melatonin increased in those receiving the active intervention and decreased in those receiving the inactive intervention, suggesting better entrainment in those receiving the active intervention



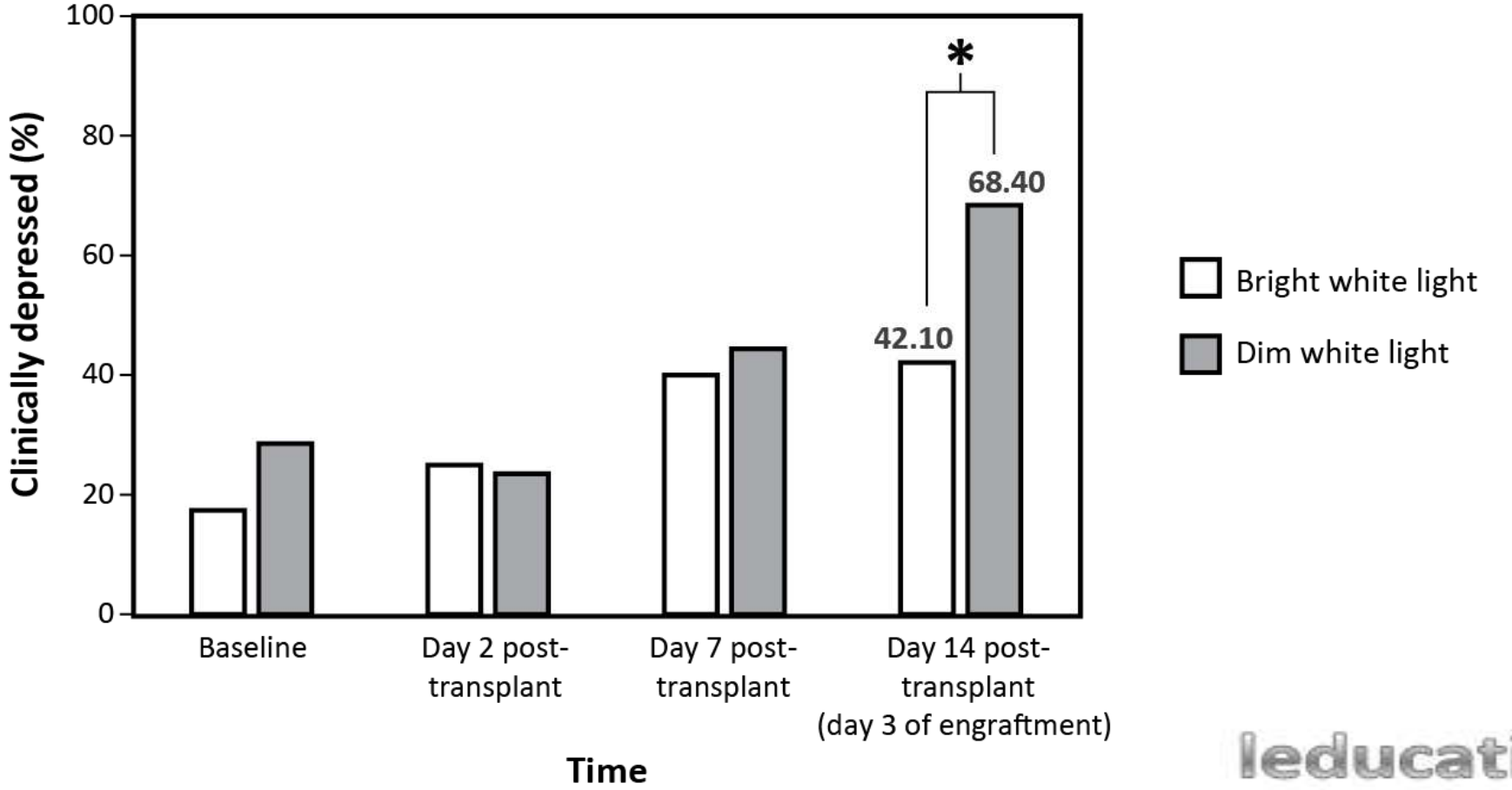
A positive number means that melatonin levels were lower after intervention compared to baseline (* $p < 0.05$).

Concentrations of creatinine-adjusted urinary melatonin (6-sulfatoxymelatonin [6-SMT]), a major melatonin metabolite, for participants exposed to the bright white (left) and dim white (right) lighting interventions compared to baseline

Sponsors: National Cancer Institute and

Light therapy and melatonin in myeloma transplant patients

- Clinical depression (CES-D) as a function of time by condition



Sponsors: National Cancer Institute and

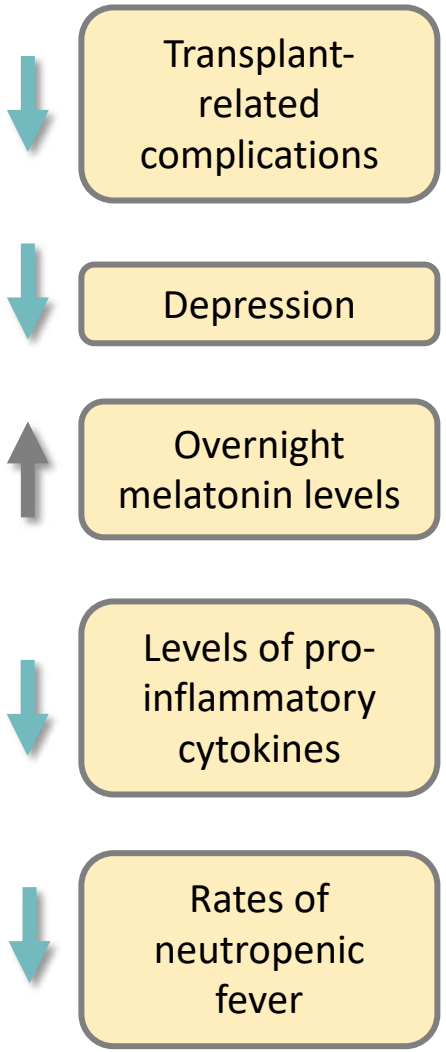
Light therapy and IL-6 and neutropenic fever

- Patients in the circadian-effective light condition had significantly lower rescaled IL-6 scores (mean = 1.669) compared to those in the circadian-ineffective light condition (mean = 2.0899)
- Patients in the circadian-effective light condition were significantly less likely to develop neutropenic fever compared to those that were exposed to the non-effective light or 25.7% and 45.7%, respectively

Sponsors: National Cancer Institute and

Light therapy for myeloma transplant patients

Among MM patients undergoing ASCT, those who were exposed to **circadian-effective light** in their hospital room had...



...compared to those who were exposed to **circadian-ineffective light**

Tailored lighting intervention to improve sleep, mood, and behavior in ADRD patients

Sponsor: National Institute on Aging

Sleep and Alzheimer's disease (AD) and related dementias (ADRD)

- Sleep – wake disturbances are a common and often debilitating feature of Alzheimer's disease (AD)
- Sleep – wake disturbances may be one of the earliest symptoms in preclinical AD
- Evidence from animal and human studies suggests that AD pathology disrupts the sleep–wake cycle, including:
  - Increased sleep fragmentation and wakefulness
  - Decreased slow-wave sleep
- Evidence from animal and human studies also suggests that prolonged wakefulness may increase levels of soluble Aβ in the brain, and may both exacerbate and accelerate the onset of AD pathology

Lim MM, Gerstner JR, Holtzman DM. The sleep-wake cycle and Alzheimer's disease: What do we know? *Neurodegenerative Disease Management.* 2014;4(5):351-362.

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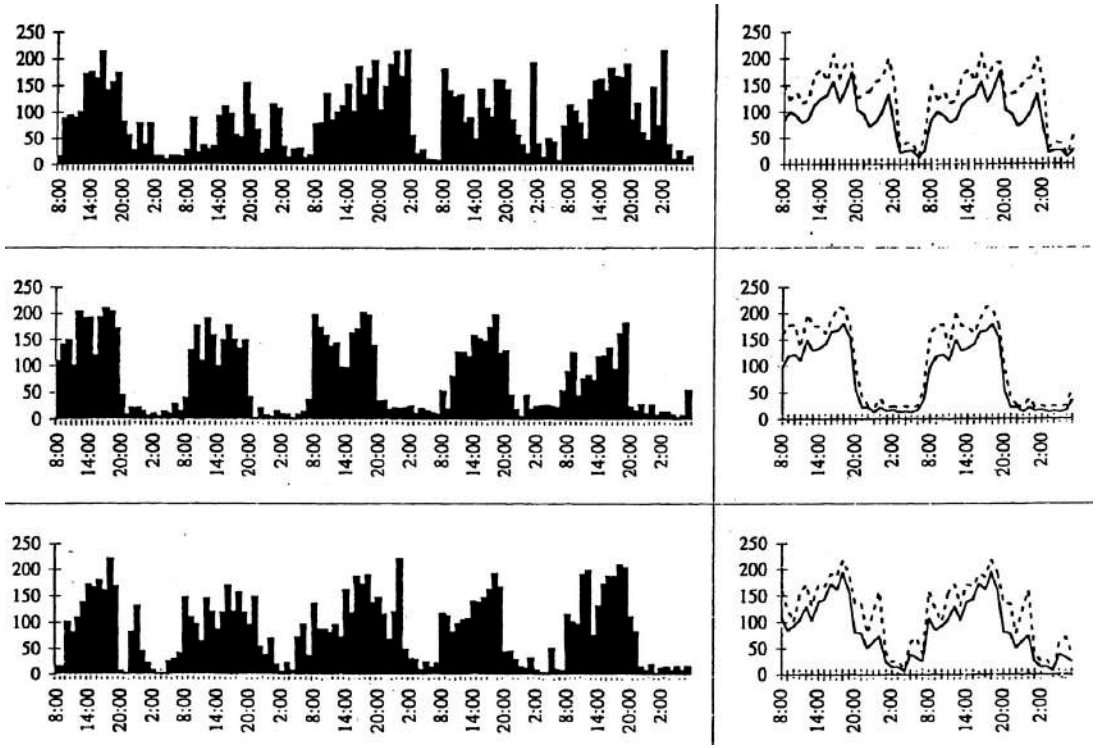
Light therapy for persons living with dementia

- Alzheimer's patients exposed to 1136 ± 89 lx at the eye during the entire day showed an improvement in the circadian rest-activity rhythms disturbances
- Riemersma-van der Lek et al. 2008 showed that long term (up to 3.5 years) light therapy delivered to patients with dementia
  - Attenuated cognitive deterioration by 5%
  - Ameliorated depressive symptoms by 19%
  - Attenuated the increase in functional limitations over time by 53%



Van Someren et al. 1997. Indirect bright light improves circadian rest-activity rhythm disturbances in demented patients. *Biological Psychiatry* 1;41(9):955-63.

Riemersma-van der Lek RF, Swaab DF, Twisk J, Hol EM, Hoogendijk WJ and Van Someren EJ. Effect of bright light and melatonin on cognitive and noncognitive function in elderly residents of group care facilities: A randomized controlled trial. *JAMA*. 2008; 299: 2642-55.

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Sponsor: NIA (R01AG034157)

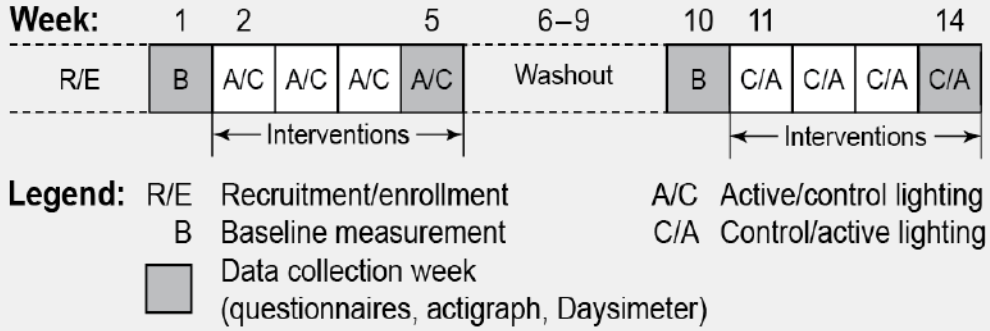
Light therapy for sleep and mood in ADRD

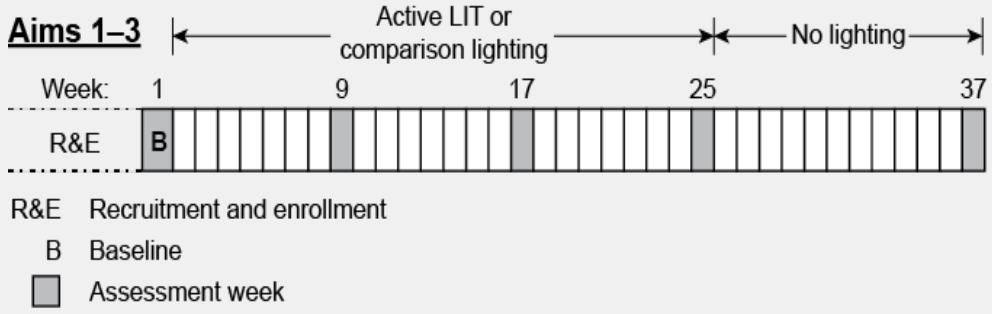
Short term (14 weeks)

- Randomized, placebo-controlled, crossover design clinical trial
- Two 4-week periods (4-week washout)
- 46 patients with ADRD in 8 long-term care facilities

Long term (6 months)

- Randomized single-arm, within-subjects design clinical trial
- 47 patients with ADRD in 9 long-term care facilities





- Administered all-day (≈ 06:00 to 08:00 – 18:00) **active TLI** (high circadian stimulus [CS] = 0.4) for both studies
- Administered all-day **control TLI** (low CS < 0.1) for short-term study only

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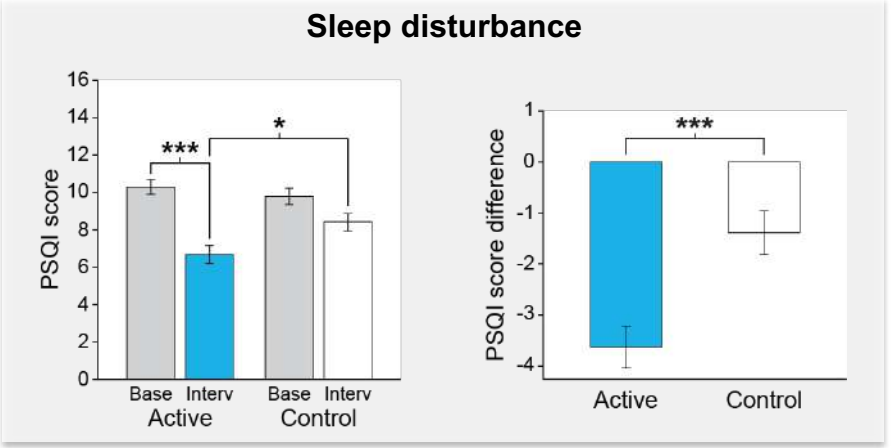
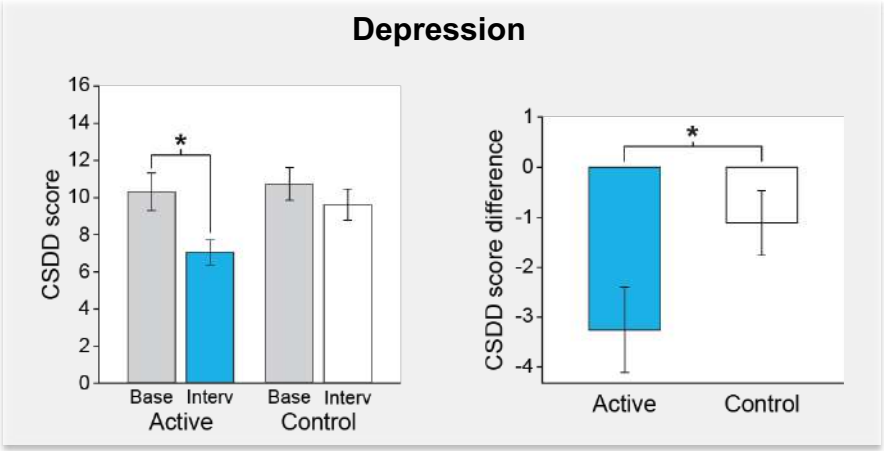
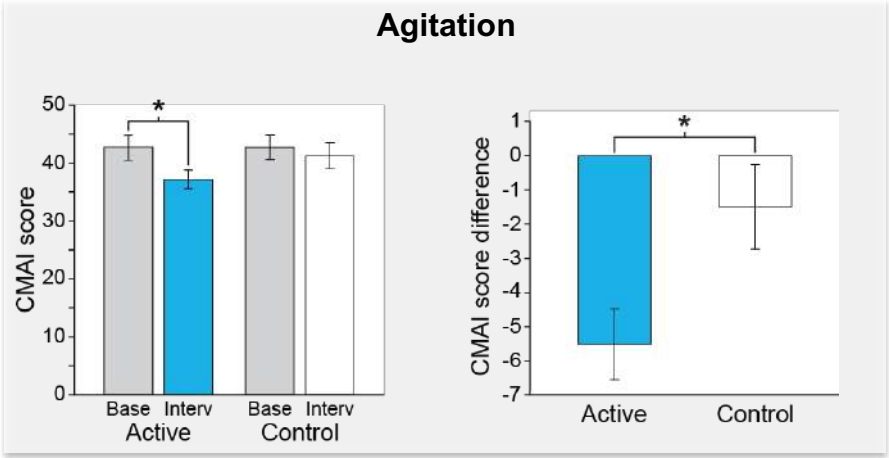
Sponsor: NIA (R01AG034157)

Light therapy for sleep and mood in ADRD

- Short-term study
- Fewer sleep disturbances (PSQI) and depressive symptoms (CSDD) during active TLI compared to baseline and the control
- Fewer agitation behavior symptoms (CMAI) during the active TLI compared to baseline and greater reductions in symptoms compared to the control







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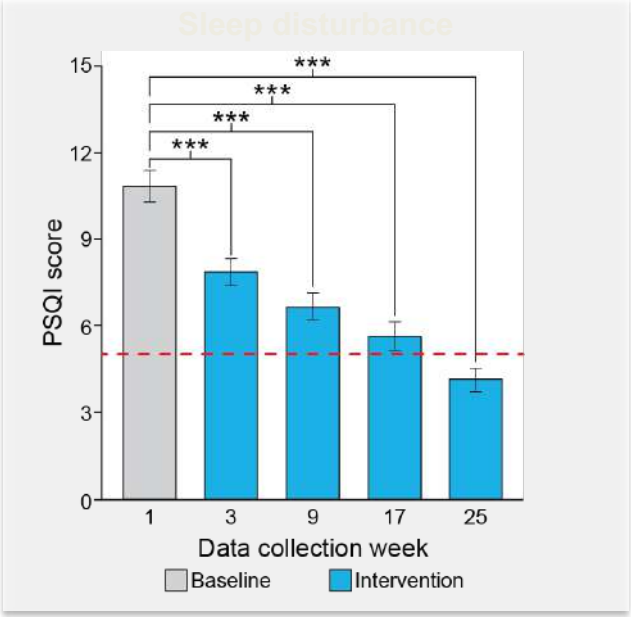
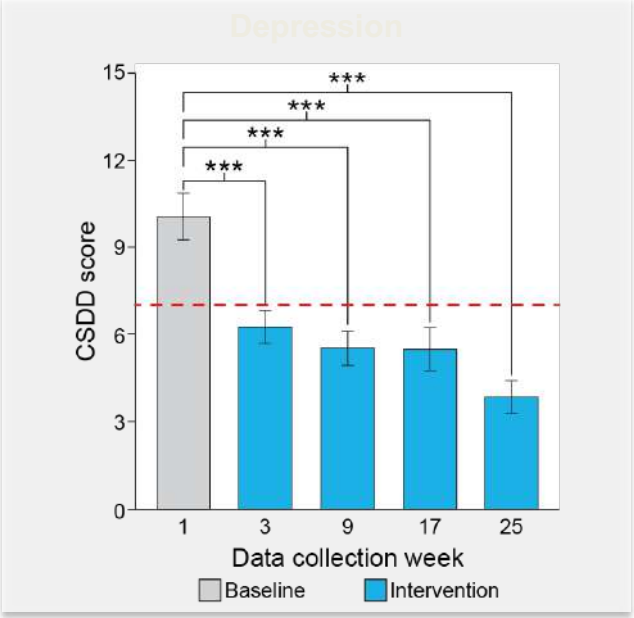
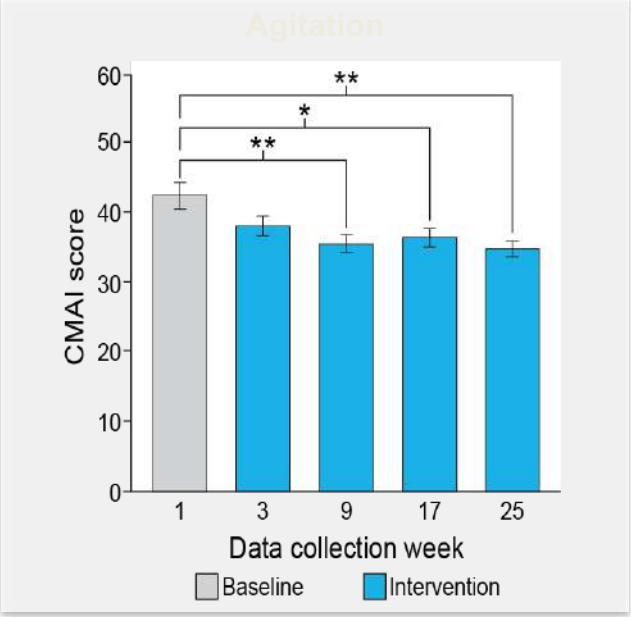
Sponsor: NIA (R01AG034157)

Light therapy for sleep and mood in ADRD

- Long-term study
- Fewer sleep disturbances (PSQI scores) and depressive symptoms (CSDD scores) during the TLI compared to baseline
- Fewer agitation behavior symptoms (CMAI scores) during the TLI compared to baseline







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

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Photoperiod strength and amyloid load in 5XFAD mice

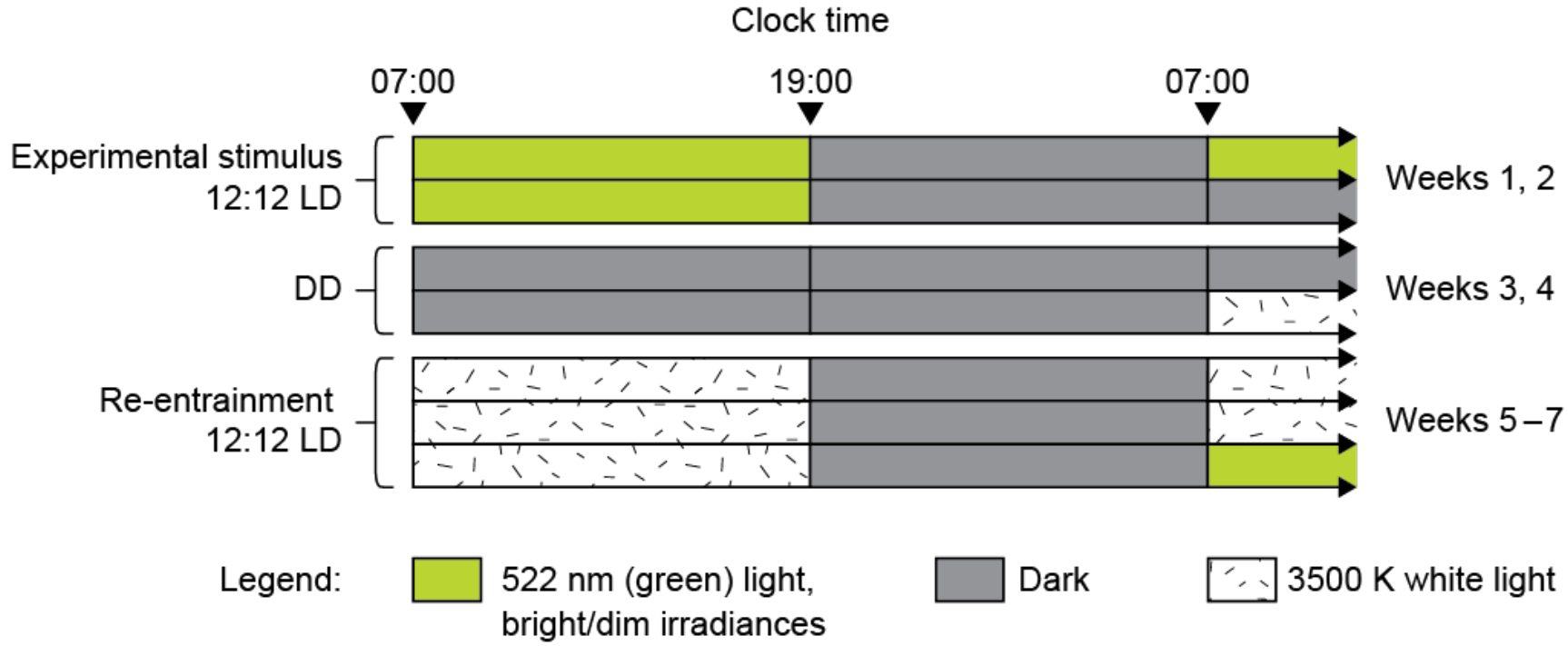
Sponsor: National Institute on Aging (NIA 5T32AG057464-03)

Richter Family Fund

Sponsors: NIA 5T32AG057464-03
Richter Family Fund

Protocol

- 23 5XFAD and 24 control mice (12 females) experienced the protocol
  - Half assigned to bright light/dark
  - Other half assigned to dim light/dark conditions



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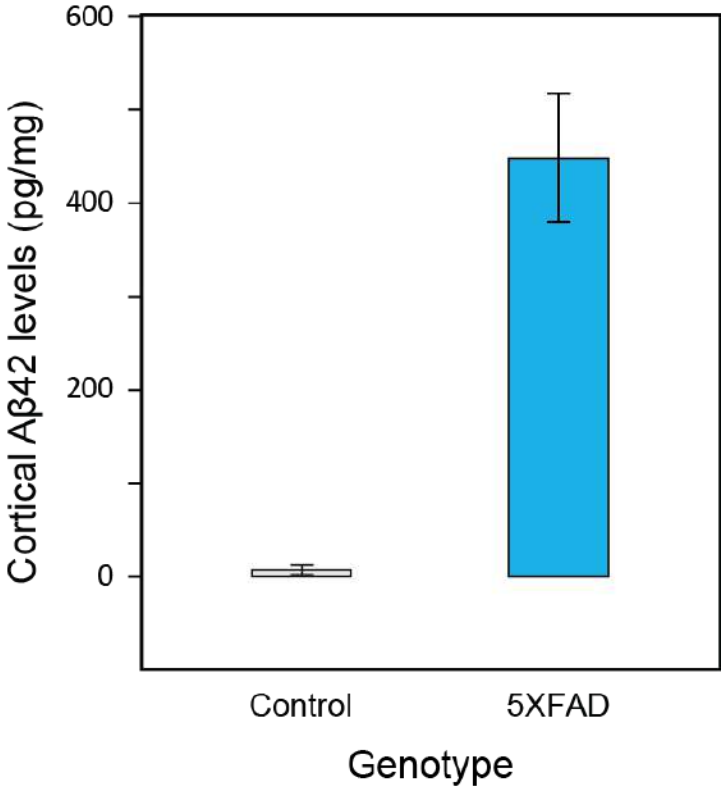
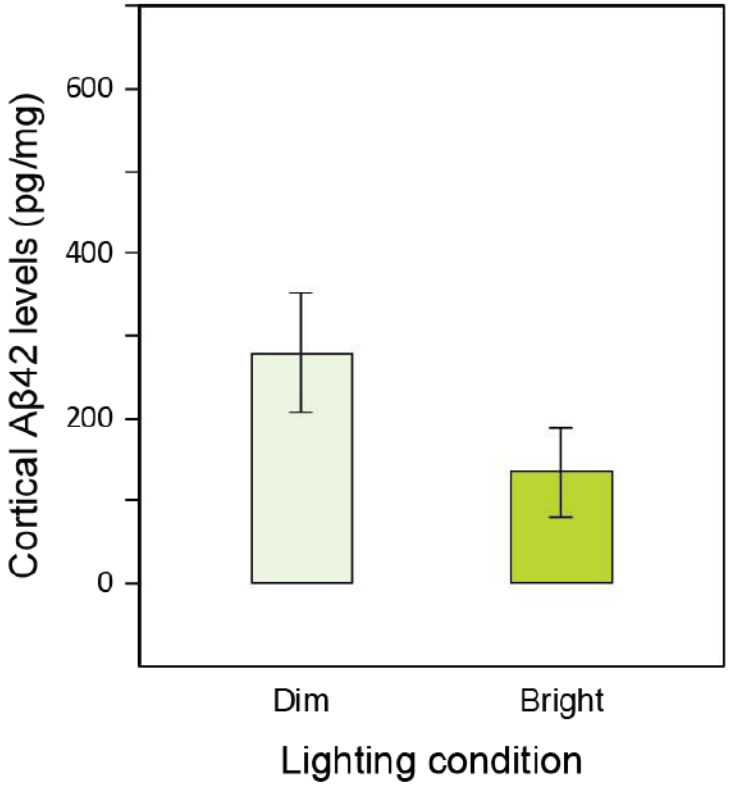
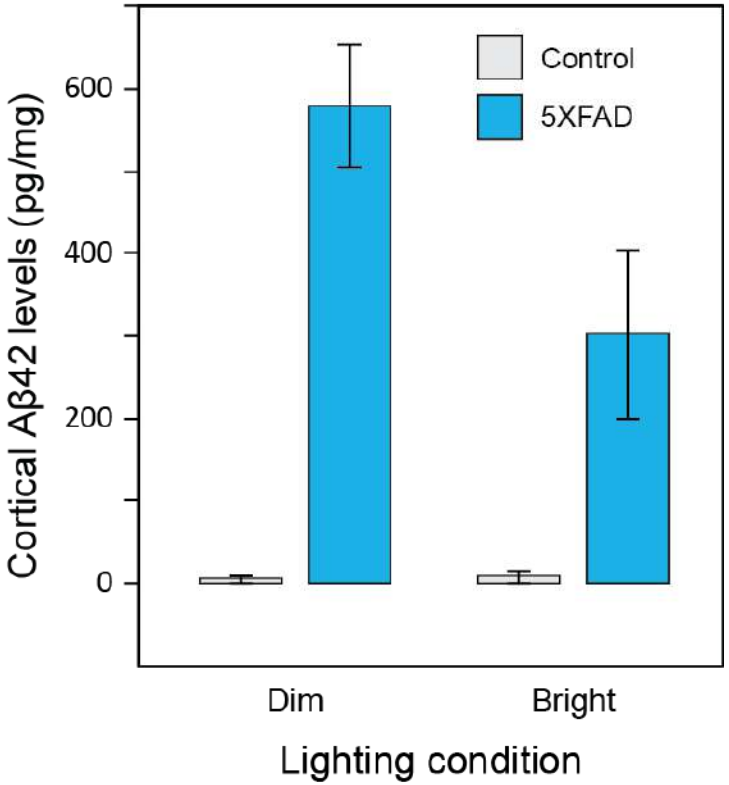
Results







Cortical Aβ42 levels in the 5XFAD mice and their littermate controls. There was a significant main effect of genotype on cortical Aβ42 levels.

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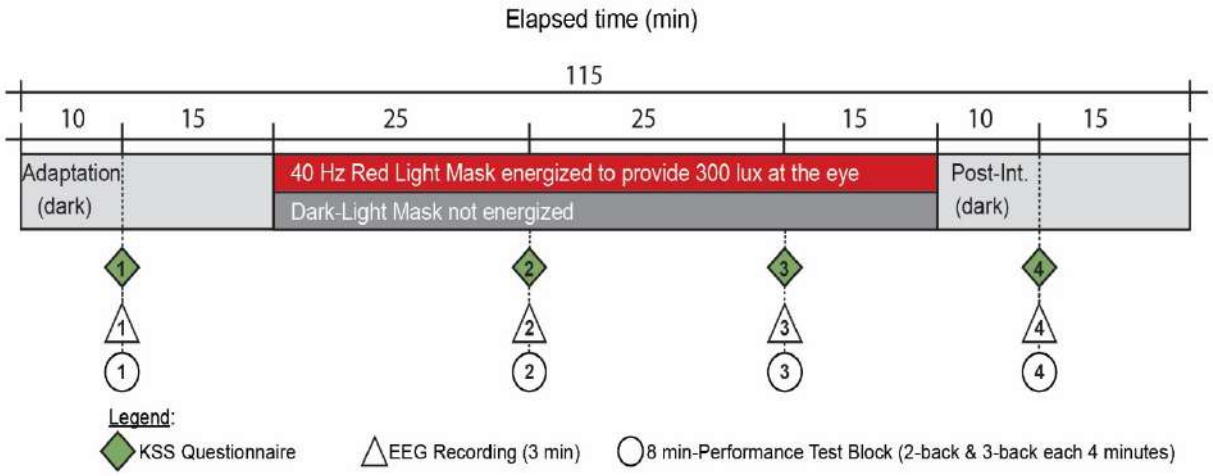
Examples of current human subjects studies

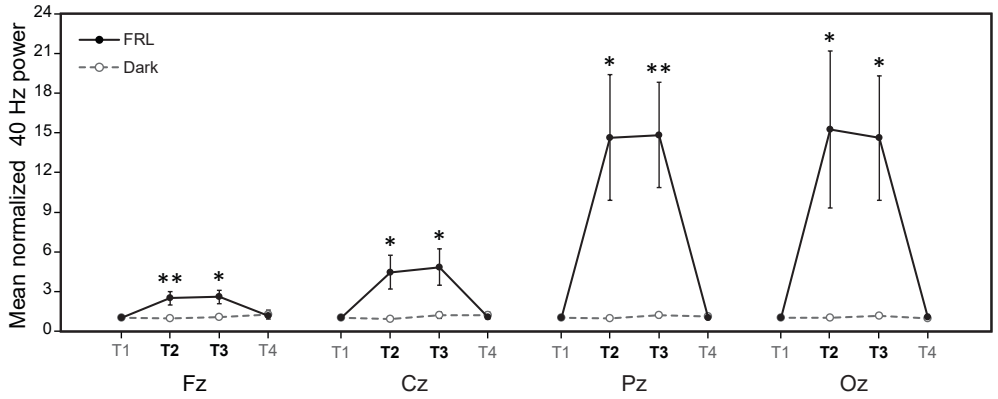
Sponsor: Richter Family Fund
NIA AG072762

Neurostimulation: 40 Hz flickering lights

- 40 Hz neural oscillation is a fundamental frequency of healthy brain activity (Herman et al., 2005)



40 Hz



- Significant increase in 40 Hz power when the mask was energized

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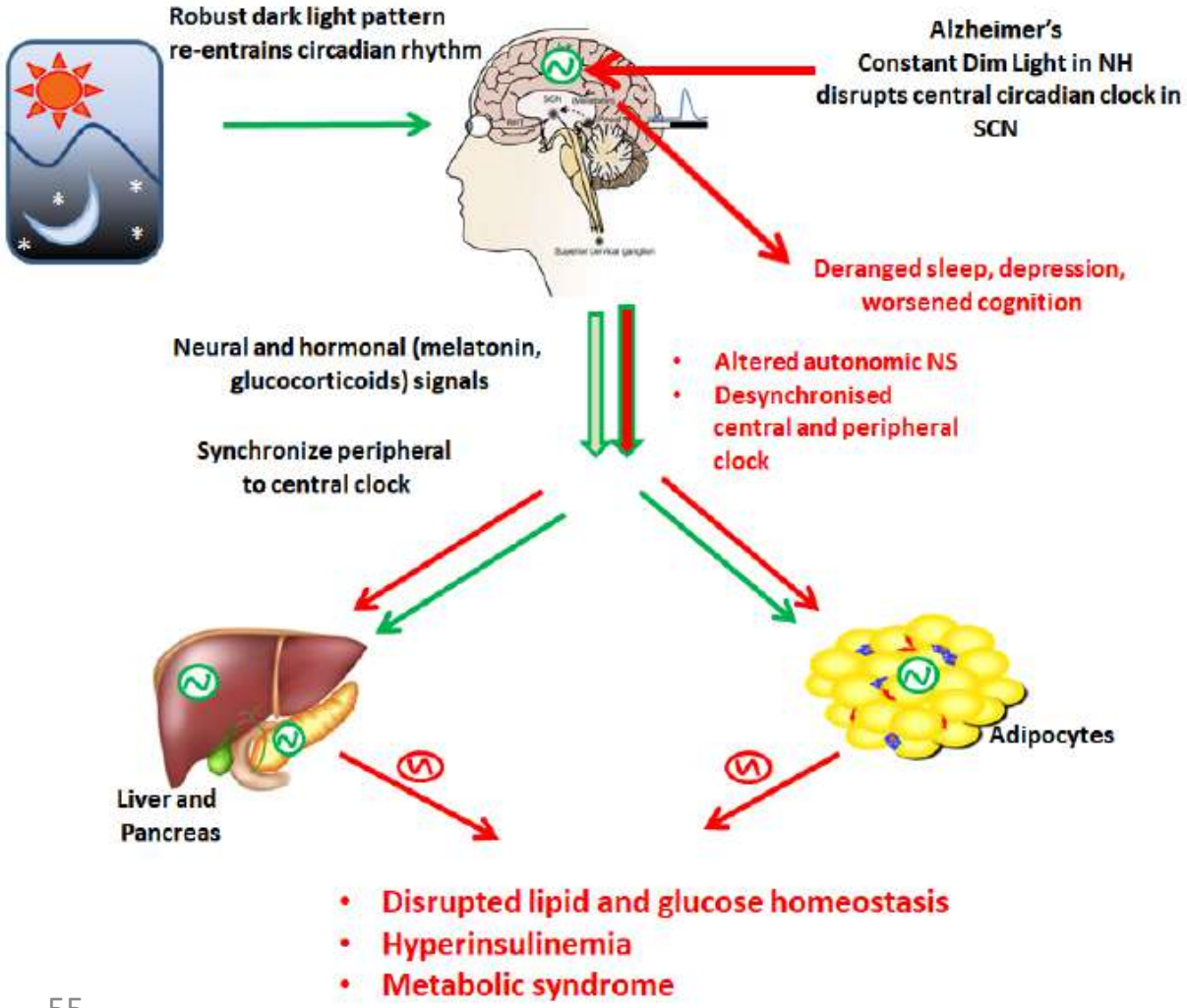
Sponsor: NIA R01AG060716
MPI: Christoph Buettner, MD
Co-I: Mary Sano, PhD

Circadian entrainment: Diabetes and Alzheimer's disease



- Overarching hypothesis of the proposal
  - AD and constant dim light disrupts the circadian clock that in turn disrupts the circadian rhythm
  - TLI will re-entrain the circadian clock and improve metabolic control

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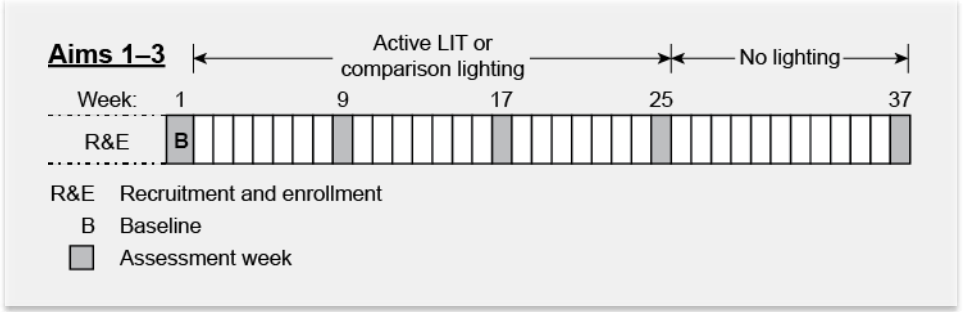
Sponsor: NIA (R01AG062288)
MPI: Sara Mednick, PhD, UC Irvine

Circadian entrainment: Sleep and cognition in persons with mild cognitive impairment and their caregivers

- Aims 1–2: Single-arm, placebo-controlled, between-subjects design
  - Test short-term effect of TLI on primary (sleep and cognition) and secondary (depression, QoL) outcomes
- Aim 3: Single-arm, placebo-controlled, between-subjects design
  - Test impact of TLI on caregiver sleep, burden, QoL, and depression
- 37-week protocol



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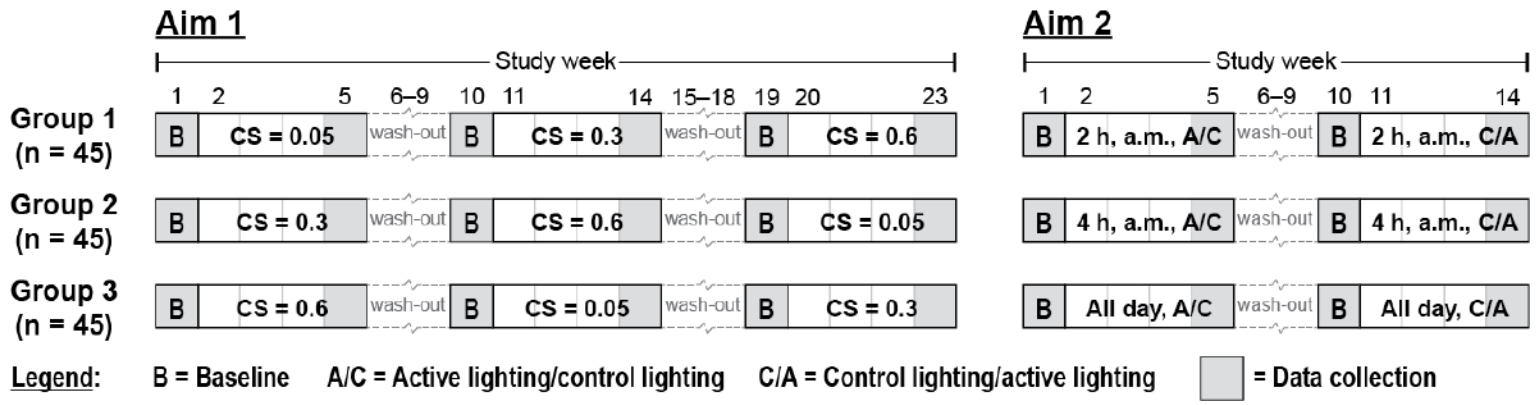
Sponsor: NIA (R01AG034157)

Circadian entrainment: Impact of dose and duration on sleep, mood, and behavior in Alzheimer's disease patients

- Develop a dose (amount and duration) response to determine effective light to improve sleep, mood and behavior in Alzheimer's disease patients
- Currently recruiting

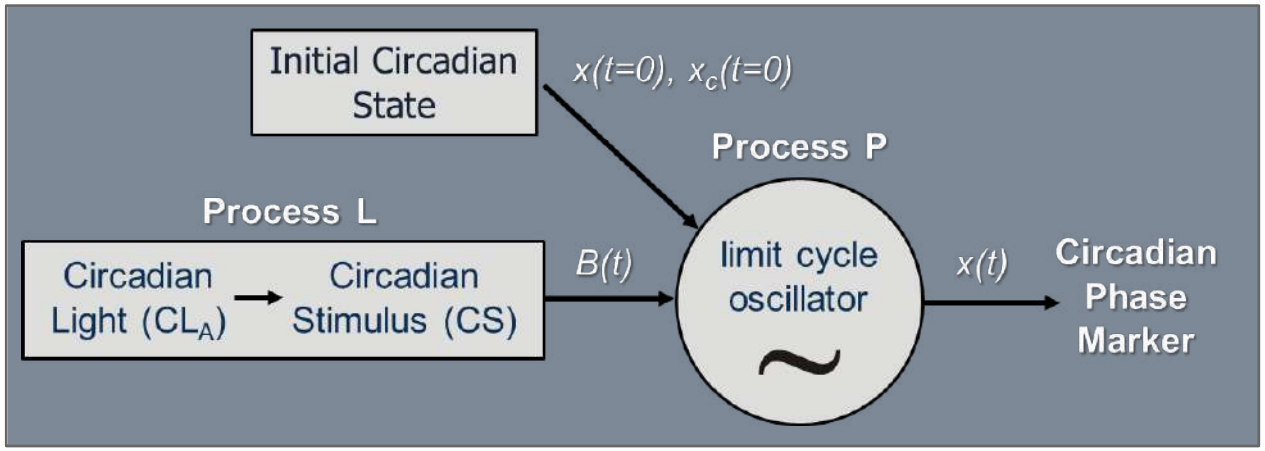


Sponsors: IAI/Army Research Office
Swedish Energy Agency

Personal medicine: Circadian monitoring device

- Continuously monitor circadian stimulus (CS) and physiological signals
- Quantify circadian entrainment/disruption
- Use predictive model to compute light treatments

LHRC's CS-Oscillator Model of Human Circadian Pacemaker



Based on Kronauer RE, Forger DB, Jewett ME. Quantifying human circadian pacemaker response to brief, extended, and repeated light stimuli over the photopic range. *Journal of Biological Rhythms*. 1999; 14: 500-516.

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Sleep Math: Brighter days = Better Nights

Nagare R, Woo M, MacNaughton P, Plitnick B, Tinianov B, Figueiro M. Access to Daylight at Home Improves Circadian Alignment, Sleep, and Mental Health in Healthy Adults: A Crossover Study. *International Journal of Environmental Research and Public Health*. 2021; 18: 9980.

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Acknowledgements

- LEDucation event organizers
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  - National Institute of Diabetes and Digestive and Kidney Diseases (R01DK128972 MPI: Yechoor, Figueiro, Paul)
  - National Cancer Institute (R21CA209419 PI: Redd, Co-I, Figueiro)
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  - Office of Naval Research
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  - Michael Richter Family
  - General Services Administration
  - View, Inc.
  - U.S. Department of State
  - Light for Human Health Partnership
    - Axis Lighting
    - GE Lighting, a Savant Company
    - USAI Lighting
    - iGuzzini

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Do you
or someone you know
have mild Alzheimer's Disease?

Consider participating
in our research

We are testing the benefits of
lights designed to:

- Improve sleep
- Aid cognitive function
- Enhance mood and emotional well-being

Icahn School of Medicine at Mount Sinai
Light and Health Research Center

Mariana G. Figueiro, PhD

mariana.figueiro@mountsinai.org

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Thank You!

This concludes The American Institute of Architects Continuing Education Systems Course

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