#### Biologically Focused Lighting – The Science and Application of Circadian Lighting



# About **BIOS**

- We are a NASA Spin-Off  $\bullet$ 
  - Robert Soler (VP of Technology) developed the first LED light on Space Station
  - Circadian Lighting for Space Station
- Jet Lag Mitigation Expert for ullet**Professional Athletes** 
  - Olympic Ski and Snowboard team
  - Los Angeles Dodgers
  - Pittsburgh Pirates
- Named Inventor on over 75 issued  $\bullet$ patents
- PhD student at UCSD and Salk Institute  $\bullet$ 
  - Behavioral Neuroscience
- National Science Foundation (NSF) ulletFellow
- WELL Faculty Member ullet



First LED light aboard NASA's ISS (Credit: nasa.gov)

CURRENT The development of lighting countermeasures for sleep disruption and circadian misalignment during spaceflight

> George C. Brainarda, Laura K. Bargerb, Robert R. Solerc, and John P Hanifin

e review addresses the development of a new solid-state lighting system for the International Space on (ISS) that is intended to enhance the illumination of the working and living envi and to improve sleep, circadian entrainment, and daytime ale

sed, analog studies, Installation of this lighting system on the ISS is scheduled to

year. In-flight testing of this lighting system is planned to take place during ISS spacefligh Summary If the new ISS lighting system is capable of improving circadian entrainme it should enhance astronaut health, performance, well-being, and safety. S down to future liahting applications for humans living on Earth.



NASA's Flexible lighting system (credit: wired.com)

#### **Course Description**

With growing emphasis on healthy built environments, circadian lighting is a popular topic that many designers and end-users are being asked to explore. This lecture will outline the science behind circadian lighting, telling an easy-to-understand story that helps explain what we should expect from circadian lighting, as well as address important design considerations, who should expect to benefit from circadian lighting and what those benefits are.

This session will also give some insight into blue light hazard and what you need to know about it.

#### Learning Objectives

At the end of the this 4 hour course, participants will be able to:

- 1. Understand the basic science of circadian rhythms and its interaction with light.
- 2. Describe the design considerations needed for implementing circadian lighting.
- 3. Understand how color tuning addresses circadian lighting needs.
- 4. Understand how light spectrum addresses circadian lighting needs.

#### Interior Design Continuing Education Council (IDCEC)

- Your attendance will be reported to IDCEC by your instructor after this CEU.
  Please do not share the class-code with anyone who has not attended this CEU.
- Certificates of completion will be issued electronically through your IDCEC account once attendance has been reported for you. Please allow 5 business days for attendance reporting.
- Attendees who do not have a unique IDCEC number will be provided with a paper Certificate of Completion after this CEU.
- WELL certified



# About THIS presentation

- <u>MOST</u> presentations give statistics or anecdotal evidence about gains seen from circadian lighting
  - People you don't know
  - A study you don't know the details of
  - Funded by a manufacturer who stands to gain from these benefits
- <u>THIS</u> presentation will guide you through the fundamental science of <u>why</u> circadian lighting makes sense, from the vantage point of the person you know best **YOU!**

## **International Space Station**



First LED light aboard NASA's ISS (Credit: nasa.gov)

NASA's Flexible lighting system (credit: wired.com)

# Part 1: Scientific Background

- Non-visual photoreceptors
- Circadian rhythms and sleep
- Chronotypes
- Social Jet Lag

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# Hawthorne Effect

- 1920's Western Electric (Telephone part company) commissioned study to evaluate the effect of lighting on productivity.
- First they raised the light levels
  - Increased productivity
- Next they lowered the light levels
  - Productivity increased more
- Raised again
  - Productivity increased more



**Conclusion:** People's behavior changes when you know you're being observed

## Evidence Based Design Requirements

- Needs to avoid false positives and bias
- Needs to apply the fundamental science behind what we should expect....i.e. what is the point?

# What's the point of Circadian Lighting?

- Restore a 24-hour cycle
- Humans have evolved around a robust time cue – The Sun
- Modern society has broken this relationship
- How can we replicate this cue indoors?



## Circadian Rhythms

2017 Nobel Prize was awarded to physiologists who discovered mechanisms of circadian rhythms

Circadian rhythms is a pervasive part of all biology

Each cell has its own clock (Panda – Circadian Code, 2018)

43% of mammalian genetic expression is circadian (Zhang et al. 2014)

Strategic timing for resource efficiency (Brown 2016)



#### Jeffrey C. Hall Michael Rosbash Michael W. Young

"for their discoveries of molecular mechanisms controlling the circadian rhythm"

Nobelprize.org



#### Social Acceptance

Popular periodicals are beginning to write on the importance of doing things according to your circadian rhythms



#### The New York Times

When We Eat, or Don't Eat, May Be Critical for Health

A growing body of research suggests that our bodies function optimally when we align our eating patterns with our circadian rhythms.



#### BEAUTY > HEALTH & FITNESS

The Healthy Diet of the Future Focuses on When–Not Just What– You Eat

AUGUST 1, 2018 3:13 PM by KATE BRANCH



Photographed by Theo Wenner, Vogue, September 2016





The Washington Post Democracy Dies in Darkn

#### Social Acceptance

Popular periodicals are beginning to write on the importance of doing things according to your circadian rhythms

And the problems that arise when we don't

() Updated 10:52 AM ET, Fri June 23, 2017

Your smartphone may be hurting your sleep By Susan Scutti, CNN 🖂 🔂 😂 🕋



Setting an alarm might be the only thing that helps you get up in the morning, but try setting one at night to remind you when it's time to go to bed. Click through our gallery for other tips for better sleep

COSMOPOLITAN CELEBS LOVE BEAUTY FASHION BODY

#### Education Live TV U.S. Edition + D

Pediatricians say teens should sleep in. Schools won't let them.

**By Moriah Balingit** August 23, 2017 at 4:41 PM



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#### Social jet lag could be the reason why you're so tired all the time

Not understanding your body's needs could be leading to extreme fatigue.





GETTY IMAGES / CAIAIMAGE/PAUL BRADBUR

#### SCIENCE

# Not just blue light, study says prolonged screen time alone disrupts sleep



By Judy Cordova Solution By Judy Cordova Solut

KEZAR

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Ongoing study reveals kids with 7+ hours screen time have altered brain structures

People have varying reactions on how screen time affects sleep. Now comes a study conducted by researchers from Salk Institute pinpointing how certain cells in the eye process ambient light, resetting internal body clocks.

Melanopsin protein synchronizes the internal clock after 10 minutes of illumination, suppressing the hormone melatonin that is responsible for regulating deep sleep, leading to wakefulness just when the body ought to be repairing itself through sleep.

## Average Persons Rhythm



Source: https://commons.wikimedia.org/w/index.php?curid=3017148

## Not all White Light is Created Equal



Photo Credit: www.designaddict.com

## What's the difference?

#### 6500K Daylight



#### 5000K LED



Photo Credit: www.usa.philips.com

Photo Credit: www.designaddict.com

# 6500K Daylight



# 6500K Daylight



## 5000K LED



### Blue Light Paradox (John Marshall, 2017)



## Blue Light Paradox (John Marshall, 2017)







# Melanopsin





[Hughes et al. 2016, nature publishing group]

Initial Response Sustained Response

- Photopigment in newly found subset of cells in the retina (ipRGCs)
- ipRGCs respond quickly to light (black bar)
- Sustained response well after light is gone (blue spikes)
- Integrates light over time
- Intensity, wavelength and duration are important

### Measured Acute Brain Effects





[Gaggioni et al. 2014, Frontiers in Systems Neuroscience]

- Increased Alertness (Gaggioni et al. 2014, FISN)
- Increased working memory (i.e. figuring stuff out in your head)
- Emotional response
- Factors are Intensity, Duration, Wavelength and Sleepiness.

### **Other Measured Effects**





[Hughes et al. 2016, nature publishing group]

- **OPN:** Drives Pupillary Light Reflex
- **LGN:** Brightness perception
- SCN: Location of Master Clock Encodes brightness information
  - Entrains the circadian clock

## What is the Circadian Clock?



Our circadian clock regulates our biological processes to allow our bodies to conserve resources.

- Hormone Secretion
- Metabolism
- Alertness Profile
- Sleepiness Profile
- Many others (blood pressure, cell proliferation, enzyme activity, etc.)

## Sleep – A Two Process Model



[Schmidt et al. 2007, Cognitive Neuropsychology]

# **Chronotype Differences**

**EXAMPLE:** Modern Family – Mitch and Cam making dinner reservations



They can take us at 5:15...



...or 10:45...



What are we, 80?



What are we, 20?

- Chronotype = Time-type
- Our self selected preference for bed time and wake time
- Age and Sex can help predict our preferences
- Most of the time our social requirements and these sleep preferences don't agree
- This misalignment leads to <u>social jet</u> <u>lag</u>
- Social Jet lag is difference in sleep timing on work days versus free days.

[Roenneberg 2012, Harvard University Press]

# Night Owls



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# Early Birds



Sleep fragmentation increases risk of Alzheimer's Disease and cognitive decline (Lim et al. 2011)

# Health Concerns of Social Jet Lag

- Greater chance of obesity (Roenneberg et al. 2012)
  - 33% greater chance with each hour of SJL
- Increased addiction to nicotine and alcohol consumption (Wittman et al. 2006)
- Increased risk of cardiovascular disease (Wong et al. 2015)
- Increased risk of metabolic disease (Scheer et al. 2009)
- Overall attenuation of circadian process (Jan-Dijk et al. 2012)



# Chronotypes in Modern Society



- We spend more than 90% of our time indoors under electric light
- Light signals at the flip of a switch
- Indoor lighting signals are inappropriate
  - -Too dim to be day
  - -Too bright to be night
- In presence of a stronger, more appropriate light cue, Chronotypes become more consolidated
#### Camping study looked at this...

Current Biology 23, 1554–1558, August 19, 2013 ©2013 Elsevier Ltd All rights reserved http://dx.doi.org/10.1016/j.cub.2013.06.039

Report

## Entrainment of the Human Circadian Clock to the Natural Light-Dark Cycle

Kenneth P. Wright, Jr.,<sup>1,\*</sup> Andrew W. McHill,<sup>1</sup> Brian R. Birks,<sup>1</sup> Brandon R. Griffin,<sup>1</sup> Thomas Rusterholz,<sup>2</sup> and Evan D. Chinoy<sup>1</sup> <sup>1</sup>Sleep and Chronobiology Laboratory <sup>2</sup>Sleep and Development Laboratory Department of Integrative Physiology, University of Colorado Boulder, Boulder, CO 80309-0354, USA

**Objective:** Take a group of college students out on a two week camping trip to see how chronotype changes

### Camping Study Results...

 Measured the variance of chronotype before the camping trip

 Measured the variance of chronotype after the two week camping trip

### Light Levels + Melatonin Response



- Sigmoidal Response Curve:
  - Floor at < 15 vertical lux
  - Ceiling at > 1,000 vertical lux
  - Linear transition from 50 to 500 vertical lux
- Typical Indoor light levels fall in-between these two areas.
- We are constantly in a state of biological twilight – where our bodies aren't receiving a strong signal one way or the other.
- This means there is an great deal of opportunity for indoor lighting to help create that robust daytime signal.

#### **Timing Matters**



(St. Hilaire et al. 2011)

Our daytime receptors look for daytime signals and sync our body to it.

When they receive daytime signals BEFORE they expect it. Our Clock SPEED UP (advance) to catch up.

When they receive daytime signals AFTER they expect it. Our clock SLOWS DOWN (delay) to not move ahead.









#### Can we do this indoors?



#### **Original article**

Scand J Work Environ Health 2011;37(5):437-445





Objective: Can we entrain to normal office lighting?

### Results



- Experiment was done when day were getting longer and dawn came sooner each day
- Control group (4000K) mid-sleep was 30 minutes earlier
  - They shifted with the change of the season
- Experimental group (8000K) midsleep had negligible change
  - They received a significant light signal such that the change in season did not impact their sleep time.

Conclusion: Office workers entrained to the office lighting

#### Eating After Dark...

Eating closer to circadian night is associated with significant weight gain (McHill et al. 2017)

- When we sleep, our bodies enter a minihibernation
  - Metabolism shuts down for fasting
- Sending nighttime signals in the workplace would initiate this hibernation process
- If you did this....you should not eat after work.



Image credit: Huffington Post

Until society revolves around the sun, our electric lights should not!

#### 2017 Clinical and Field Studies

- Early morning light given to night owls significantly reduces ADHD symptoms (Fargason et al. 2017)
- Higher daytime circadian signal in the office is associated with better sleep and mood (Figuiero et al. 2017)

# There's a big benefit to providing high daytime signals during our biological daytime

#### Part 1: Quiz

- What do circadian rhythms regulate?
  - Hormones, metabolism, alertness, sleep, and so much more
    - (43% of genetic expression is circadian Zhang et al. 2014)
- What is a chronotype?
  - Self selected preference for sleep and wake time
- What is social jet lag?
  - When internal time and social time don't agree
- Who has social jet lag?
  - 87% of non-shift workers
- Can we synchronize to electric lighting?
  - Yes!
- Should we synchronize to electric lighting?
  - Three (3) possible approaches:
    - support chronotype variance (social time Simple on/off controls) which we do now.
    - reduce chronotype variance (solar time advanced controls) expensive / winter really?
    - Support chronotype variance within reason (i.e. daytime from 6am to 8pm) see slides next

#### Part 2: Techniques

- What factors can be used to maximize or minimize circadian stimulation?
- How can we maximize daytime circadian stimulation?
- How can we minimize nighttime circadian stimulation?
- How can we create a proper dynamic 24-hour scenario?

#### How do we Affect Circadian Stimulation?



#### **Five Levers:**

- Intensity
- Timing
- Light History
- Spatial Distribution
- Spectrum

#### **Spatial Distribution**



- Light coming from above the horizon is best
- Light coming from below has negligible effect (Glickman et. al 2003, Lasko et al. 1995)
- Side periphery is okay as well. (Adler et al. 1992)
- Designing for horizontal (taskplane) illuminance may have little effect

Image credit: www.osram.com

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#### **Color Temperature and Intensity**



- Daytime color temperature doesn't change much outside of twilight ~ 5500K – 6500K
- Cooler temperature coincides with dramatic reduction in intensity
- High circadian stimulus during the day, low circadian stimulus at night

<sup>[</sup>Hernandez-Andres et al. 2001]

#### **Cones for Color Vision**



#### Addition of Melanopsin



#### 5000K "Daylight" LED



#### 'Bad Blue' for Reference



#### 5000K Daylight



#### 5000K Daylight



#### 5K Daylight – 10K Daylight



#### Tunable White LED













Acute Effects: Photochemical induced injury RG0: No cause for concern w/exposure less than 2.8h Blue Light Hazard is strongly correlated to CCT Chronic Effects: Oxidative Stress **How long before it's a problem? We don't know** 

### And.....

- Among the factors that get in the way of long sound sleep is blue light. It turns out blue light can suppress melatonin more than green light, and shifts circadian rhythms by twice as much (three hours vs. 1.5 hours), Harvard Health reported
- By better understanding the interactions of melanopsin and how the eyes react to light, Prof. Panda hopes to find new targets of countering skewed circadian rhythms due to artificial illumination.



#### Figure 1

A comparison of the power spectrum of a standard white-light LED, a tricolor fluorescent lamp, and an incandescent source. The radically different power spectrums can look similar when viewed directly by the eye, irrespective of how much blue emission is present.

### Why would LED have a higher risk?



- Melanopsin drives our pupillary light reflex.
- That reflex is initiated when we receive light that is rich in the sky blue signal
- Traditional LED have a very clear dip in that sky blue region, which means they are lacking in that spectrum
- Traditional LED spectra actually undermine our natural bodies protection mechanism and increase risk of exposure to the bad blue

#### **Other Considerations:**

Lens Transmission with Age, secondary protection mechanism?



"ANSES recommends: To avoid the use of light sources emitting cold-white light (light with a strong blue component) in places frequented by children (maternity wards, nurseries, schools, leisure centers, etc.) or in the objects they use (toys, electronic display panels, game consoles"

– Behar-Cohen et al. 2011, Progress in Retinal and Eye Research
### Standards and Models

- WELL Building Standard
  - -v2 released in May 2018
  - Uses a ratio to convert photopic lux to equivalent melanopic lux (EML)
- LRC CS (Circadian Stimulus Model)

- Requires the use of the LRC calculator and spectral data

Uses sub-additivity which is a phenomena that occurs in color vision

## WELL Building Standard v2

- WELL Building Standard has adopted melanopic lux in Feature L03 of their Light Concept.
- Feature L03: Circadian Lighting Design
  - Light levels measured in the <u>vertical plane</u> 18" above task plane (i.e. eye level of the occupant).
  - The target EML light levels to be achieved for at least 4 hours - Between 9 a.m. and 1 p.m.
  - Melanopic Lux requires use of an EML ratio to convert photopic lux to melanopic lux.



## WELL Building Standard v2

Feature L03: Circadian Lighting Design

- Electric Lighting Only
  - 240 EML (3pts)
  - 150 EML (1pt)
  - (CRI > 50 is 1pt)
- Electric + Daylighting
  - 180 EML (3pts)
  - 120 EML (1pt)
  - \*And Meet 2pts from Enhanced Daylight portion in LO5



### What Are Our Design Options?

#### Keep the color temperature you want – BUT this requires more light output



Increasing light output will increase glare

## WELL Building Standard v2

- L03: Circadian Lighting Design
  - 120, 150, 180, 240 vertical melanopic lux for a minimum of 4 hours per day.
- L04: Electric Light Glare Control Fixtures have a luminance less than 8,000 cd/m<sup>2</sup> between 45 °- 90° from nadir, and/or an intensity of less than 1,000 candela between 45 °-90° from nadir.



#### Increase fixture quantity



#### Might help keep glare down, but increases cost and energy

#### Specify Cooler Color Temperature to Improve EML Efficacy



#### Higher CCT's Not Desirable in Most Architectural Applications

## WELL Building Standard v2

- L03: Circadian Lighting Design 120, 150, 180, 240 vertical melanopic lux for a minimum of 4 hours per day.
- L04: Electric Light Glare Control Fixtures have a luminance less than 10,000 cd/m<sup>2</sup> between 45 °- 90° from nadir, and/or an intensity of less than 1,000 candela between 45 °- 90° from nadir.
  - L07: CRI > 90 CRI > 80 and R9>50 TM30 requirements too

 $\bullet$ 



## But wait...The WELL says 4000 is 0.76

- Reference guide shows 7
  EML ratio of 0.76 for 400K
  LED
- Turns out this is NOT a compercially viable LED

	See 1	ight Source	Ratio
	2 00		0.45
	3000	Fluorescent	0.45
	2800	Incandescent	0.54
	4000	Fluorescent	0.58
	4000	LED	0.76
	1000		
L	5450	CIE E (Equal Energy)	1.00
L	5450 6500	CIE E (Equal Energy) Fluorescent	1.00
L	5450 6500 6500	CIE E (Equal Energy) Fluorescent Daylight	1.00 1.02 1.10

#### 4000K Spectrum provided to WELL



### LRC model

- The main difference here is it includes this idea of sub-additivity
- They basically agree at 3500K and warmer
  - 485nm peak versus 490nm
- Recommendation: CS of 0.3 or greater is a good daytime stimulus



#### CS @ 300 lux (LED)



#### Traditional "Circadian" LED Product



CCT = 6000KEML ratio = 0.87 R9 = 16



### **Reimagined Circadian LED**

Lighting that is spectrally optimized to provide the circadian stimulation you need, in a color temperature you want







#### HYBRID VEHICLES & CIRCADIAN LIGHTNG









20MPG vs 58MPG .50EML vs .83EML



#### What about load shedding / overlit space??

- Are you 'losing' the good blue spectrum/melanospin?
- Load shed
- Over lighting to achieve WELL ( don't want to fall short on numbers)



## Melanopic Lux Trend of Optimized Spectrum



- Spectrally Optimized lighting has a completely different trend line.
- We can achieve much higher circadian stimulation without sacrificing color preference

## Putting It All Together

- During the Day time, light up your "sky"
  - High photopic lux
  - High vertical lux
  - Melanopic rich spectrum
- During the Night time, darken your "sky" and light your "fire"
  - Low vertical lux
  - Melanopic depleted spectrum
  - Focus light on horizontal surfaces

### **Assisted Living**

#### Diagytittime



Horizon

FIRE

### Offices

#### Diaghtintime



SKY

Horizon

FIRE

#### Do you need color tuning for circadian regulation?

- No
- Color tuning's best known asset is to psychologically tell you "it's getting late"
- Including controls, color tuning can more than double the cost
- More benefit can be had from layering light, using static spectrums that are optimized for biological day or biological night.
  - This is only really necessary in 24-hour applications

#### Where does simple static spectrum make sense?

Places where you go ONLY during your biological daytime

- Offices
  - Wide range of chronotypes
  - Wide range of schedules
- <u>Classrooms</u>
  - Kids are more susceptible to blue light hazard
  - High school students are prone to be night owls
- <u>Assisted Living Facility Community/Daytime Areas</u>
  - Aging Eye offers unique opportunities
- Sports locker rooms and gymnasiums
  - There is a circadian peak to athletic performance

#### Part 2: Quiz

- Light coming from which direction has the strongest circadian impact?
  Above the horizon
- Does LED color tuning provide day versus night delineation?
  - Not alone. You need to do more with your lighting design. Dim and change spatial distribution.
- What is the simplest way to help boost our circadian rhythms?
  - By better delineating our biological daytime from our biological night.

## Things you can do today

- Install f.lux on your computer and smart phones
  - <u>www.justgetflux.com</u>
  - <u>www.fluxometer.com</u>
- Turn on "night shift" on your iPhone
- Keep your bedroom lights as warm as possible
- Cooler white light in your kitchen and shower (if you shower in the morning)
- Turn on cubicle lights at the office, if applicable

## Liability and Misinformation

- Liability starts with misinformation
  - Color tuning is complicated and expensive
    - Requires justification
      - More productivity
      - Better academic performance
      - Better health
    - All of these things are intensity driven and will NOT come with just color tuning
- Whomever promise these things is liable for fulfilling those promises

## Liability in Medicine

- It's all about the language, nothing is certain
  - "is used to treat"
  - "has been shown to"
  - "may reduce"
  - "can help"
- "Circadian stimulating lighting in the office is used to treat an epidemic known as Social Jet Lag"

## Should we be manipulating people's biology?

#### We've been manipulating people's biology



Image credit: The Matrix

#### Now it's time to stop

# THANK YOU!



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https://fluxometer.com/rainbow/#!id=BIOS% 20Lighting/BIOS%20Puck%204000K