Overview of light, sleep an circadian rhythms as they relate to college students

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Acknowledgments

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  - Geoff Jones
  - Dennis Guyon

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- National Institute on Aging
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- National Cancer Institute
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- Eunice Shriver National Institute of Child Health and Development
- National Institute of Occupational and Safety Health (CDC/ NIOSH)
- General Services Administration (US GSA)
- Office of Naval Research
- US Navy
- US Green Building Council
- The Swedish Energy Agency

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Light and Health Alliance Sponsors

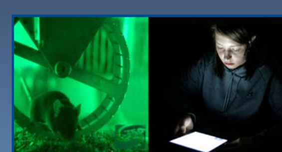
Acuity Brands, Cree, GE Lighting, Ketra Inc., Philips Lighting, OSRAM Sylvania, Sharp, USAI Lighting

Mission

To bridge the science of light and health to practical applications, and to provide objective information based on basic and applied research

Goals:

- Conduct evaluations, demonstrations, and research projects to develop practical devices and applications
- Institutes to educate key audiences on light and health with a particular emphasis on developing quantitative lighting specifications
- Presentations at conferences to promote the topic of light and health, and the Light and Health Alliance



LIGHT AND HEALTH ALLIANCE

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Project collaborators

- Mt. Sinai Ichan School of Medicine
- Brown University
- Yale University
- Case Western Reserve University
- University of North Carolina, Chapel Hill
- Harvard University School of Public Health
- Skidmore College
- Duke University
- National Institute on Drug Abuse Intramural Research
- Netherlands Institute for Neuroscience
- Cornell University
- Naval Submarine Medical Research Laboratory

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Outline

- Science
  - Basics of circadian rhythms
  - Lighting characteristics affecting circadian rhythms
- Applications
  - Summarize research on how light affects sleep timing and mood in college students
  - Discuss possible ways to deliver light

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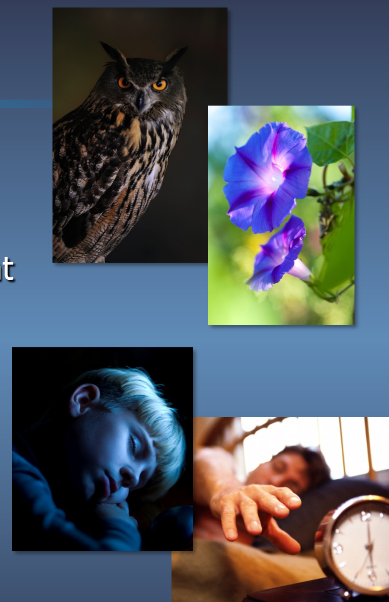
Circadian system

- Plants and animals exhibit patterns of behavioral and physiological changes over an approximately 24-hour cycle that repeat over successive days—these are circadian rhythms
- circa = about; dies = day
- Circadian rhythms are influenced by exogenous and endogenous rhythms



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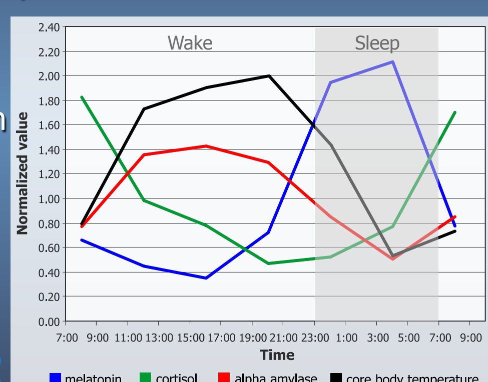
Circadian system

- Biological (circadian) rhythms in humans can be measured in several ways
  - Sleep/wake cycle
  - Core body temperature
  - Melatonin concentration
  - Cortisol concentration
  - Alpha amylase concentration



Figueiro et al., 2009
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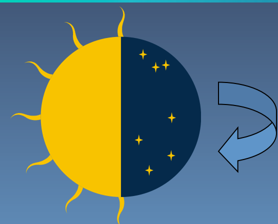
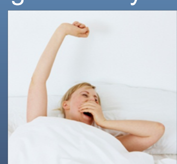
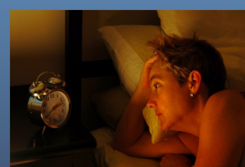
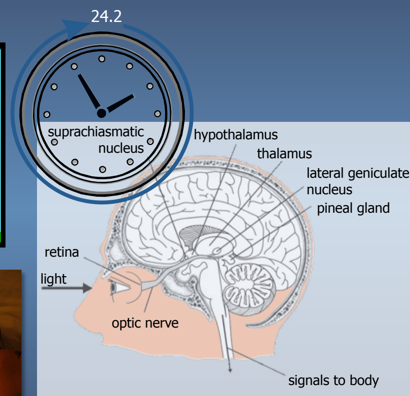
Light is the primary synchronizer of circadian rhythms to local position on Earth




The natural, 24-hour, light-dark cycle

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

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

…also the major disruptor

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Circadian disruption

- Circadian disruption has been associated with:
  - Poor sleep and higher stress
    - Eismann et al., 2010
  - Increased anxiety and depression
    - Du-Quiton et al., 2009
  - Increased smoking
    - Kageyama et al., 2005
  - Cardiovascular disease
    - Young et al., 2007; Maemura et al., 2007
  - Type 2 diabetes
    - Kreier et al., 2007
  - Higher incidence of breast cancer
    - Schernhammer et al., 2001, Hansen, 2006

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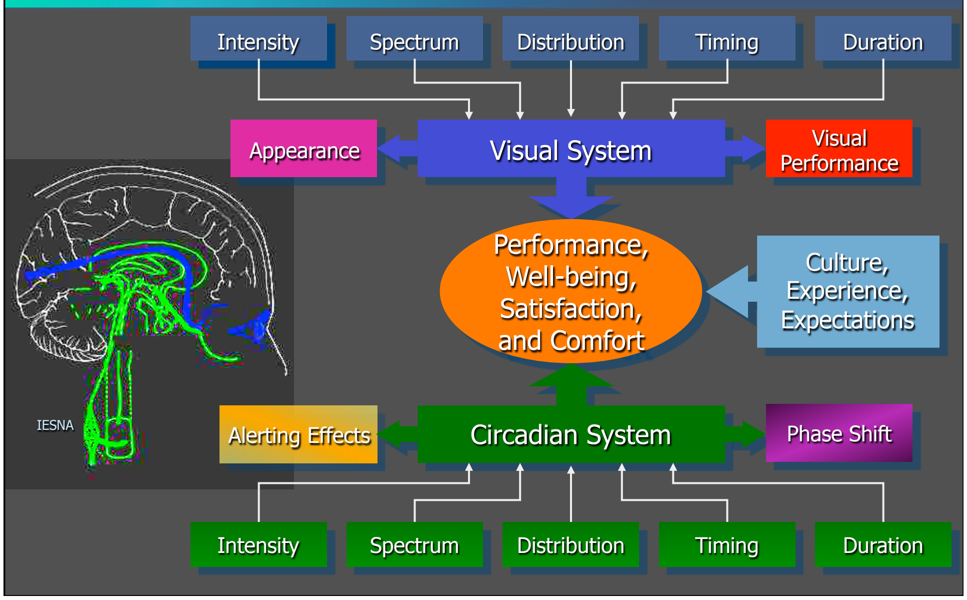
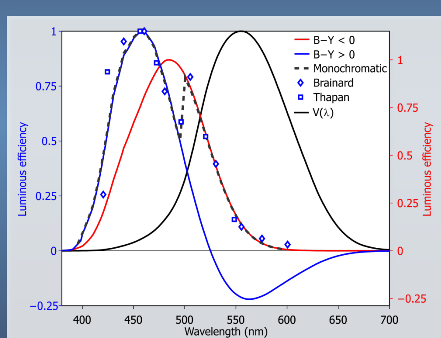
Lighting characteristics

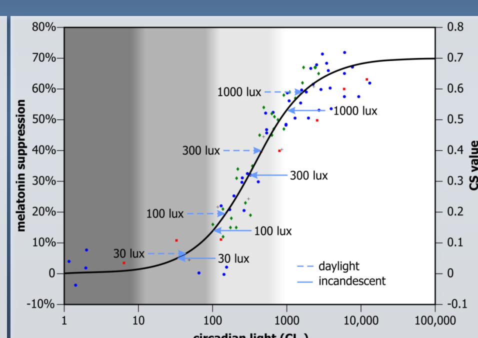


Circadian rhythms and light

Spectral sensitivity



Absolute sensitivity



Rea et al 2005; 2011

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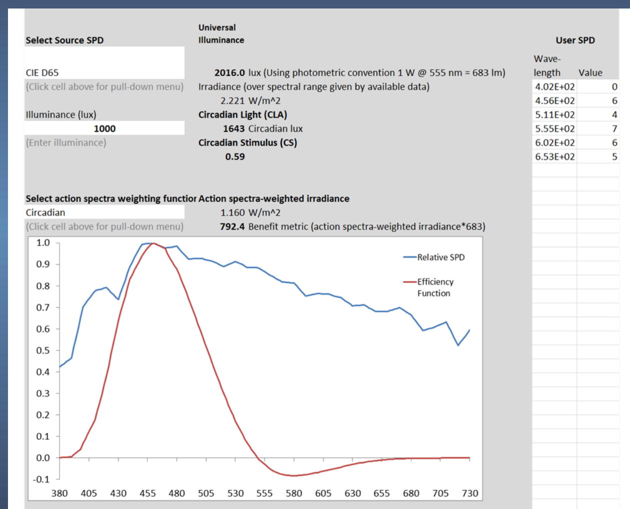
Circadian stimulus calculator



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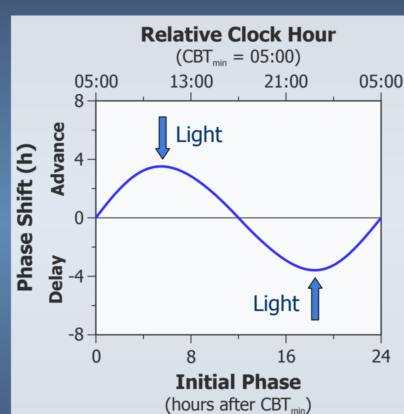
Circadian rhythms and light

- Light has a dual effect on the 24-hour melatonin profile
  - Acute effect – appears immediately after the exposure to "bright" or "blue" light
  - Phase-shifting effect – detectable several hours or a few days later
    - Change in direction and magnitude of phase shift as a function of circadian time can be plotted as a phase response curve (PRC)



5 hr pulse of 7,000 to 13,000 lux

Based on Khalsha et al. 2003

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Summary

- Quantity and spectrum matters!
  - Light is the major synchronizer of circadian rhythms to the local time on Earth
  - Melatonin is used as a marker of the circadian clock
  - Short-wavelength (blue) light maximally affects melatonin profiles
  - But light levels are just as important
- Timing matters!
  - Light can also be a disruptor if applied at the wrong time
    - Circadian disruption has been linked to diabetes, obesity and cancer
- Photic history matters!
  - Total light exposure over the course of the day needs to be monitored

http://www.dare2dream-dare2do.com/your-guide-to-sleep-stop-screwing-your-circadian-clock/

Sleep/wake cycle

- Two-process model
  - Circadian (C)
  - Homeostatic (S)
    - SCN maintains wakefulness, counterbalancing the homeostatic sleep
    - In both humans and monkeys, circadian timing system promote and maintain wakefulness across the subjective day and opposes accumulating "homeostatic sleep drive"

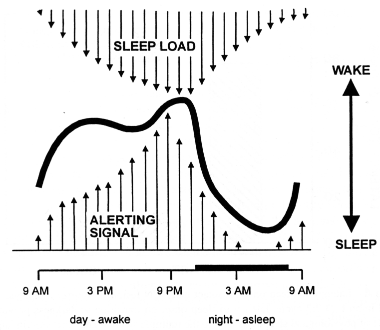

Figure 5 Schematic of the "opponent processes" mediating physiological sleepiness as a function of time of day. Sleep drive increases in response to wakefulness imposed and/or maintained by the suprachiasmatic pacemaker. Increasing levels of SCN-dependent alerting over the subjective day opposes homeostatic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

Zee, Circadian rhythms presentation
www.aasmnet.org/medsleep/rhythmslides.htm

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Acute effects of light

- Light of certain characteristics can
  - Suppress the hormone melatonin
  - Increase morning cortisol levels
  - Increase brain activities
  - Reduce subjective sleepiness
  - Improve certain types of performance

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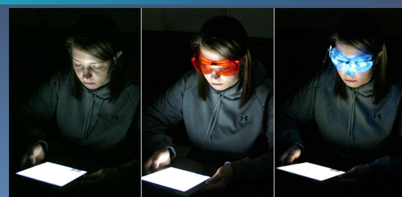
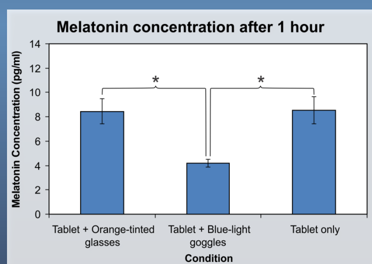
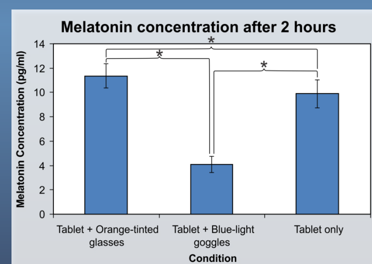
Impact of light from iPads on melatonin levels







Sponsor: Sharp Labs of America

Wood B, Rea MS, Plitnick B and Figueiro MG. Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Applied Ergonomics.* 2013; 44: 237-40.

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Impact of light from e-Readers on melatonin

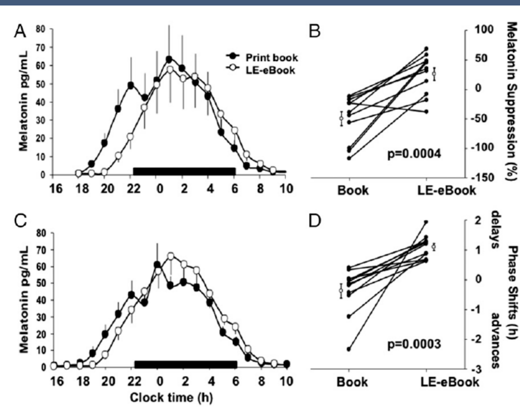

Fig. 2. Melatonin suppression (*A* and *B*) and phase shifting (*C* and *D*) during and after the LE-eBook and print book reading conditions. (*A*) Average waveforms of melatonin (±SEM) during the fifth night of each reading condition. The black bar denotes the scheduled sleep episode (22:00–06:00). (*B*) Percent suppression for each condition for each participant (filled symbols) and group average (±SEM; open symbols). (*C*) Average waveforms of melatonin (±SEM) on the evening/night after each reading condition. (*D*) Average phase shift of melatonin onset for each condition for each participant (filled symbols) and group average (±SEM; open symbols). The main effect of *Condition* was significant ($P < 0.05$, mixed model).

Biological Sciences - Physiology: Anne-Marie Chang, Daniel Aeschbach, Jeanne F. Duffy, and Charles A. Czeisler. Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness *PNAS 2014 ; published ahead of print December 22, 2014, doi:10.1073/pnas.1418490112*

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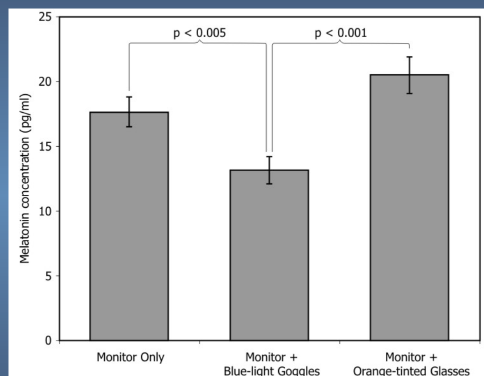
Impact of light from computer screens on melatonin levels



Sponsor: Sharp Labs of America

Figueiro MG, Plitnick B, Wood B and Rea MS. The impact of light from computer monitors on melatonin levels in college students. Neuro Endocrinol Lett. 2011; 32: 158-63.

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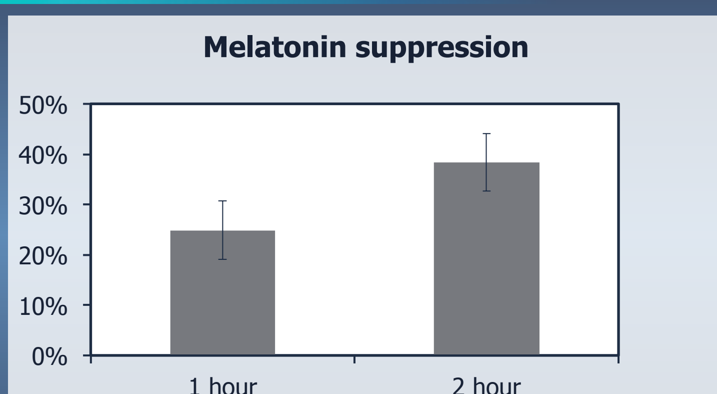
Impact of computer screens on melatonin levels in adolescents



Predicted suppression from Daysimeter data: 10%
Actual suppression: 25%

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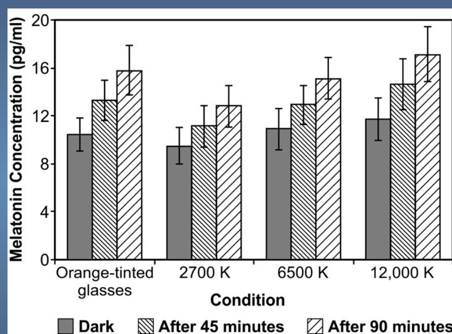
Impact of light from televisions on melatonin levels



Sponsor: Sharp Labs of America

No significant melatonin suppression after 45 min and 90 min

Figueiro MG, Wood B, Plitnick B and Rea MS. The impact of watching television on evening melatonin levels. *Journal of the Society for Information Display.* 2013; 21: 417-21.

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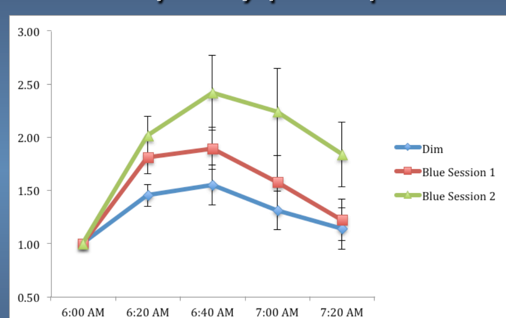
Impact of short-wavelength light on cortisol awakening response in adolescents

- 18 adolescents (ages 12-17 years) participated in the study
  - Allowed to sleep 4.5 hours
- Exposed to 470-nm light upon awakening
- Results:
  - CAR was significantly enhanced after 20-40 minutes exposure to 470-nm light



Rea and Figueiro 2012

Sponsor: Sharp Labs of America

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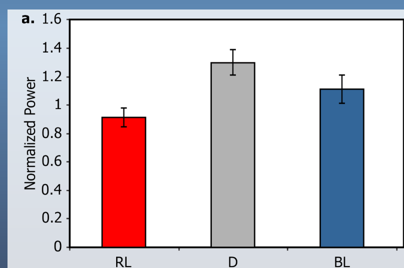
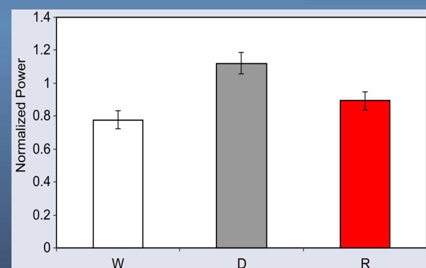
Light increases daytime alertness

- Exposure to 40 lux of long-wavelength light increased alertness in the afternoon more so than 40 lux of short-wavelength (blue) light
- Exposure to 200 lux of long-wavelength (red) light and 360 lux of 2650 K lights in the afternoon also increased alertness in the afternoon





Sponsor: Office of Naval Research (N00014-11-1-0572)

Sahin L., and Figueiro, MG. Alerting effects of short-wavelength (blue) and long-wavelength (red) lights in the afternoon. *Physiology and Behavior,* 2013, 116:17; 1-7.
Sahin L, Wood BM, Plinick BA, Figueiro MG. Daytime light exposure: Effects on biomarkers, measures of alertness, and performance. *Behavioral Brain Research*, 2014, 274:176-185.

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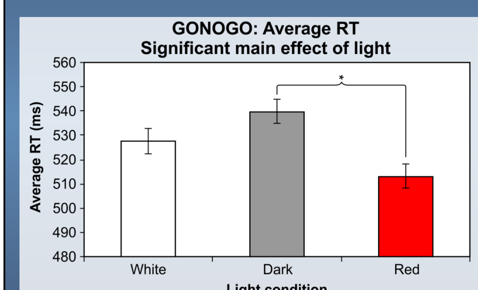
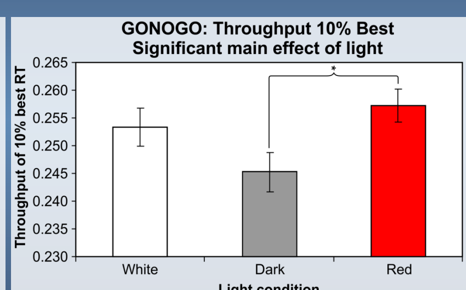
Red light increases certain types of daytime performance

200 lux of long-wavelength (red) and 2650 K lights increase performance in short-term tasks





Sponsor: Office of Naval Research (N00014-11-1-0572)

Sahin L, Wood BM, Plinick BA, Figueiro MG. Daytime light exposure: Effects on biomarkers, measures of alertness, and performance. Behavioral Brain Research, 2014, 274:176-185.

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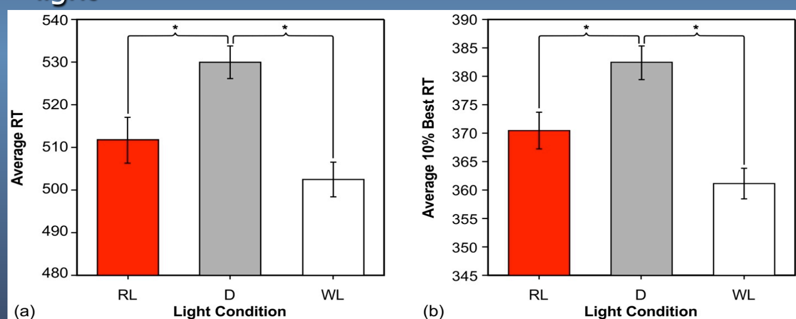
Lighting for nightshift workers

- Studies showed that red light, which does not suppress nocturnal melatonin can:
  - Improve certain types of performance, similar to white light



Figueiro MG, Sahin L, Wood B and Plitnick B. Light at night and measures of alertness and performance: Implications for shift workers. *Biological Research for Nursing.* 2014; In Press.

Sponsor: Office of Naval Research

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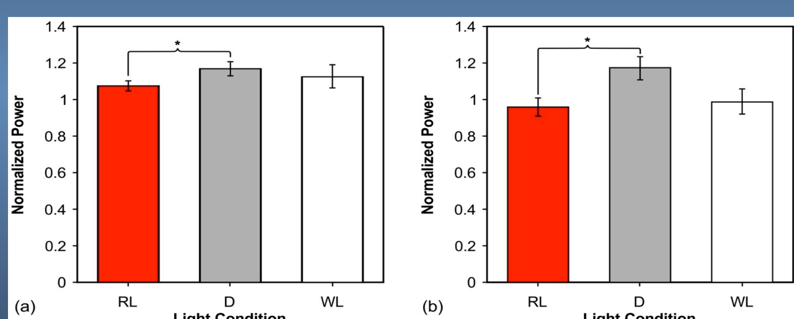
Lighting for nightshift workers

- Studies showed that red light, which does not suppress nocturnal melatonin can:
  - Improve subjective and objective measures of alertness



Alpha theta power

Alpha power

Figueiro et al. in press

Sponsor: Office of Naval Research (N00014-11-1-0572)

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Summary
Acute effects

- Low levels of blue light and higher levels of white light, but not red light, suppresses melatonin at night
- Blue and red lights will increase cortisol levels at night
- Blue, white and red lights increase subjective and objective measures of alertness and certain types of performance
- Acute effects dissipate soon after light exposure is removed

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Putting it all together
Acute effects

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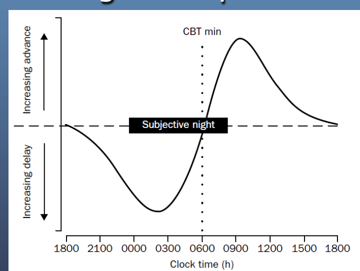
Phase shifting effects of light

- Light can change the timing of sleep and either promote entrainment or cause disruption
  - Morning light (after minimum core body temperature) will advance the timing of sleep
  - Evening light (before minimum core body temperature) will delay the timing of sleep



Rajaratnam S, Arendt J. Health in a 24-h Society. *The Lancet.* 2001; 358(9286):999-1005.

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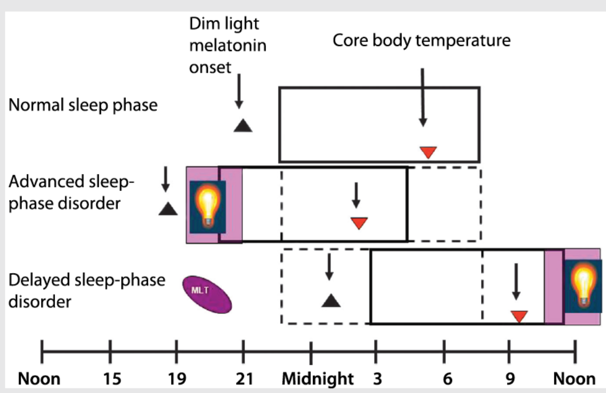

FIGURE 7-4 Summary of treatment approaches for delayed sleep-phase disorder and advanced sleep-phase disorder. Bright light administered before the nadir of body core temperature is a potent stimulus for delaying circadian phase. The most commonly used treatment for advanced sleep-phase disorder is early-evening light therapy, usually between 7:00 PM and 9:00 PM. This approach has been shown to improve sleep duration and sleep maintenance, as well as daytime performance. The combination of light therapy and melatonin has been shown to have complementary benefits. Bright light in the morning for 1 to 2 hours shortly after the minimum of the core body temperature rhythm advances circadian rhythms and 0.5 mg to 5 mg of melatonin taken 5 to 6.5 hours before dim light melatonin onset (13 to 14 hours after natural wake-up time) results in advanced sleep and wake times in patients with delayed sleep-phase disorder.

MLT = melatonin.

Zee et al. Continuum (Minneap Minn). 2013 Feb; 19(1 Sleep Disorders): 132–147.

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Phase shifting effects of light

- Delayed sleep phase disorder (DSPD)
    - Common in adolescents and young adults
    - Delayed bedtime, inability to entrain to daytime schedule
    - Light treatment in morning (after MCBT), light restriction in evening
        - Reduce use of self-luminous displays or at least filter them

Rosenthal NE, Joseph-Vanderpool JR, Levendosky AA, Johnston SH, Allen R, Kelly KA, Souetre E, Schultz PM, Starz KE. 1990. *Phase-shifting effects of bright morning light as treatment for delayed sleep phase syndrome.* Sleep. 1990 Aug;13(4):354-61.

Cole RJ, Smith JS, Alcalá YC, et al. 2002. *Bright-light mask treatment of delayed sleep phase syndrome. J Biol Rhythms.* 2002;17:89–101.

Lack L, Bramwell T, Wright H, Kemp K. 2007. *Morning blue light can advance the melatonin rhythm in mild delayed sleep phase syndrome.* Sleep Biol Rhythms. 2007;5:78–80

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Light and daylight in schools

- USGBC research grant
    - Light impacts students' performance and well-being by promoting their circadian entrainment to the solar day
    - Performed three field studies
- Hypothesis
    - Lack of "circadian" morning light (or much "circadian evening light) will de dim light melatonin onset resulting in
        - Later bedtimes
        - Shorter sleep times
        - Reduced performance and mood

Sponsor: USGBC

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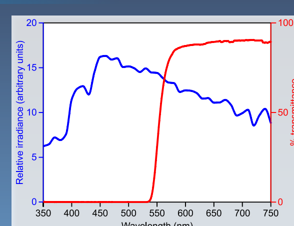
Daylight in schools: Study 1

- Site: Smith Middle School, NC
- 11 students participated in the within-subjects study
- Students wore orange glasses while at school for one week
    - Dim light melatonin onset before and after wearing the glasses

35

Daylight in schools (Study 1)

- Those wearing the orange glasses had:
    - Dim light melatonin onset (DLMO), delayed by approximately 1/2 hour



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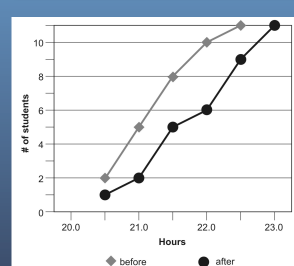

Figueiro and Rea, 2010

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Daylight in schools: Study 2

- Site: Smith Middle School, NC
- 22 students participated in the between-subjects study
  - 11 subjects wore orange glasses for one week while at school
  - 11 subjects did not wear the glasses
- All students were asked to:
  - Perform daily short performance tests
  - Keep a sleep diary
  - Fill out psychosocial stress questionnaires
  - Provide saliva samples for DLMO

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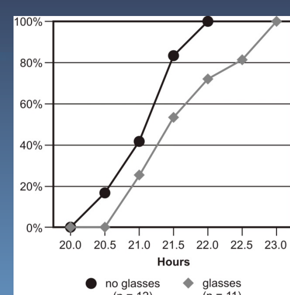
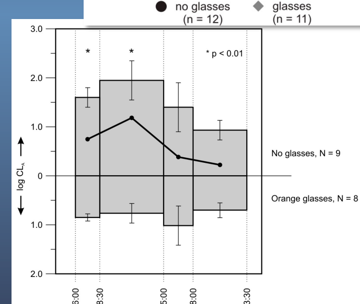
Daylight in schools: Study 2

- Those wearing the orange glasses had:
  - DLMO delayed by approximately a half hour
  - Sleep times delayed by approximately 10 minutes
  - No significant effect on performance or self-reports of stress





Figueiro et al. 2011

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Daylight in schools (Study 3)

- Site: Algonquin Middle School, NY
- 16 students participated in the study conducted in winter and spring 2009

Figueiro and Rea 2010

Sponsor: USGBC

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Daylight in schools: Study 3

- Spring is associated with:
  - More evening light
  - Delay in circadian phase (DLMO)
  - Shorter sleep duration

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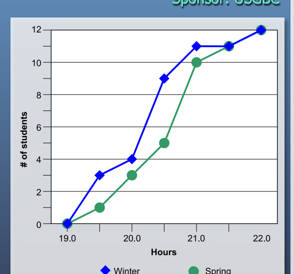

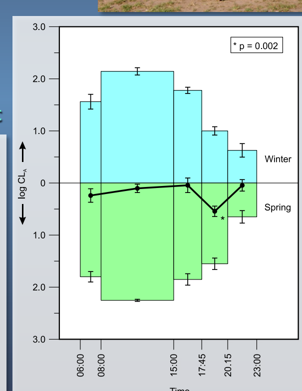

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Lighting intervention using college students

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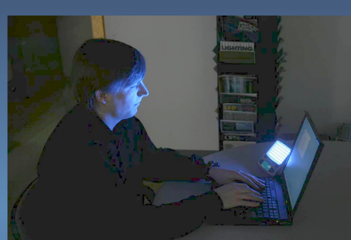
Field Study 1

Advanced sleep schedule + 470-nm light



Sharkey et al., 2011

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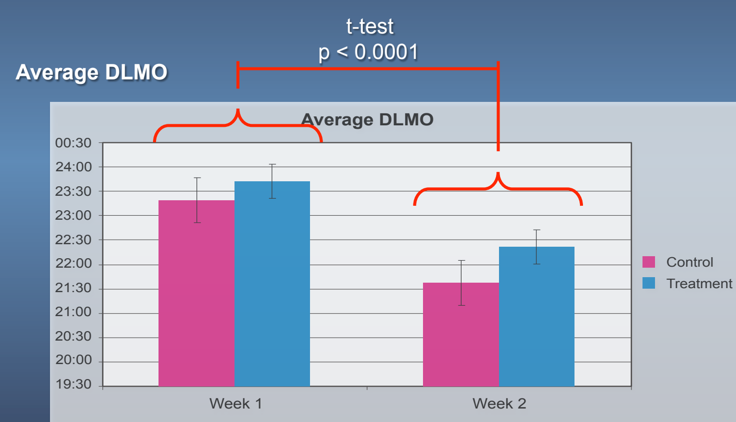
Field Study 1
Sharkey et al. 2011

After six days in an advanced sleep/wake schedule, morning short-wavelength (blue) light was not associated with larger phase shifts than dim-light exposure



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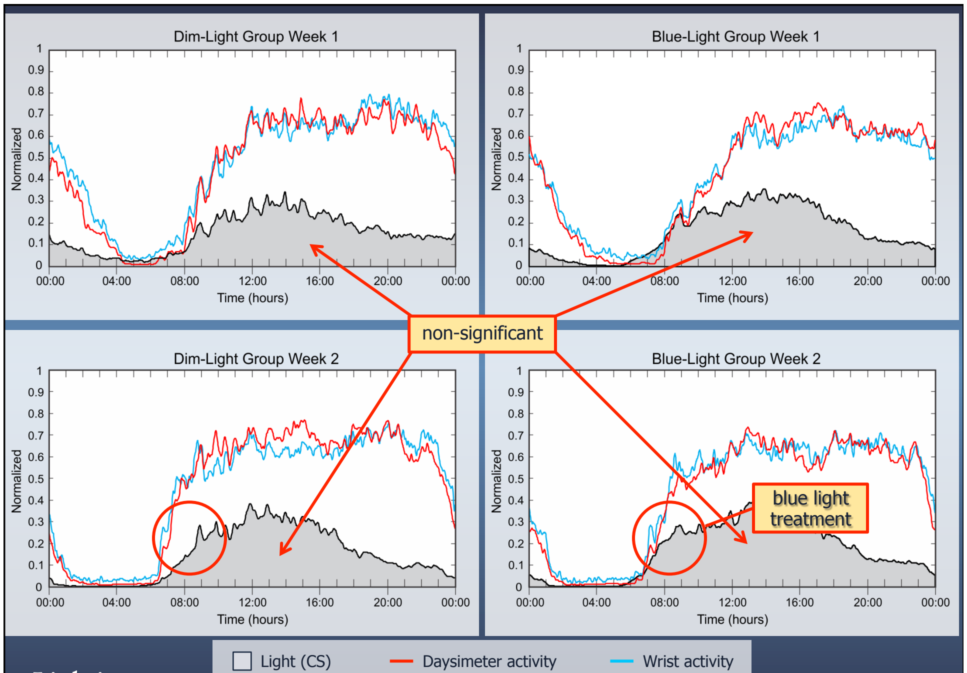

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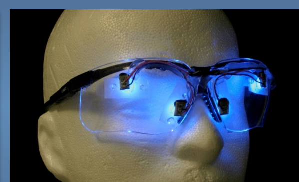
Field study 2

470-nm light + orange goggles + sleep/wake schedule

Orange-tinted Glasses



Blue LED Goggles

Dimesimeter

Appleman et al. 2013

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Field Study 2

470-nm light + orange goggles + sleep/wake schedule

- 21 subjects
- All were placed on an advance sleep schedule
- Half experienced blue light in the morning/orange goggles in the evening and the other half experienced orange goggles in the morning and blue light in the evening
- Daysimeter data were collected during the 12-day experiment

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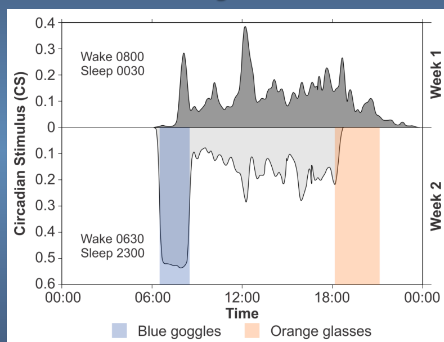
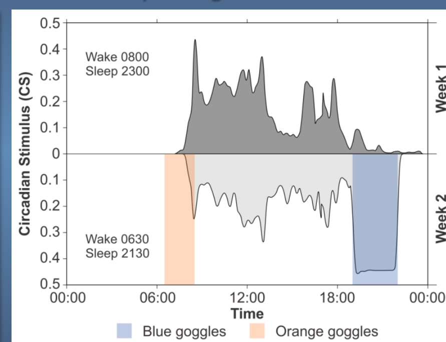
Field Study 2
Protocol

Advanced Light-Dark Pattern



Delayed Light-Dark Pattern



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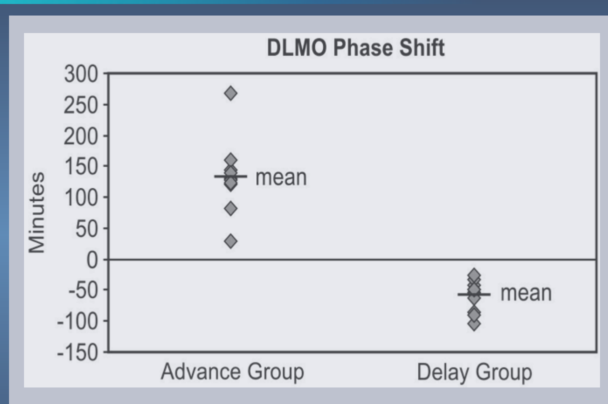
Field Study 2
Results



The mean ± standard error of the mean (SEM) phase shift for the advance group was + 132 ± 19 minutes and for the delay group was 59 ± 7.5 minutes

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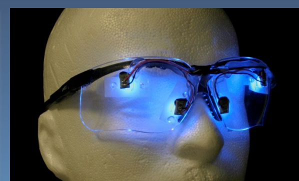
Field Study 3

470-nm light + orange goggles + sleep/wake schedule

Orange-tinted Glasses



Blue LED Goggles

Daysimeter

Session 1: Subjects delayed (orange glasses for 2 hours in the morning; blue light goggles for 3 hours in the evening)

Session 2: Subjects advanced (blue light goggles for 2 hours in the morning and orange goggles for 3 hours in the evening)

All subjects in 1.5-hour advanced sleep schedule; subjects experienced sessions in a counterbalanced manner

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Field Study 3

470-nm light + orange goggles + sleep/wake schedule

- Collected data from 23 subjects
  - 12 early chronotypes (9 females)
    - MCTQ range = 0-2
    - Mean ± SD MSFsc = 02:30 ± 30 min
    - Mean ± SD age: 40 ± 7.4
  - 11 late chronotypes (8 females)
    - MCTQ range = 5-6
    - Mean ± SD MSFsc = 05:30 ± 60 min
    - Mean ± SD age: 21.5 ± 2.3

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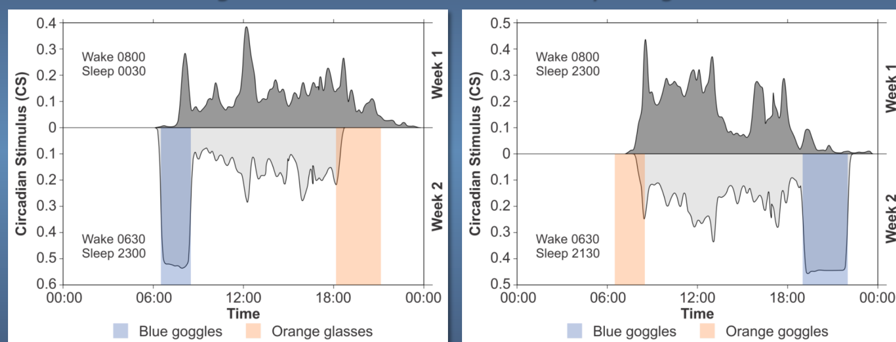
Protocol

Advanced Light-Dark Pattern

Delayed Light-Dark Pattern



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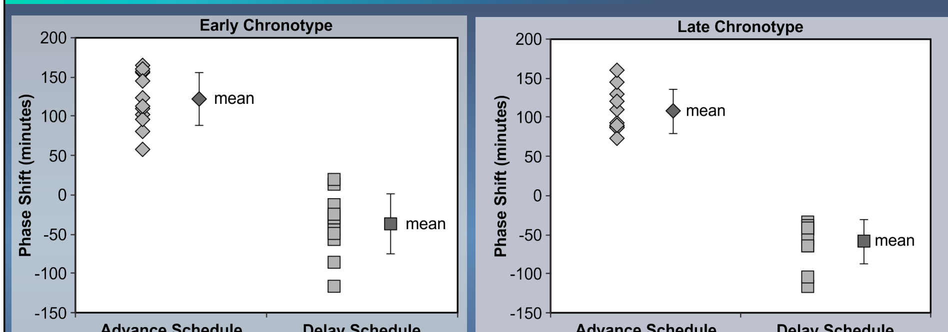
Results



The ANOVA using DLMO phase shift revealed

- Significant main effect of light intervention ($F_{1,21}$ = 440.7; $p < 0.0001$)
- There was no significant difference between chronotype groups ($F_{1,21}$ = 2.6; p = 0.1), nor was there an interaction between light intervention and chronotype group ($F_{1,21}$ = 0.19; p = 0.67)

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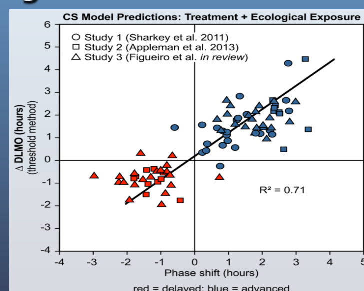
Summary

- Controlled light/dark exposures will improve effectiveness of light treatment
  - Need to deliver an remove light at correct circadian times
- Need to keep track of overall light exposure to better predict light treatment effectiveness



Rea et al. 2014

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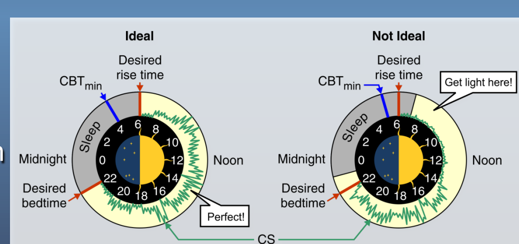
A Model of the Human Circadian Timing Mechanism

- Development of the Daysimeter and a model of the SCN's limit cycle oscillator helps the LRC to "write a prescription" so that a person can receive a light-dark pattern that matches their desired rise and sleep times
  - A biological watch may track a person's circadian time and provide a recommendation for when to receive or avoid light



Sponsors:
National Institute on Aging (R01AG034157)
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Office of Naval Research (N00014-11-1-0572)
Army Research Office through IAI

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Putting it all together
Phase shifting effects

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Putting it all together
Phase shifting effects

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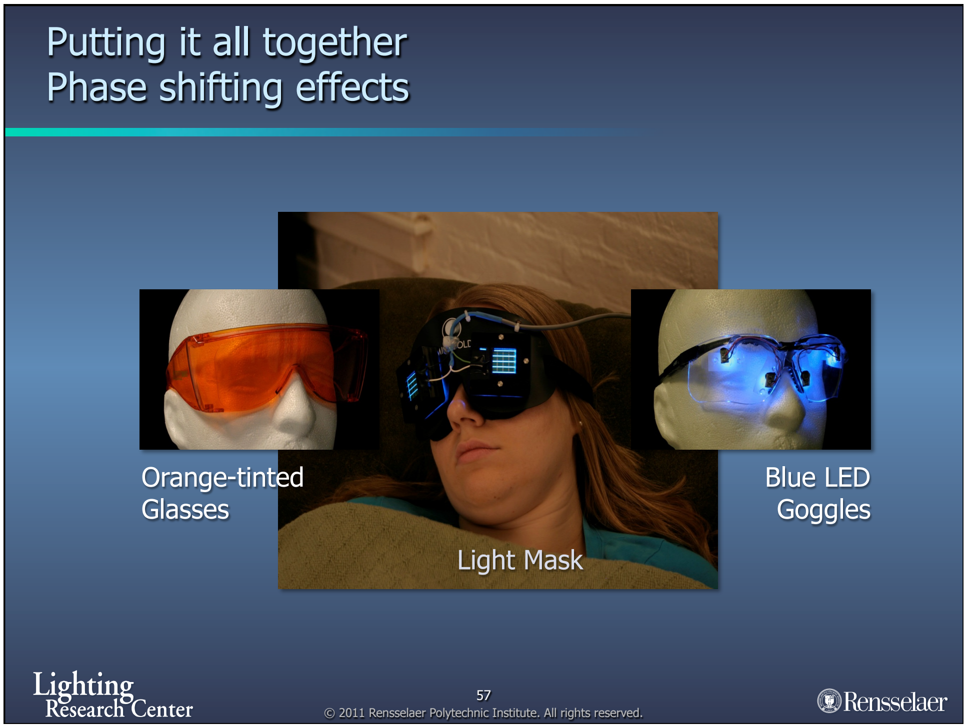
Putting it all together
Phase shifting effects
Orange-tinted Glasses
Light Mask
Blue LED Goggles
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57
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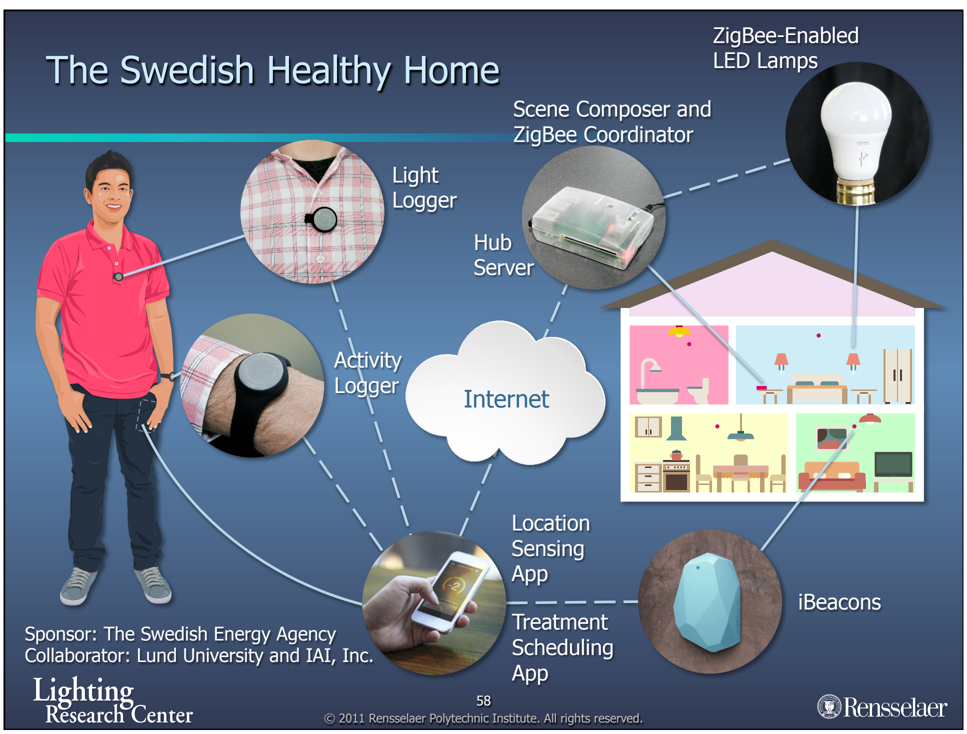
The Swedish Healthy Home
ZigBee-Enabled LED Lamps
Scene Composer and ZigBee Coordinator
Light Logger
Hub Server
Activity Logger
Internet
Location Sensing App
Treatment Scheduling App
iBeacons
Sponsor: The Swedish Energy Agency
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Applications

- Treatment of mood disorders: Seasonal Affective Disorder (SAD) and non-SAD disorders
  - Mood disorders are associated with alterations in hormone cycles and disturbance of sleep/wake cycles.
  - SAD is distinguished by seasonal depressive episodes.
  - Light treatment is typically given in the morning. Afternoon or evening light therapy may also be considered if morning is inconvenient.

Rosenthal NE, Sack DA, Gillin JC, Lewy AJ, Goodwin FK, Davenport Y, Mueller PS, Newsome DA, Wehr TA. 1984. *Seasonal affective disorder. A description of the syndrome and preliminary findings with light therapy.* Arch Gen Psychiatry. 1984 Jan;41(1):72-80.

Lam RW, Levitt AJ, Levitan RD, et al. *The Can-SAD Study: A randomized controlled trial of the effectiveness of light therapy and fluoxetine in patients with winter seasonal affective disorder.* Am J Psychiatry. 2006;163:805–12
Terman JS, Terman M, Lo ES, Cooper TB. *Circadian time of morning light administration and therapeutic response in winter depression.* Arch Gen Psychiatry. 2001;58:69–75.

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Summary

- Therapeutic light treatments have been shown to be effective at treating circadian related disorders.
  - Total light exposures need to be monitored
  - Same light at one time during the day can be beneficial or detrimental
  - We are moving to a more "individualized" lighting solution
- Light can also elicit an acute alerting effect on people
  - Use red light when circadian phase shifting is not desired

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Thank you!

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