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

Mariana G. Figueiro, PhD, FIES
Professor
Lighting Research Center
Rensselaer Polytechnic Institute
Troy, NY
October 29, 2015

Acknowledgments

- Organizers of the Event
- Lighting Research Center’s faculty, staff and students
  - Mark S. Rea, PhD
  - Barbara Plitnick, RN
  - Sharon Lesage
  - Kassandra Gonzalez, MS
  - Ryan Brommer
  - Andrew Bierman, MS
  - Geoff Jones
  - Dennis Guyon
Light and Health Project Sponsors

- National Institute on Aging
- National Institute on Drug Abuse
- National Institute of Nursing Research
- National Cancer Institute
- National Center for Complementary and Alternative Medicine
- 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

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
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

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
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.

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
Sponsor: Office of Naval Research
Light is the primary synchronizer of circadian rhythms to local position on Earth

The natural, 24-hour, light-dark cycle

Light is also the major disruptor

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
Lighting characteristics

- Intensity
- Spectrum
- Distribution
- Timing
- Duration

Visual System

- Appearance
- Visual Performance

Performance, Well-being, Satisfaction, and Comfort

Culture, Experience, Expectations

Alerting Effects

Circadian System

Intensity, Spectrum, Distribution, Timing, Duration

Circadian rhythms and light

Spectral sensitivity

Absolute sensitivity

Rea et al 2005; 2011
Circadian stimulus calculator

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)

Based on Khalsha et al. 2003

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

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**YOUR GUIDE TO SLEEP**

What's your circadian clock got to do with it?

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"

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
Impact of light from iPads on melatonin levels


Impact of light from e-Readers on melatonin

Impact of light from computer screens on melatonin levels


Impact of computer screens on melatonin levels in adolescents

Predicted suppression from Daysimeter data: 10%
Actual suppression: 25%
Impact of light from televisions on melatonin levels

No significant melatonin suppression after 45 min and 90 min


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
**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.

**Red light increases certain types of daytime performance**

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

![Graph showing performance improvement with red light](image)


Lighting for nightshift workers

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

![Graph showing alertness measures](image)

Figueiro et al. in press
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

Putting it all together
Acute effects
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

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


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 delay dim light melatonin onset resulting in:
    - Later bedtimes
    - Shorter sleep times
    - Reduced performance and mood
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

Daylight in schools (Study 1)

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

Sponsor: USGBC

Figueiro and Rea, 2010
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

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
Daylight in schools (Study 3)

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

Daylight in schools: Study 3

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

Sponsor: USGBC
Lighting intervention using college students

Field Study 1
Advanced sleep schedule + 470-nm light

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.

Average DLMO

- Week 1
  - Control: 20:30, 21:00, 21:30, 22:00
  - Treatment: 19:30, 20:00

- Week 2
  - Control: 22:30, 23:00, 23:30, 00:00
  - Treatment: 22:30, 23:00, 23:30, 00:00

**t-test**

\[ p < 0.0001 \]
Field study 2
470-nm light + orange goggles + sleep/wake schedule

Orange-tinted Glasses
Blue LED Goggles
Dimesimeter

Appleman et al. 2013

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
- Dimesimeter data were collected during the 12-day experiment
Field Study 2
Protocol

Advanced Light-Dark Pattern

Delayed Light-Dark Pattern

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.
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

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
Protocol

Advanced Light-Dark Pattern

Delayed Light-Dark Pattern

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 ($F_{1,21} = 0.19; p = 0.67$)
Summary

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

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)
National Institute on Drug Abuse (U01DA023822)
Office of Naval Research (N00014-11-1-0572)
Army Research Office through IAI
Putting it all together
Phase shifting effects

Putting it all together
Phase shifting effects
Putting it all together
Phase shifting effects

Orange-tinted Glasses  Blue LED Goggles
Light Mask

The Swedish Healthy Home

Sponsor: The Swedish Energy Agency
Collaborator: Lund University and IAI, Inc.
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.


Terman JS, Terman M, Lo EY, Cooper TB. Circadian time of morning light administration and therapeutic response in winter depression. Arch Gen Psychiatry. 2001;58:69–75.

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
Thank you!

www.lrc.rpi.edu
Email: figuem@rpi.edu