Light’s Effects on Human Health, Alertness, and Sleep

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Dr. Figueiro is well known for her research on the effects of light on human health, circadian photobiology, and lighting for older adults.

She is the author of more than 80 scientific articles in her field, and her research is regularly featured in national media.
Disclosures

- Dr. Mariana G. Figueiro has no relevant financial or non-financial relationships to disclose relating to the content of this activity.
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Learning Objectives

At the conclusion of this activity, participants will be able to:

1. Explain basic concepts of light’s effects on the circadian system and human health.

2. Comprehend and implement lighting strategies for promoting alertness without adversely affecting the circadian system.

3. Recognize and implement lighting strategies for promoting sleep and general well-being.
Circadian system

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

\[ \textit{circa} = \text{approximately}; \quad \textit{dies} = \text{day} \]

- Circadian rhythms are generated and regulated by a biological clock in the brain
  - In humans, circadian rhythms free-run with a period slightly greater than 24 hours
YOUR GUIDE TO SLEEP
What’s your circadian clock got to do with it?
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.)
Why do we sleep?

In bed, it's 6AM you close your eyes for 5 minutes, it's 7:45. At school it's 1:30, close your eyes for 5 minutes, it's 1:31.

Some national parks have long waiting lists for camping reservations. When you have to wait a year to sleep next to a tree, something is wrong.

I'm so good at sleeping, I can do it with my eyes closed.
Why do we sleep?

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

Why do we sleep?

- Sleep promotes learning and consolidates memory
  - Different types of tasks are correlated with different sleep stages

Consequences of sleep deprivation

- Sleep deprivation has been linked to:
  - Reduced performance
  - Increased risk for diabetes, obesity, and cardiovascular disease
  - Increased risk for depression
  - Increased risk for Alzheimer’s disease
  - Increased risk for falls
Sleep and surgeon’s dexterity performance

- Surgeons who were awake all night:
  - Made 20% more errors and took 14% longer to complete the same tasks than those who had had a full night’s sleep
  - Showed increased stress and decreased arousal
  - Showed a decrease in operative dexterity

Sleep and cardio-metabolic functions

- 2 days of 4-hour bedtimes decreased leptin (satiety hormone), increased ghrelin (hunger hormone), and increased self-reported hunger

Sleep and Alzheimer’s disease (AD)

- 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, and 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.

Sleep and AD

- One night of sleep deprivation, relative to baseline, resulted in significant increases in Aβ burden in the right hippocampus and thalamus.
- These increases were associated with mood worsening following sleep deprivation, but were not related to the genetic risk (APOE genotype) for AD.

How does light affect sleep and circadian rhythms?

- Light entrains the biological clock to the local time on Earth
  - Short-wavelength, blue light (peak close to 460 nm) is maximally effective
- Light has an acute, direct effect on humans
  - Increases measures of alertness
  - Impacts production of hormones
  - Decreases reaction times
  - Reduces feelings of sleepiness
- Light provides perceptual cues of the environment
  - Increases postural control and stability
Light and sleep in office workers

- Those exposed to higher morning (08:00 a.m. to noon) circadian stimulus (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)

Source: U.S. General Services Administration


(*** = p < .01; ** = p < 0.05)
Light and sleep survey

- During COVID-19 pandemic we 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

At home light exposure

<table>
<thead>
<tr>
<th>Light Exposure</th>
<th>Sleep disturbance</th>
<th>Sleep related impairment</th>
<th>Anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very bright</td>
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<td>Somewhat bright</td>
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<td>Neutral</td>
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<td>Somewhat dim</td>
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<tr>
<td>Very dim</td>
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</table>

Time spent outside

<table>
<thead>
<tr>
<th>Time Spent Outside</th>
<th>Sleep disturbance</th>
<th>Sleep related impairment</th>
<th>Anxiety</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;2 hours</td>
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<td>1-2 hours</td>
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<td>30-60 min.</td>
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<td>10-30 min.</td>
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<td>&lt;10 min.</td>
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</table>
Light and sleep survey

At home light exposure

- **Very bright**
- **Somewhat bright**
- **Neutral**
- **Somewhat dim**
- **Very dim**

Time spent outside

- **>2 hours**
- **1-2 hours**
- **30-60 min.**
- **10-30 min.**
- **<10 min.**

**Stress**
- Better
- Worse
- 50

**Depression**
- Better
- Worse
- 50

**Positive effect**
- Worse
- Better
- 50
Lighting affects three systems: Visual + Non-visual + Message/Perceptual

- Visual System
  - Appearance
  - Visual Performance
  - Performance, Well-being, Satisfaction, and Comfort
  - Non-Visual Systems
    - Alerting Effects
    - Phase Shift
  - Culture, Experience, Expectations

Factors:
- Amount
- Spectrum
- Distribution
- Timing
- Duration
Light’s alerting effects
It does not have to be blue light!

Alertness (brain activity)

Melatonin levels

4 light levels: dim (D), low (5 lux), medium (75 lux), and high (150 lux)

Error bars represent standard error of the mean
* P < 0.05, ** P < 0.01

Source: Office of Naval Research
Summarizing what we know so far…….

Science

- **Light sets the timing of the biological clock (promotes entrainment)**
  - For entrainment
    - *Morning light* is needed to advance the timing of the clock (timing is important)
    - *Short-wavelength and high light levels at the eye* are most effective
    - Any white light can be used, however, if you increase light levels, change fixture distribution, or increase duration
    - Melatonin is used as a marker, but melatonin suppression and phase shifting of the clock, but may use different pathways in the brain to accomplish that

- **Light has a direct (acute) effect on people (cup of coffee)**
  - Does not have to be blue light, but it must be at the eye!
  - Any time of day is effective
  - Effect is generally observed within 15-30 min
What Does the Research Tell Us?
1. Ambient light therapy to promote entrainment in cancer patients

Sources: National Cancer Institute and Acuity Brands
Study 1: Light therapy and melatonin in myeloma transplant patients — Protocol

- In collaboration with Dr. William Redd (Icahn School of Medicine at Mt. Sinai, NYC), we investigated the impact of a CS = 0.3 (1000 lux at pillow, 3000 K light source) between 07:00 and 10:00 on entrainment, sleep, fatigue, and depression

  - 30 patients undergoing bone marrow transplant received the circadian active light (CS = 0.3) and 30 patients received a circadian-inactive light (CS < 0.1)
  - Urine melatonin, actigraphy, questionnaires were collected at baseline and at the end of hospitalization

Sources: National Cancer Institute and Acuity Brands
Study 1: Light therapy and melatonin in myeloma transplant patients — Results

- 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.

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

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

Sources: National Cancer Institute and Acuity Brands
Study 1: Light therapy and melatonin in myeloma transplant patients — Results

High CS exposure led to significantly lower CES-D total scores (depression) than low CS exposures ($P = 0.0051$)

Source: National Cancer Institute and Acuity Brands
2. Tailored lighting intervention (TLI) for patients with Alzheimer’s disease and related dementias (ADRD) in long-term care facilities

Source: National Institute on Aging
Study 2a: Short-term TLI for patients with ADRD

- 14-week randomized, placebo-controlled, crossover design clinical trial
- Administered all-day (≈ 06:00 – 08:00 to 18:00) active (high circadian stimulus [CS] = 0.4) or control (low CS < 0.1) TLI
- 46 patients with ADRD in 8 long-term care facilities for two 4-week periods (separated by a 4-week washout)

![Study 2a Protocol Table]

Source: National Institute on Aging
Study 2a: Short-term TLI for patients with ADRD

- Participants’ CS exposures were significantly greater during the active TLI compared to baseline.

* $P < 0.05$, ** $P < 0.01$

Source: National Institute on Aging
Participants experienced fewer sleep disturbances (PSQI scores) and depressive symptoms (CSDD scores) during the active TLI compared to baseline and the control.

* $P < 0.05$, *** $P < 0.001$

Source: National Institute on Aging
Participants experienced fewer agitated behavior symptoms (CMAI scores) during the TLI compared to baseline and greater reductions in symptoms compared to the control.
Study 2b: Long-term TLI for patients with ADRD Protocol

- 6-month randomized single-arm, within-subjects design clinical trial
- Administered all-day (≈06:00 – 08:00 to 18:00) active TLI (high CS = 0.4)
- 47 patients with ADRD in 9 long-term care facilities

Source: National Institute on Aging
Study 2b: Long-term TLI for patients with ADRD

- Participants experienced fewer sleep disturbances (PSQI scores) and depressive symptoms (CSDD scores), along with fewer agitated behavior symptoms (CMAI scores), during the TLI compared to baseline.

Sleep disturbances

Depression scores

Agitation scores

Source: National Institute on Aging

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$
3. Lighting to promote entrainment and increase alertness in office workers

Source: General Services Administration and US Department of State
Study 3a: Circadian entrainment in office workers

- Those exposed to higher morning (08:00 – 12:00) 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)


Source: U.S. General Services Administration

(* P < 0.05, ** P < .01)
Test, in a 3-week field study, the impact of morning blue light and afternoon red light on:

- Sleep quality at home
- Subjective sleepiness and vitality scores during work

<table>
<thead>
<tr>
<th>Time of day</th>
<th>Week 1 (Days 1–5)</th>
<th>Week 2 (Days 1–5)</th>
<th>Week 3 (Days 1–5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrive</td>
<td>12.00</td>
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<td>15.00</td>
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<th>Week 1 (Days 1–5)</th>
<th>Week 2 (Days 1–5)</th>
<th>Week 3 (Days 1–5)</th>
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<tr>
<td>Waking to bedtime</td>
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<td>Waking to bedtime</td>
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<th>Wear actigraph</th>
<th>Week 1 (Days 1–5)</th>
<th>Week 2 (Days 1–5)</th>
<th>Week 3 (Days 1–5)</th>
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<th>Lighting intervention</th>
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<th>Week 2 (Days 1–5)</th>
<th>Week 3 (Days 1–5)</th>
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<tbody>
<tr>
<td>Off</td>
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<th>Questionnaires</th>
<th>Week 1 (Days 1–5)</th>
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<th>Week 3 (Days 1–5)</th>
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<td>PSS-10</td>
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<tr>
<td>CES-D</td>
<td>First day of week 1 only</td>
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<td>PSQI</td>
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<td>PSS-10</td>
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<tr>
<td>CES-D</td>
<td>Last day of week 3 only</td>
<td></td>
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</tbody>
</table>

Source: U.S. General Services Administration
Morning blue light (CS ≥ 0.3):
- Promote circadian entrainment, advance circadian phase
- Advance sleep onset at night, sleep offset in the morning
- Advance activity acrophase

Morning blue light (CS ≥ 0.3):
- Elicit acute alerting response
- Reduce subjective sleepiness
- Increase subjective vitality/energy

Afternoon red light (CS = 0):
- Elicit acute alerting response
- Reduce subjective sleepiness
- Increase subjective vitality/energy, especially around 15:00 (the post-lunch dip)
- Avoid excessive CS exposure in late afternoon, thereby limiting any possible light-induced delay of circadian phase


Source: U.S. General Services Administration
Study 3b: Daytime office workers
Lighting interventions

- LRC developed and built 20 plug-in LED luminaires, mounted on participants’ desktops

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Lighting Intervention</th>
<th>$\lambda_{\text{max}}$ (nm)</th>
<th>$E_V$ (lux)</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>06:00 to 12:00</td>
<td>blue</td>
<td>455</td>
<td>50</td>
<td>0.30</td>
</tr>
<tr>
<td>12:00 to 13:30</td>
<td>white (6500 K)</td>
<td>n/a</td>
<td>200</td>
<td>0.30</td>
</tr>
<tr>
<td>13:30 to 17:00</td>
<td>red</td>
<td>634</td>
<td>50</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: U.S. General Services Administration
Study 3b
Results — Questionnaires

- Sleepiness (KSS) scores were reduced significantly during the intervention (week 3) at 15:00 (with red light)

![Graph showing change in sleepiness scores](source: U.S. General Services Administration)

Error bars represent standard error of the mean (* \( P < 0.05 \))
4. Light for day- and night-shift nurses

Source: National Institute for Occupational Safety and Health (NIOSH)
Study 4: Red light for shift-working nurses

- Translate lab findings into the field
  - 20-week protocol
  - 45 day-shift nurses (07:00 – 19:00)
  - 45 night-shift nurses (19:00 – 07:00)
- Outcome measures:
  - Reaction time performance testing
  - Saliva samples for melatonin and cortisol levels
  - Subjective sleep and global health questionnaires
  - Actigraphy

Source: National Institute for Occupational Safety and Health (NIOSH)
Study 4: Red light for shift-working nurses
Lighting interventions

- Intervention sessions:
  - Every workday for 2 weeks

- Experimental conditions:
  - 50 lux blue light (476 nm)
  - 50 lux red light (630 nm)
  - 30 lux white light (2700 K)

- Light goggles worn for 30 min, 3 times per shift
  - Beginning, middle, and end of shift

- Performance tests and saliva samples collected before and after wearing light goggles

Source: National Institute for Occupational Safety and Health (NIOSH)
Study 4: Red light for shift-working nurses
Preliminary results

- Workers responded faster after red light at the end of the dayshift and at the middle of the nightshift, when they were likely to be more tired

Source: CDC/NIOSH
5. Using light to increase alertness in train operators

Source: Metro Istanbul
Study 5: Using light to increase alertness in a train dispatch center

- Investigate whether exposure to high CS in the morning and low CS (red combined with white light) in the afternoon and at night would promote circadian entrainment (phasor magnitude) and increase objective (actigraphy) and subjective sleep quality (PSQI) as well as alertness (KSS) in the operational context.

Source: Metro Istanbul
Study 5: Using light to increase alertness in a train dispatch center — Lighting interventions

- **Morning schedule**
  - 07:00 – 12:00
  - CS > 0.3
  - (A) 6500K white light
  - (B) 470 nm blue light

Source: Metro Istanbul
Study 5: Using light to increase alertness in a train dispatch center — Lighting interventions

- Afternoon & night schedule
  - 12:00 – 07:00
  - CS < 0.1
  - (A) 4000K white light
  - (B) 630 nm red light

Source: Metro Istanbul
Study 5: Using light to increase alertness in a train dispatch center — Results

- Sleep Quality (PSQI)

![Chart showing improvement in sleep quality](chart.png)

*Better Sleep*

Source: Metro Istanbul

(* $P < 0.05$)
Summary: What does the research tell us?

- Light and health is about more than just “circadian,” “tunable,” or “blue-enriched” light.

- The amount, timing, duration, and distribution must be included in any design:
  - Spectrum is important, but amount and duration are key for applications.

- We don’t know it all, but if we “overdesign” the dose, we see positive results in the field:
  - Field studies are showing promising results when using CS = 0.3 during the day (300 – 500 lux at the eye of a 3000 K source) and CS = 0.1 (< 30 lux at the eye) in the evening.
The future

- DaysiLight
- DaysiMotion
- Hub
- Lamps
- HealthyHome App
- HomeLocation App
- Beacons
Tips for Designing for Circadian Entrainment and Alertness

- Think about *layers* of light!
  - Some designers or specifiers may have strict energy constraints that prevent CS targets from being met
    - Consider using saturated blue (e.g., peak wavelength = 470 nm) LEDs as a way to boost CS in creative ways
  - Studies have shown that red light can have an acute alerting effect without suppressing melatonin
    - Consider using red light as a way to boost alertness for occupants
Think Beyond the Ceiling
Portable/Personal Light Devices

- Custom built luminaires with static/tunable spectrum light engines and manual or digitally programmable controls
- Used for field studies as well as lab experiments investigating circadian effective light as well as light for acute alerting effect
- Very few if any equivalent products commercially available
- Go outdoors for 1-2 h in the morning!
How to make a circadian-effective light device

https://www.youtube.com/watch?v=__QsTrrIC2s
Saturated, narrow-band blue
Peaking between 460 – 480 nm
Light at the eye: 30 lux
White light range

Cool

6500 K  5000 K  4000 K  3000 K  2700 K

Warm
Saturated, narrow-band red Peaking between 625 – 635 nm

Light at the eye: 100 lux
Dim, warm color light at night
Key Takeaways

- Light incident on the retinae is the primary synchronizer of circadian rhythms to our local position on Earth.
- Exposure to high levels of light at night can disrupt the circadian system and is associated with several major diseases, depression, and sleep problems, among other ailments.
- Light can provide an alerting effect, similar to a cup of coffee, at any time of day or night.
- The human circadian system is maximally sensitive to short-wavelength (“blue”) light, which makes it ideal for stimulating the circadian system early in the day.
- Long-wavelength (“red”) light can promote alertness without disrupting the sleep and the circadian system generally.
https://www.doi.org/10.1111/ ejn.14298

https://www.doi.org/10.1016/j.nbscr.2018.02.003

https://www.doi.org/10.1177/1477153517721598


https://www.doi.org/10.3389/fnbeh.2014.00162


https://www.doi.org/10.2147/NSS.S134864


References


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  - GE current, a Daintree company
  - LEDVANCE
  - OSRAM
  - USAI Lighting
Thank you!

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www.lrc.rpi.edu
https://www.lrc.rpi.edu/healthyliving/
http://www.lrc.rpi.edu/cscalculator/
https://www.youtube.com/watch?v=___QsTrrIC2s
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