SMART LIGHTING ENGINEERING RESEARCH CENTER

Lighting Innovation for a Smarter Tomorrow

Academia - Industry Day

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Boston University, Photonics Building

A Second Kind of Light

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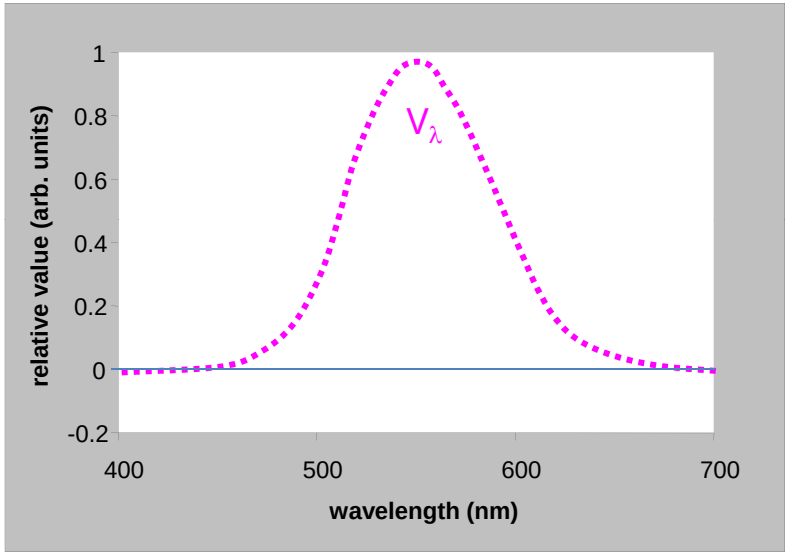
What is light?

- IESNA definition: Radiant energy capable of exciting the retina and producing a visual sensation. The visible portion of the electromagnetic spectrum extends from about 380 to 780 nanometers. CIE defines it over 360 to 830 nm.
- Official (CIE) definition: radiant energy weighted by the photopic luminous efficiency function, V(λ)



Light isn't just for vision anymore

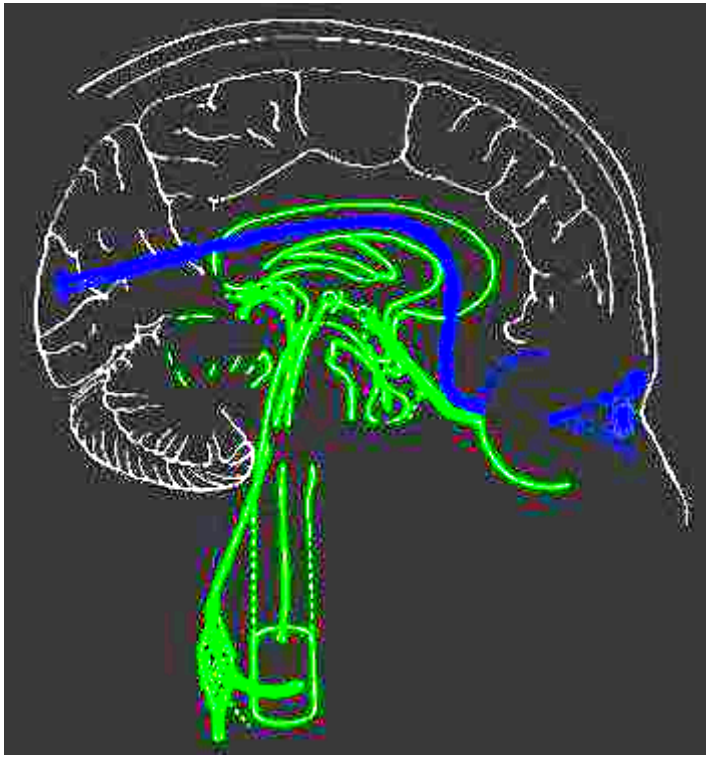
- Light reaching the retina has two effects on human behavior:
  - Visual effects
  - Non-visual effects
    - Neurobehavioral, neuroendocrine and circadian
- Light is not the same for vision as it is for the circadian system

Circadian system

- All plants and animals exhibit patterns of behavioral changes over an approximately 24-hour cycle that repeat over successive days—these are circadian rhythms

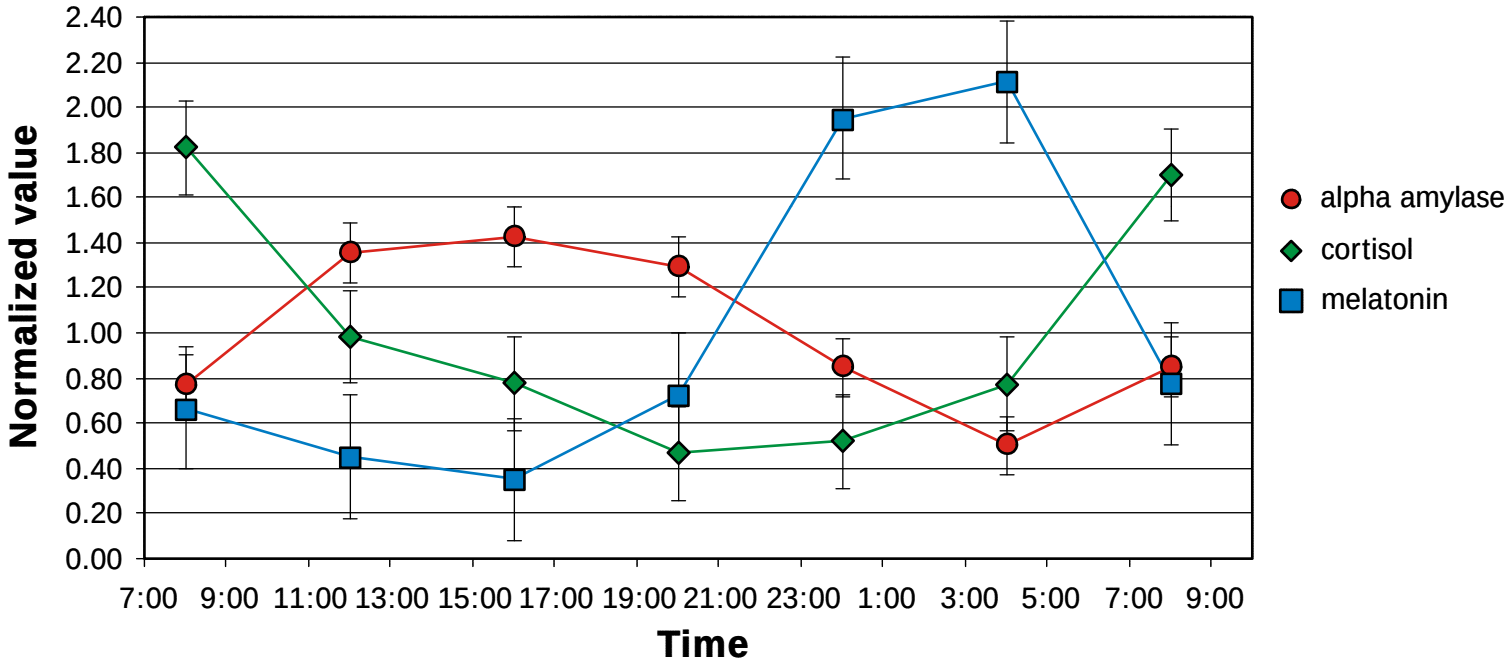
  circa = about; dies = day

- Circadian rhythms are influenced by exogenous and endogenous rhythms
  - Light/dark patterns are the strongest entrainment stimulus for the circadian system



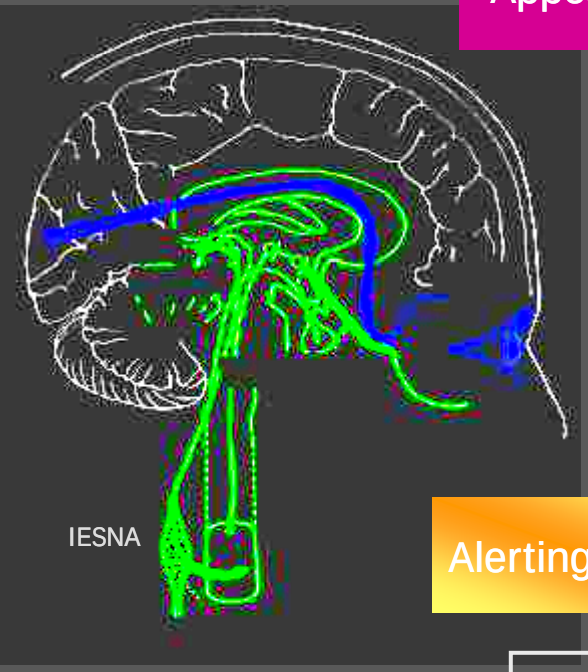
Adapted from IESNA Handbook

Three circadian rhythms



Figueiro et al., 2009
Sponsor: Office of Naval Research

New paradigm for light



Intensity
Spectrum
Distribution
Timing
Duration

Appearance
Visual System
Visual Performance

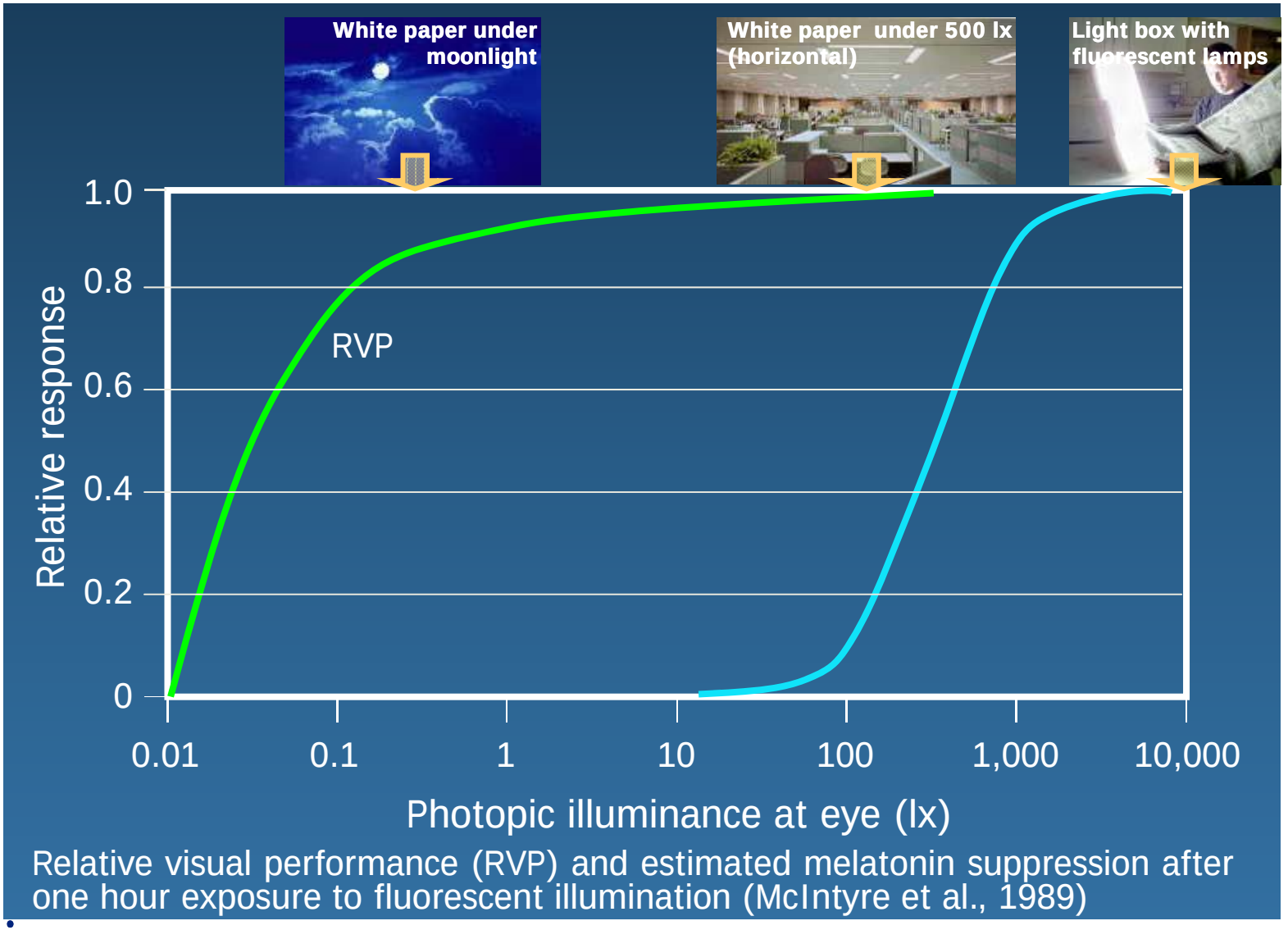
Performance, Well-being, Satisfaction, and Comfort

Culture, Experience, Expectations

Alerting Effects
Circadian System
Phase Shift

Intensity
Spectrum
Distribution
Timing
Duration

Retinal illuminance



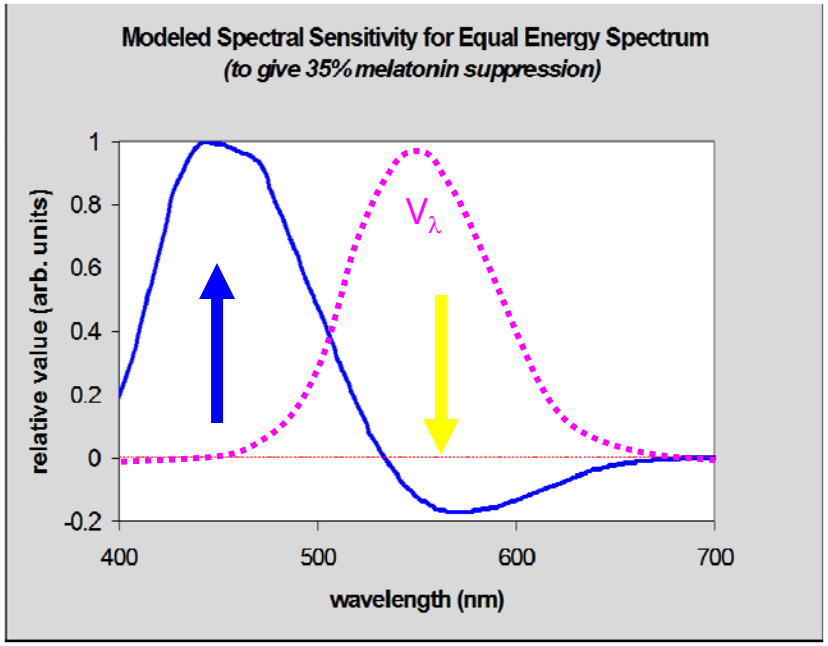
Relative visual performance (RVP) and estimated melatonin suppression after one hour exposure to fluorescent illumination (McIntyre et al., 1989)

Spectrum

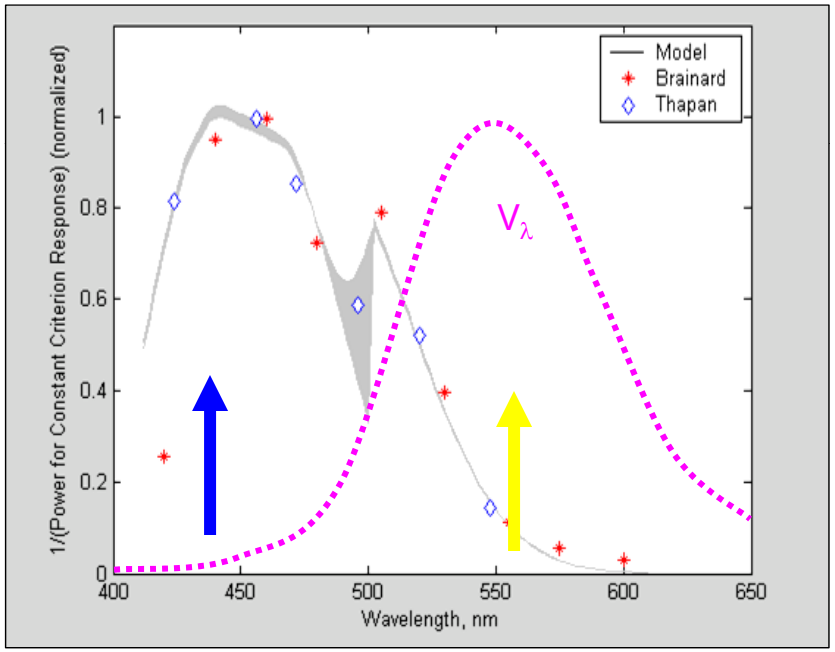
- A new photoreceptor (ipRGCs) was discovered in the retina in 2002 (Berson et al., 2002)
  - Slower to respond, less sensitive to light
  - Peak sensitivity at about 482 nm
- Subsequent studies showed that rods, cones and ipRGCs participate in how the retina converts light signals into neural signals for the circadian system (Hattar et al., 2003)
  - Overall peak sensitivity between 450 and 480 nm (blue light)
- Spectral opponency slightly reduces the effectiveness of certain polychromatic light sources compared to monochromatic blue light (Figueiro et al., 2004, 2005, 2008)

Spectrum

Spectral Response Functions for (Equal Energy) White Light and Monochromatic Light



Figueiro et al., 2004



Rea et al., 2005

Sponsor: Office of VP for Research
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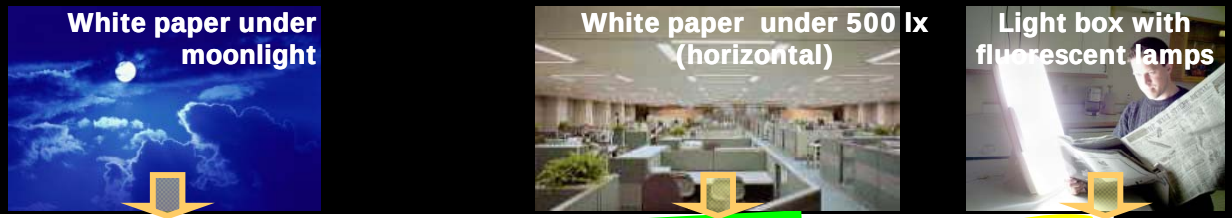
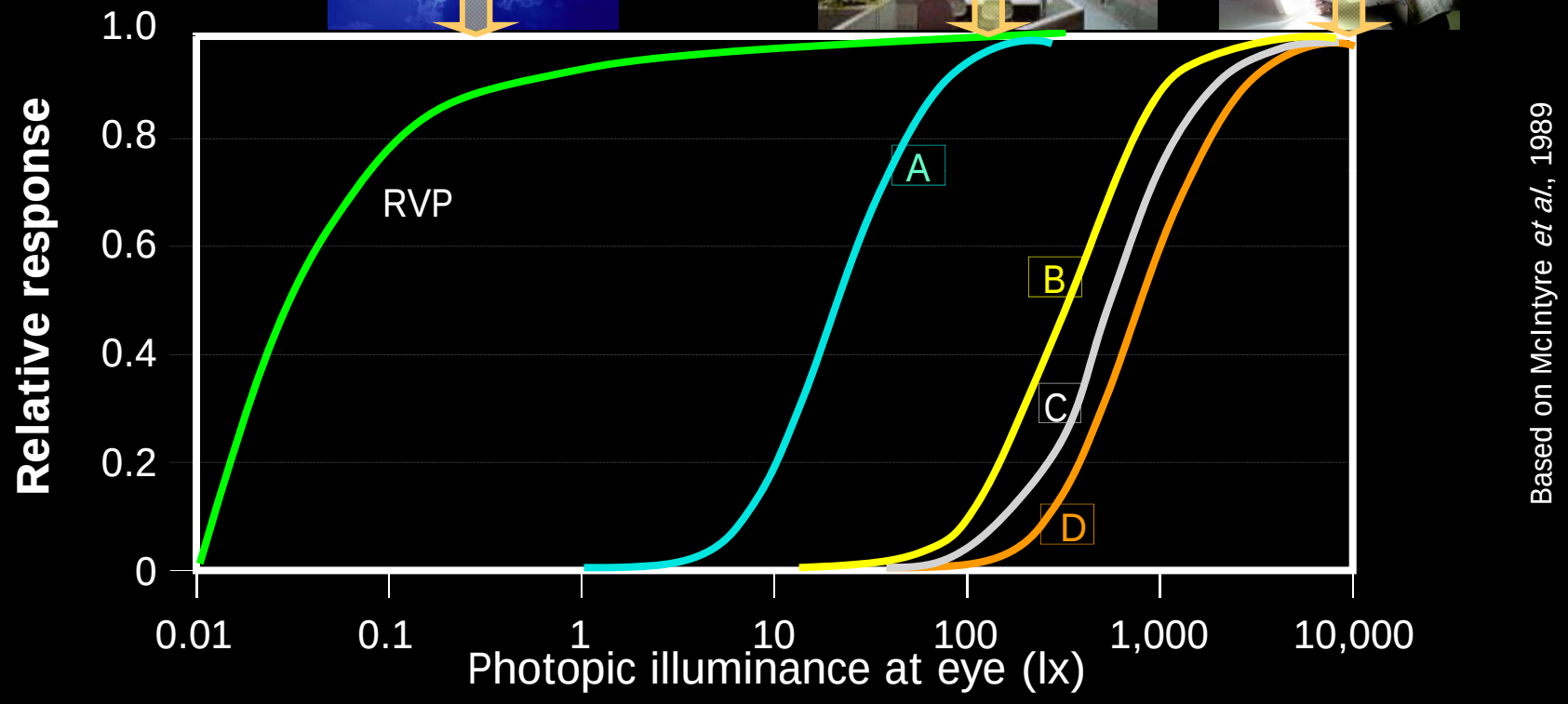
Intensity + Spectrum

Humans





Relative visual performance (RVP) and estimated melatonin suppression after 1 hour exposure to blue LED A and 7500 K B 4100 K C 3000 K D fluorescent illumination

Spectrum

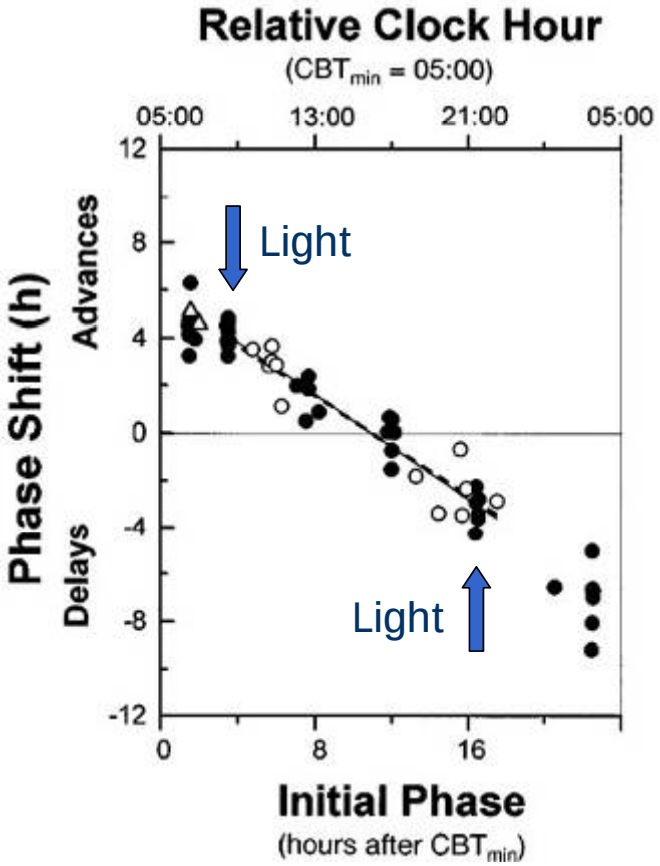
Light source	Photopic lumens/watt	Circadian stimulus/watt
Incandescent	12	12
CFL 2700K	55	38
T8 fluorescent 3000K	100	109
T8 fluorescent 4100K	100	67
T8 fluorescent 6500K	90	184
T8 fluorescent 7500K	55	90
Metal halide	95	86
White LED	35	82
Blue LED	15	295

Photopic lumens/watt (lm/W) and circadian stimulus/watt (CS/W) for some electric light sources. Values of CS/watt were arbitrarily normalized to a black body radiator of 2856 K at 1000 lux at the eye. In this way, values for both lm/W and CS/W become equal for a common incandescent light source.

Rea et al., 2005

Timing

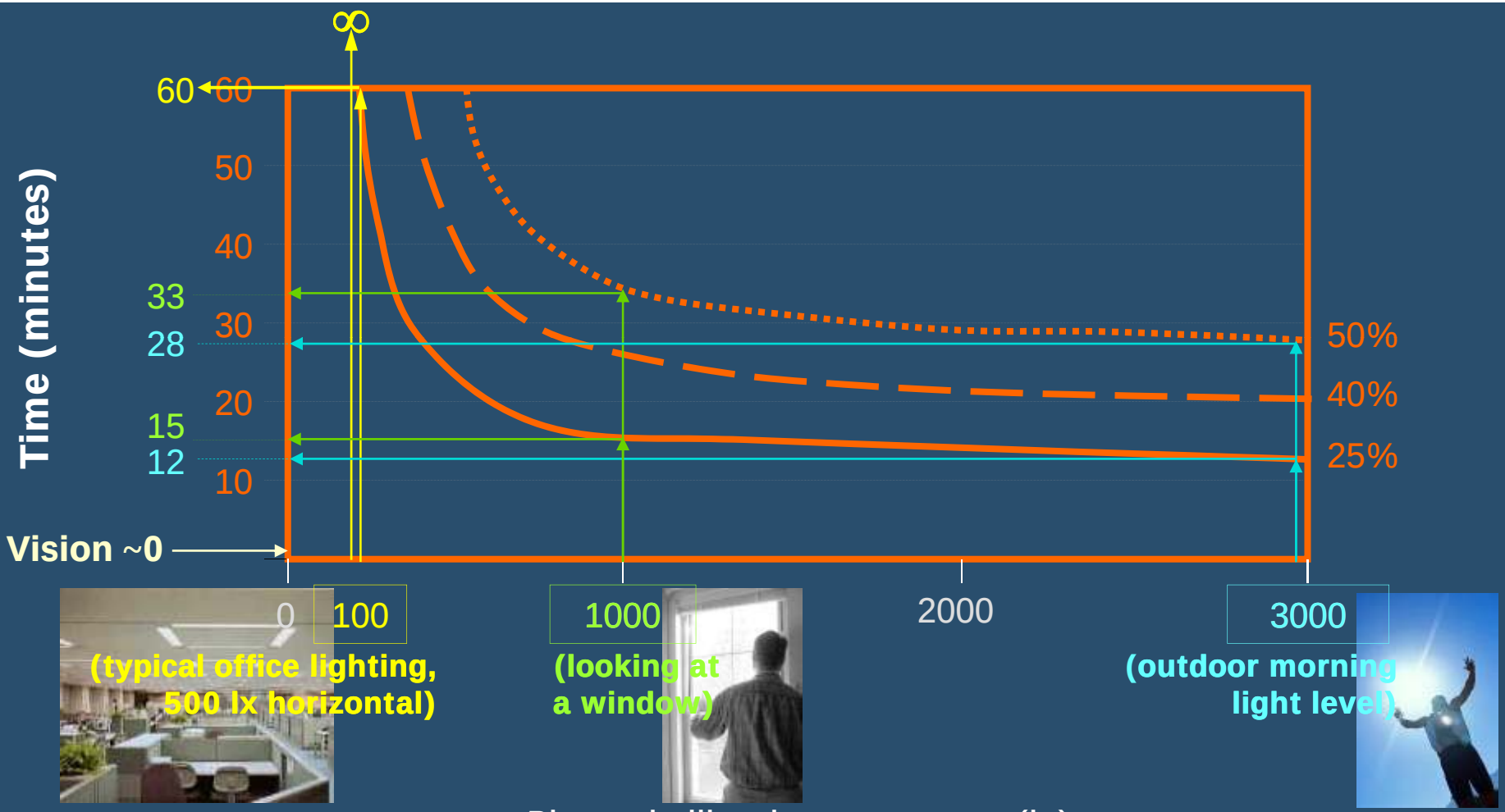
- Light of sufficient amount has a dual effect on the 24-hour melatonin profile
  - Acute effect
    - Appears immediately after the exposure to bright light
  - Phase-shifting effect
    - Detectable several hours or a few days later



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

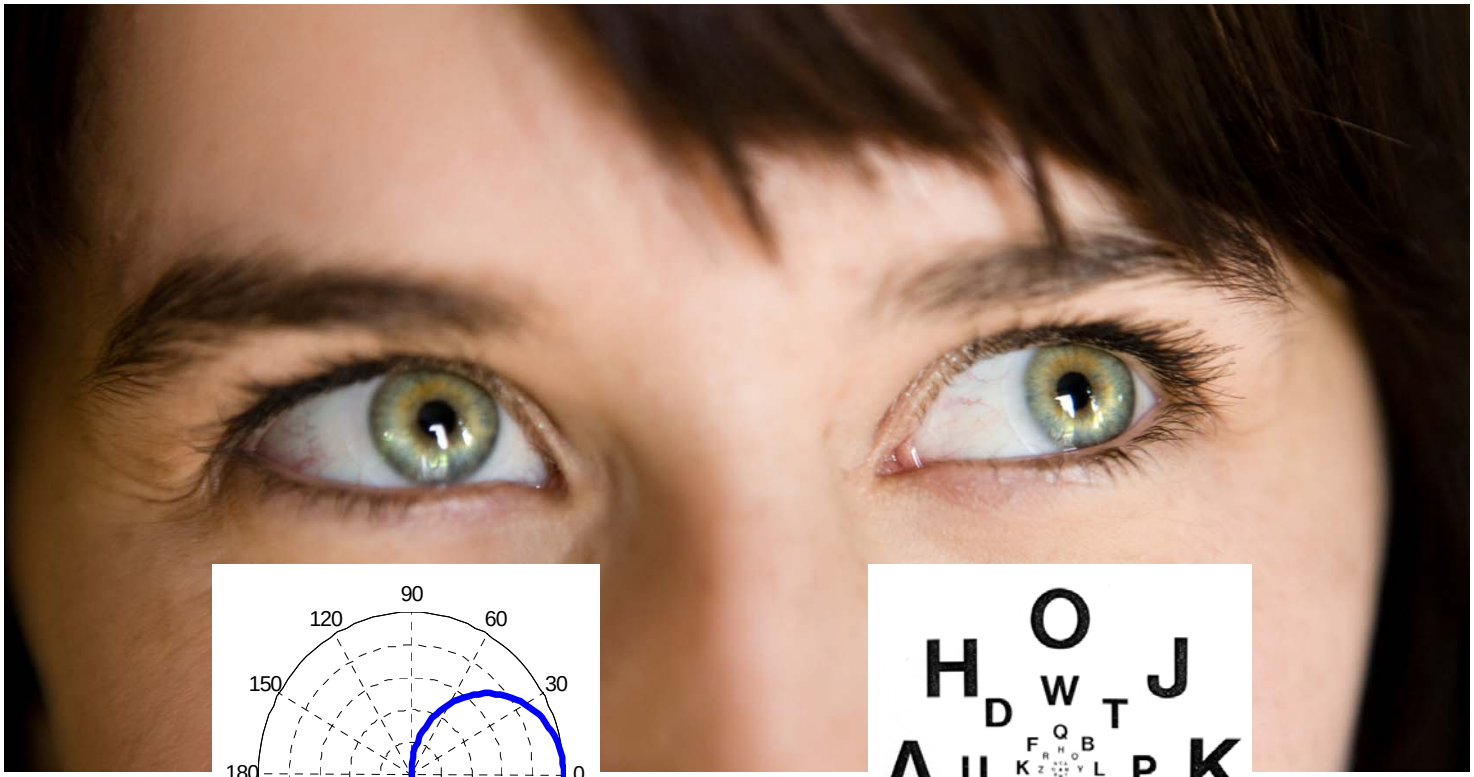
Jewett et al., 1997

Duration



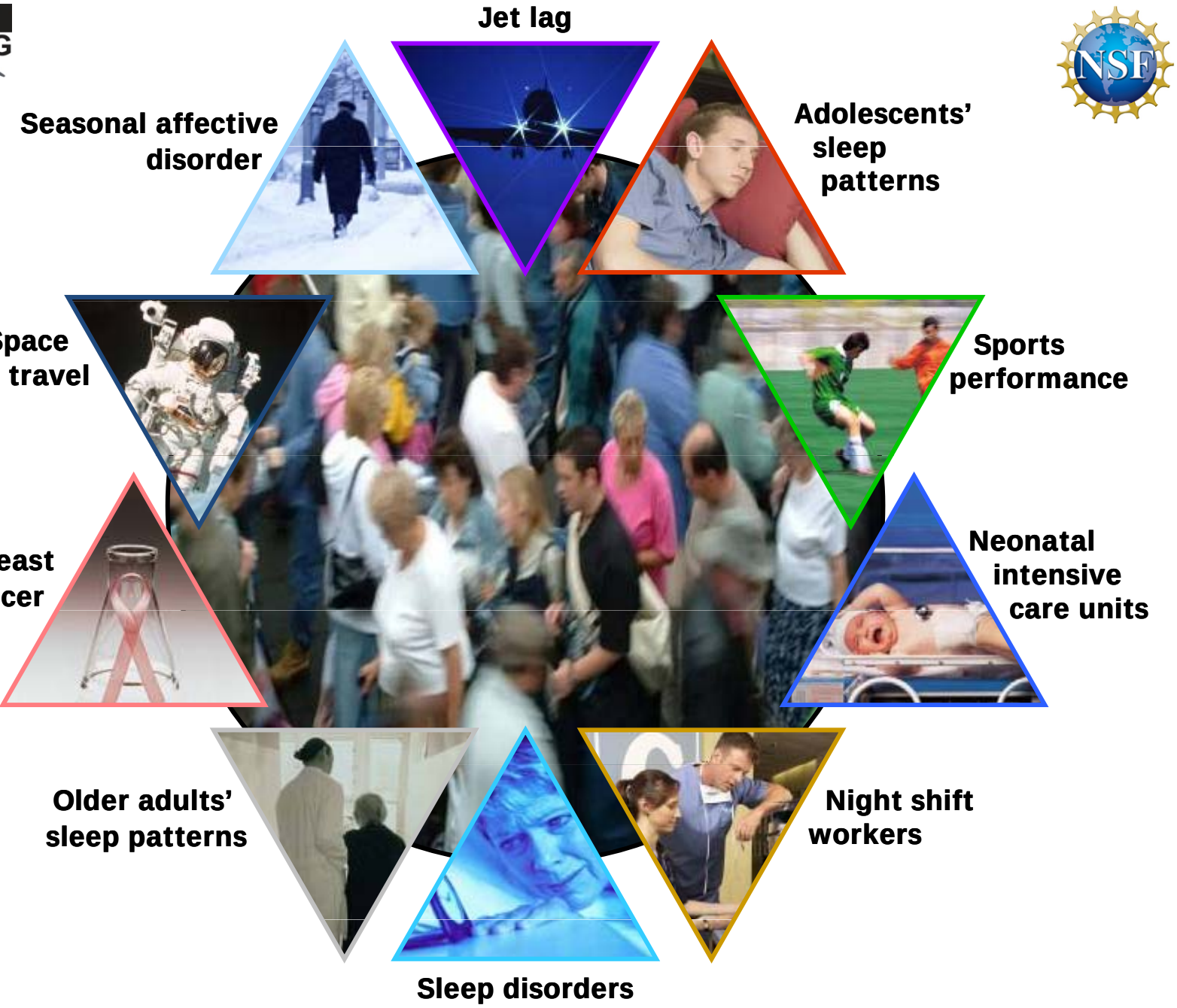
The amount of time required to measure human nocturnal melatonin suppression by light, as a function of the illuminance provided at the eye (based on McIntyre *et al*, 1989).

Spatial sensitivity



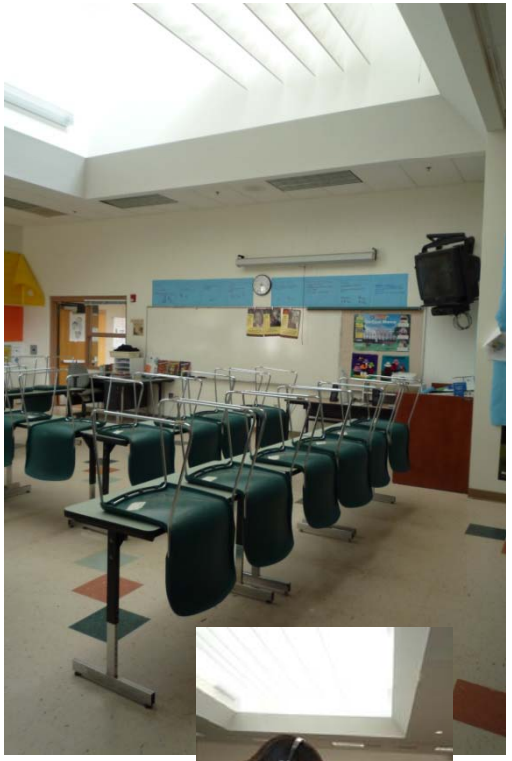
Circadian

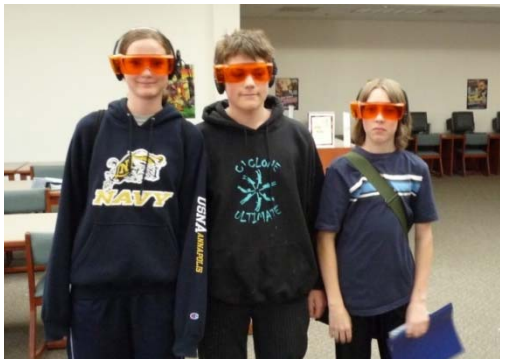
Visual


Jet lag
Seasonal affective disorder
Adolescents' sleep patterns
Space travel
Sports performance
Breast cancer
Neonatal intensive care units
Older adults' sleep patterns
Night shift workers
Sleep disorders

Daylight in schools

- USGBC Research Grant
  - Light impacts students' performance and well-being by promoting their circadian entrainment to the solar day
- Site: Smith Middle School, NC
- 22 students participated in the study conducted in February and May '09
  - 11 students wore orange glasses while at school for 1 week
    - Dim light melatonin onset
    - Daysimeter data
    - Sleep logs
    - Psychomotor vigilance tests

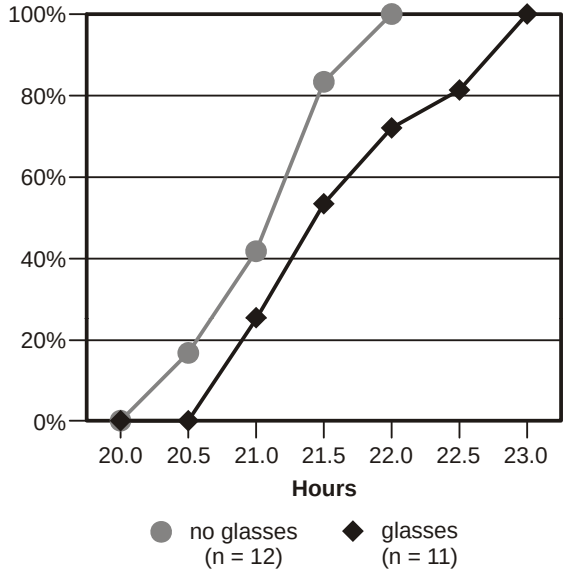


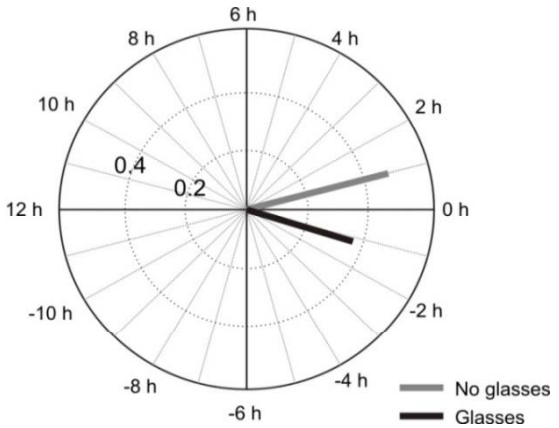


Sponsor: USGBC

Daylight in schools (February)

- Those wearing the orange glasses had:
  - Dim light melatonin onset (DLMO), delayed by 30 minutes
  - Less entrainment (shorter phasor magnitude)





Sponsor: USGBC

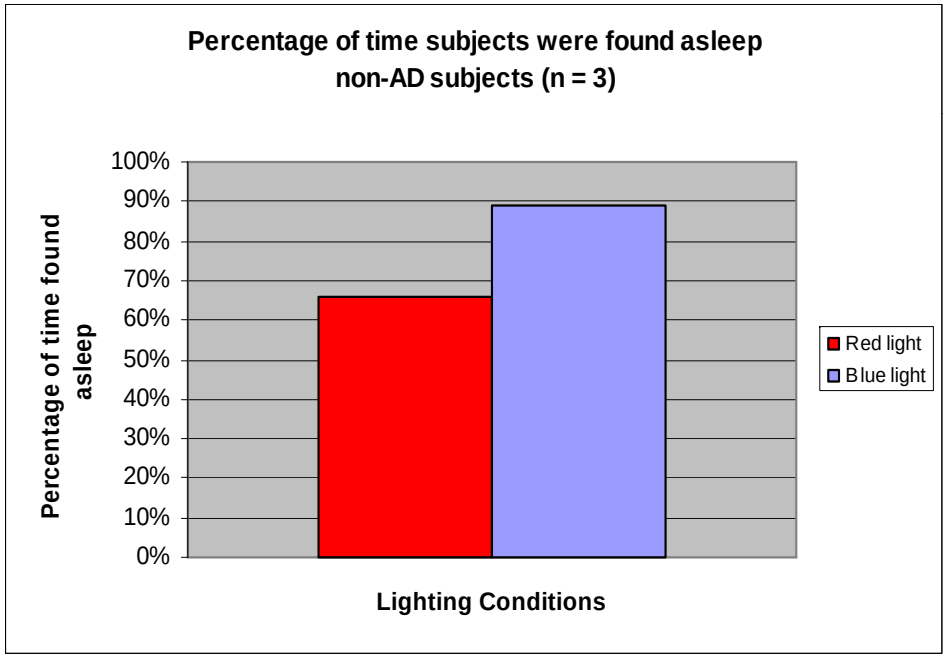
Lighting for older adults

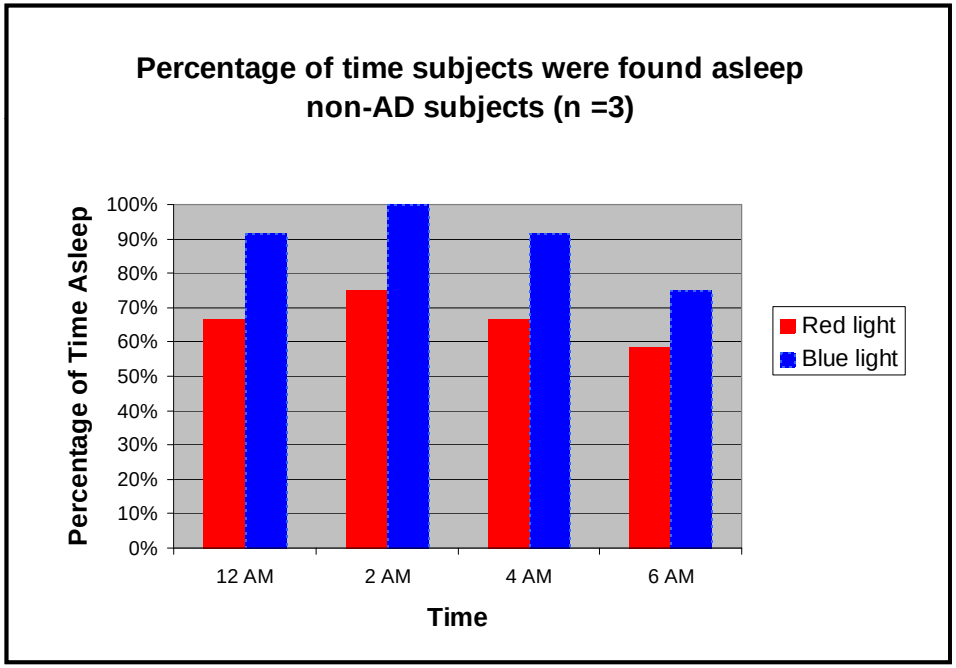
- Develop and demonstrate the effectiveness of a 24-hr lighting scheme in improving quality of life of older adults
  - › Increase sleep efficiency
    - High circadian stimulation during the day and low circadian stimulation in the evening
  - › Improve visibility
    - Good visual conditions during the day and evening
  - › Reduce falls risks
    - Nightlights that provide perceptual cues

Figueiro et al., 2008a

Increase sleep efficiency

- Blue light treatment - non-AD subjects





Product donation: Nichia America Corp

Figueiro and Rea, 2005

Blue = 89.5% asleep
Red = 67% asleep
p = 0.0003

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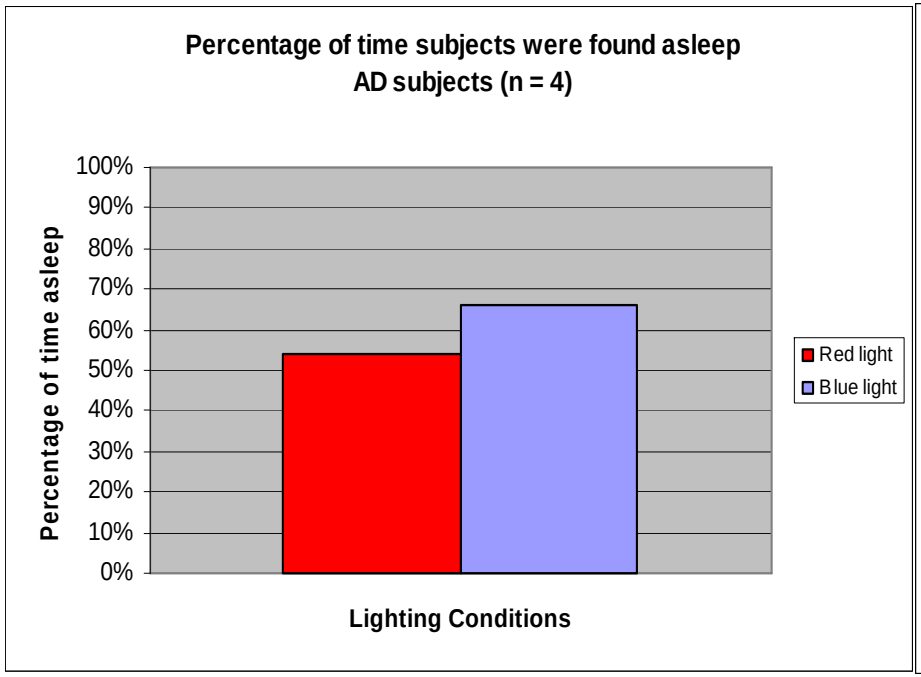
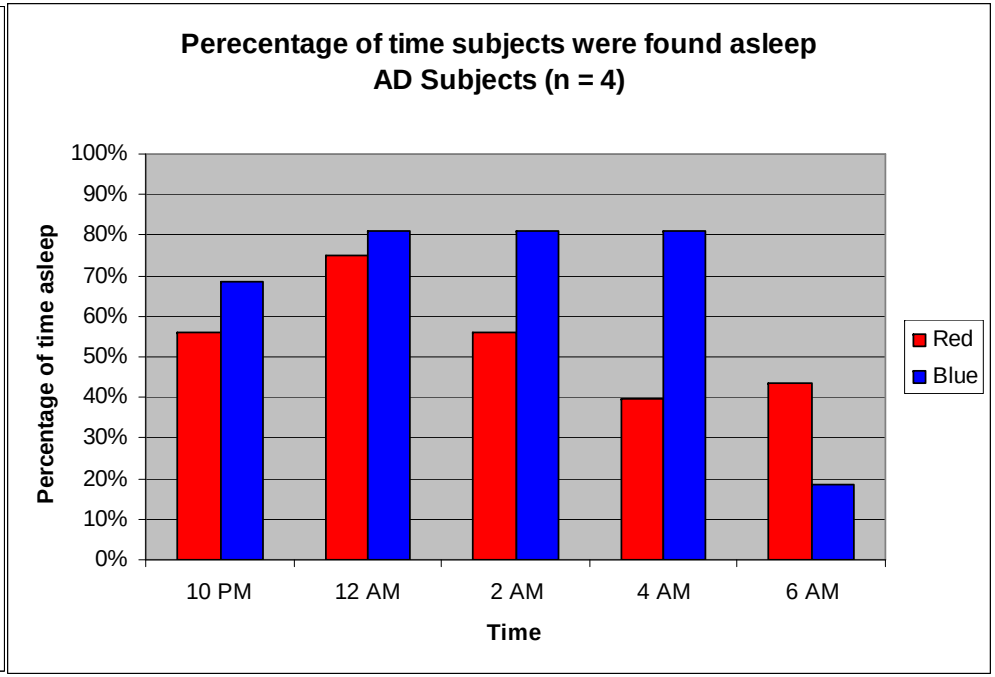
Increase sleep efficiency

- Blue light treatment – AD subjects (study 1)



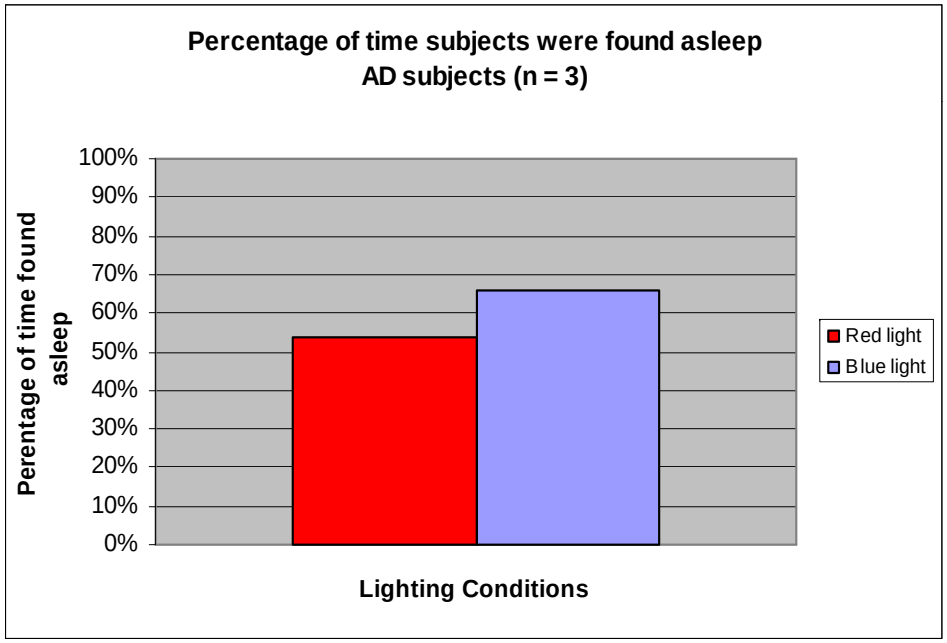


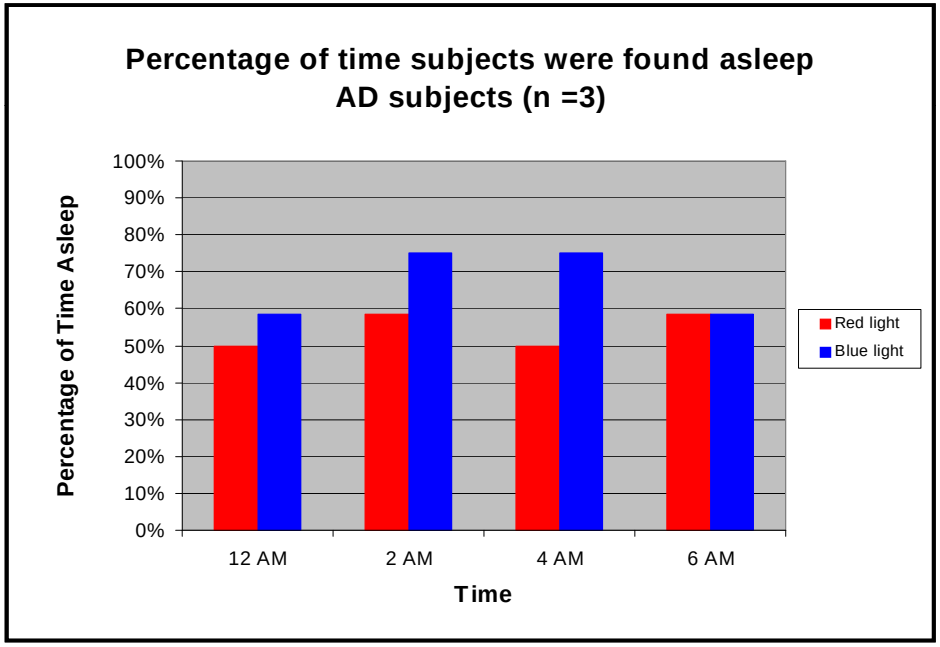
Blue = 66% asleep
Red = 54% asleep
p = 0.049

Figueiro et al., 2002

Increase sleep efficiency

- Blue light treatment – AD subjects (study 2)





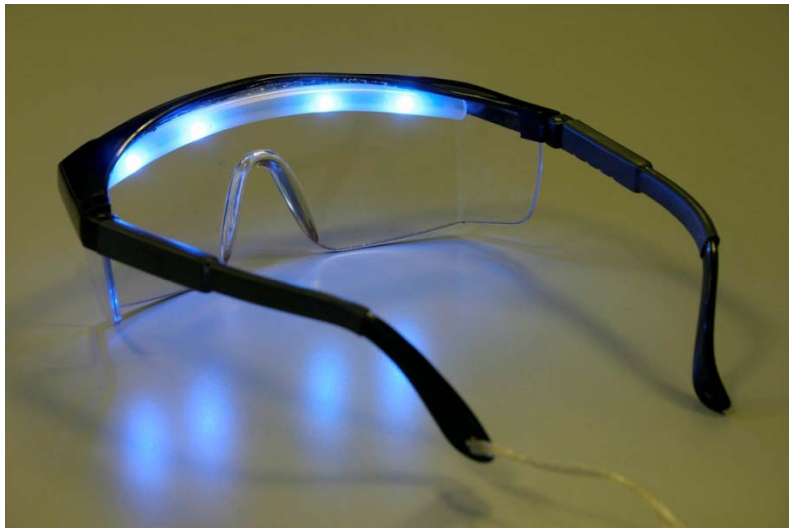
Product donation: Nichia America Corp

Figueiro and Rea, 2005

Blue = 67% asleep
Red = 54% asleep
p = 0.03

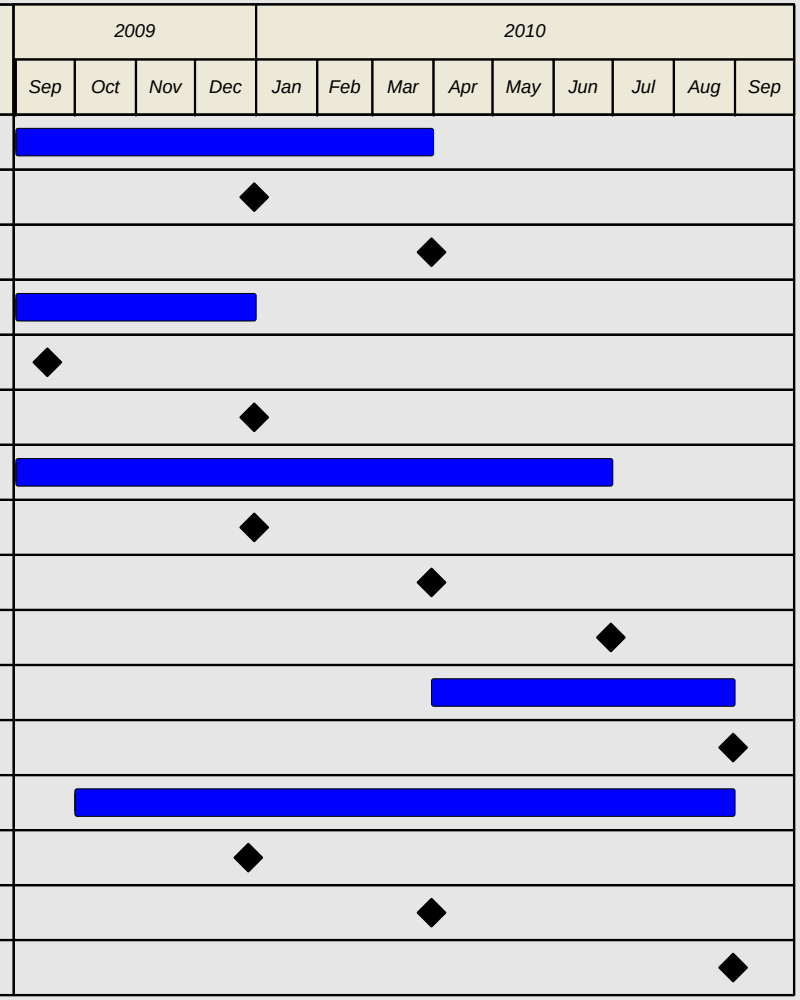
Increase sleep efficiency

- National Institutes of Health (NIA)
  - Develop light goggles to deliver blue light therapy for Alzheimer's disease patients and older adults with sleep problems



Project tasks and milestones

ID	Task Name
1	**White paper**
2	First draft
3	Final
4	**Light delivery goggles**
5	Version 1 (470 nm)
6	Version 2 (436 nm)
7	**Melatonin suppression**
8	Complete 1st study
9	Complete 2nd study
10	Manuscript submission
11	**27-hour study**
12	Complete data collection
13	**Prototype**
14	Literature review
15	Model/data comparison
16	LED + electrochromic glasses + control integration



Thank you.