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TRANSPORTATION RESEARCH BOARD

LED Roadway Lighting's Effect on Driver sleep Health and Alertness

August 31, 2021

@NASEMTRB
#TRBwebinar

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- 1.5 Professional Development Hour (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
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RCEP

REGISTERED CONTINUING EDUCATION PROGRAM

#TRBwebinar

Learning Objective

Identify the effect of difference roadway lighting sources on drivers' sleep health, alertness, and visibility

#TRBwebinar

LED Roadway Lighting's Effect on Driver Sleep Health and Alertness

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John Hanifin, Thomas Jefferson University

Ronald Gibbons, Virginia Tech Transportation Institute

George Brainard, Thomas Jefferson University

Light affects all living things

- Circadian Rhythms
  - Sleep/wake cycles
  - Hormone levels
  - Body temperature
- Acute effects
  - Nighttime melatonin suppression
  - Alertness

LITTLE TO NO RESEARCH REALISTIC ROADWAY CONDITIONS FOR DRIVERS

Laboratory

vs.

Realistic

What we don’t know

- Lack of research on LED street lighting’s effect on driver sleep physiology and alertness
  - Light with a higher blue content (LEDs)
    - Affects melatonin secretion, a component of sleep physiology
    - Contrastingly, also increases alertness (some evidence)
  - No studies in naturalistic roadway lighting exposures
- How much light does driver get from street lights vs. other light exposures?
  - Indoor Light
  - Electronic Devices

Research Questions

- What are the effects of the illuminance and spectral power distribution of LED roadway lighting on drivers?
  - alertness
  - melatonin, a component of sleep health
- LED vs. High-pressure sodium (HPS) lighting?
- LED vs. no roadway lighting?
- Roadway Lighting vs. Consumer Electronic Devices
- How can the unintended negative consequences of LED roadway lighting (if any)?

Main Conclusions from this study

- LED roadway lighting even does not significantly suppress salivary melatonin between 1:00 AM to 3:00 AM in healthy drivers.
  - At levels that are higher than specified in the IES RP-8-18
- No statistical differences in between LED and HPS roadway lighting
  - At the same light level (roadway luminance of 1.5 cd/m^2 or a corneal illuminance of 1.9 lux).
- No statistical differences between any LED and HPS roadway lighting conditions and the roadway without roadway lighting
- No increase in alertness in any lighting conditions (HPS, LED or No light)
  - Objective or Subjective measures
- Potential for melatonin suppression from consumer electronic devices is considerably higher than LED roadway lighting

Two experiments

Corneal Illuminance Dosage Experiment

- Typical levels of corneal illuminance
  - Roadway lighting
  - Electronic devices
  - Daily exposures

Driver Sleep Physiology and Alertness Experiment

- Subjective measures
- Objective measures <u>In naturalistic environments</u>

CORNEAL ILLUMINANCE DOSAGE EXPERIMENT

HOW MUCH LIGHT DO WE RECEIVE FROM DIFFERENT SOURCES?

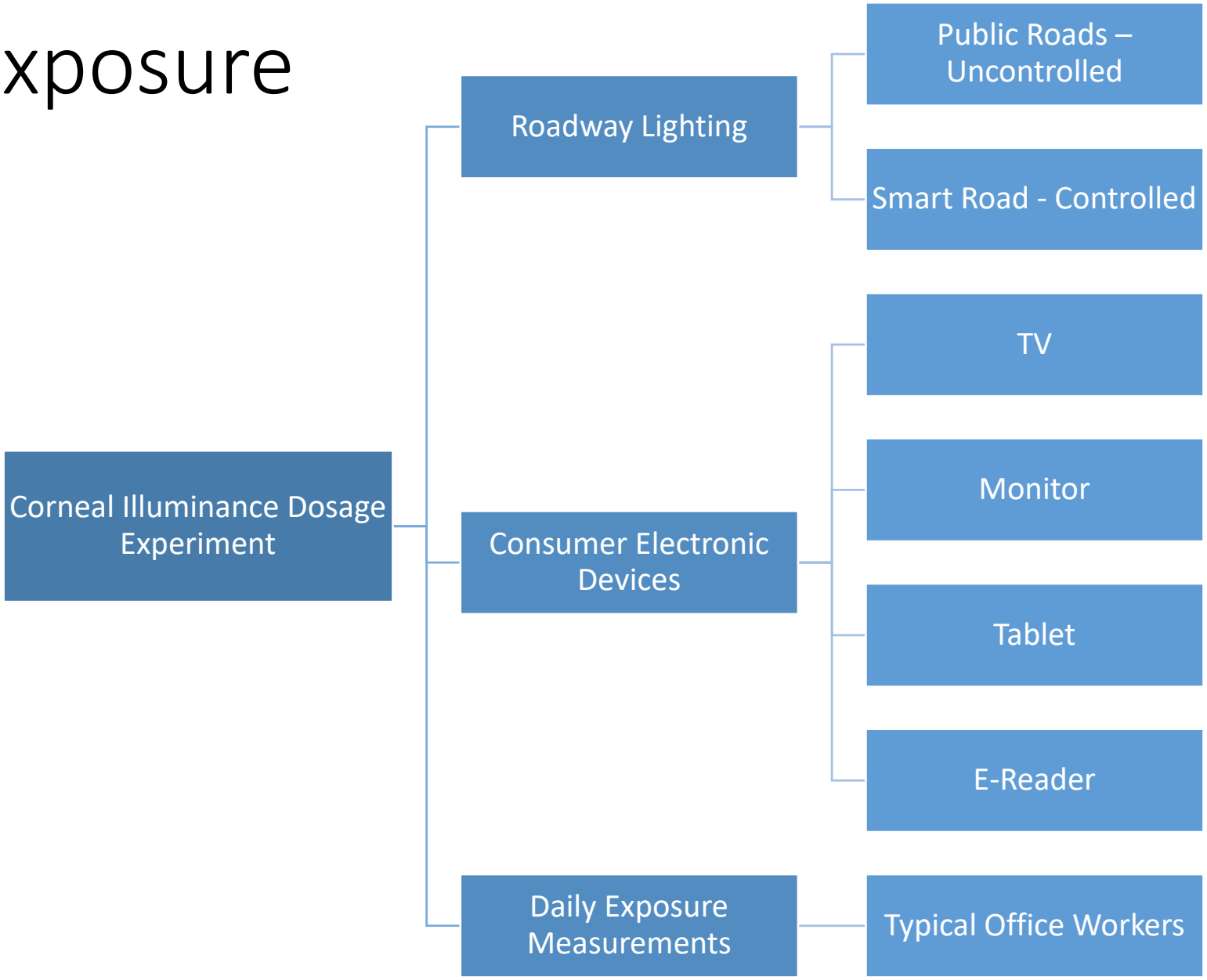
Daily Exposure Measurements

- Office workers for 24 hours
- Get a wide range of personal light exposures
- 10 employees

Consumer Electronic Devices

- Levels of corneal illuminance experienced by users
- Phone, Tablet, and/or Television
- 2 hours exposure
- 2 screen conditions
  - White screen with highest possible brightness – Biologically most potent
  - White screen with lowest possible brightness with night mode activated – Biologically least potent
- Light levels measured with
  - Illuminance Meter
  - Personal Light Dosimeter

Two Hour Exposure

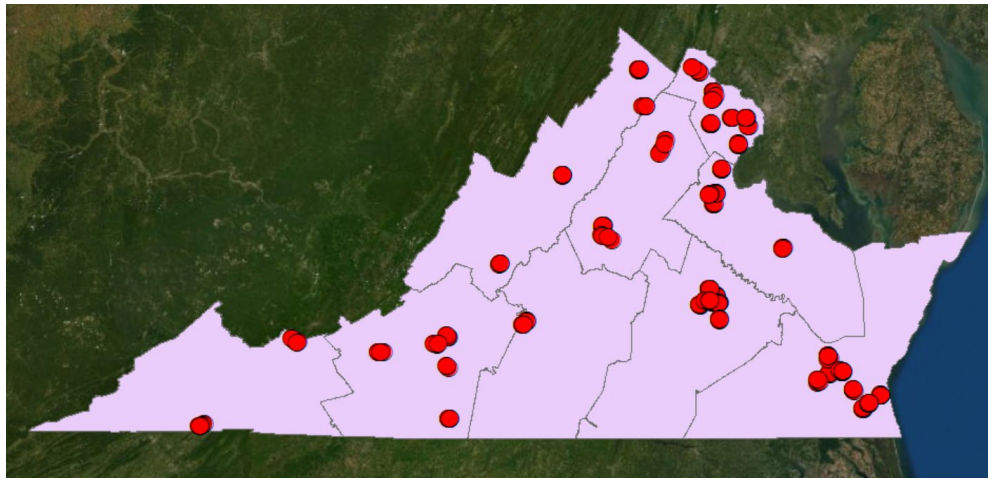


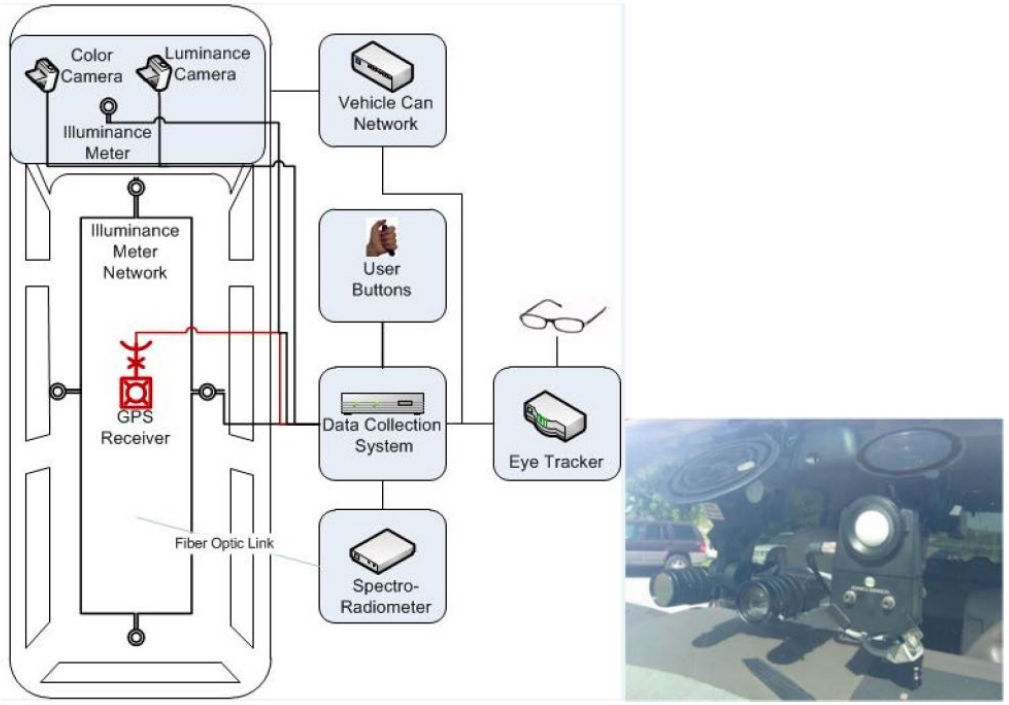
Personal Light Dosimeter

- Miniature wearable irradiance dosimeter
- Developed at VTTI
- Measures the irradiance received over a period of time

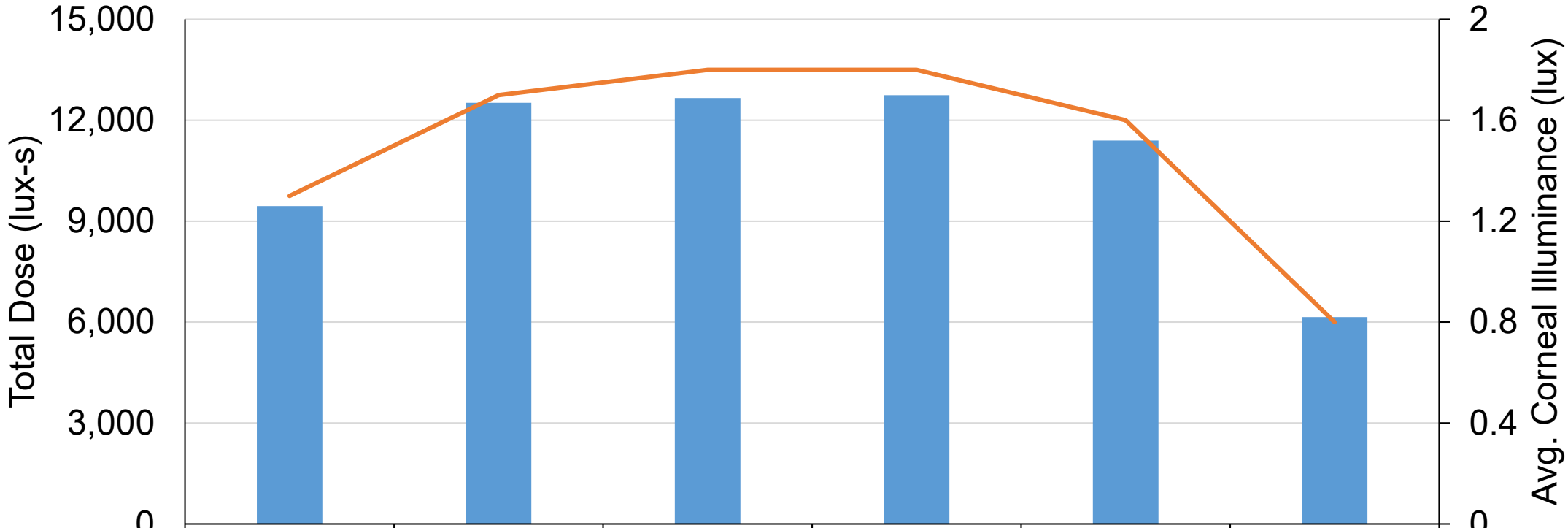
Smart and Public Road Illuminance Measurement

- Using a mobile roadway lighting mobile measurement system
- Lighted Public Roads in Virginia
  - Interstate
  - Collector
  - Arterial
  - Local





Results – Smart Road Illuminance Measurements – 2 hour exposure



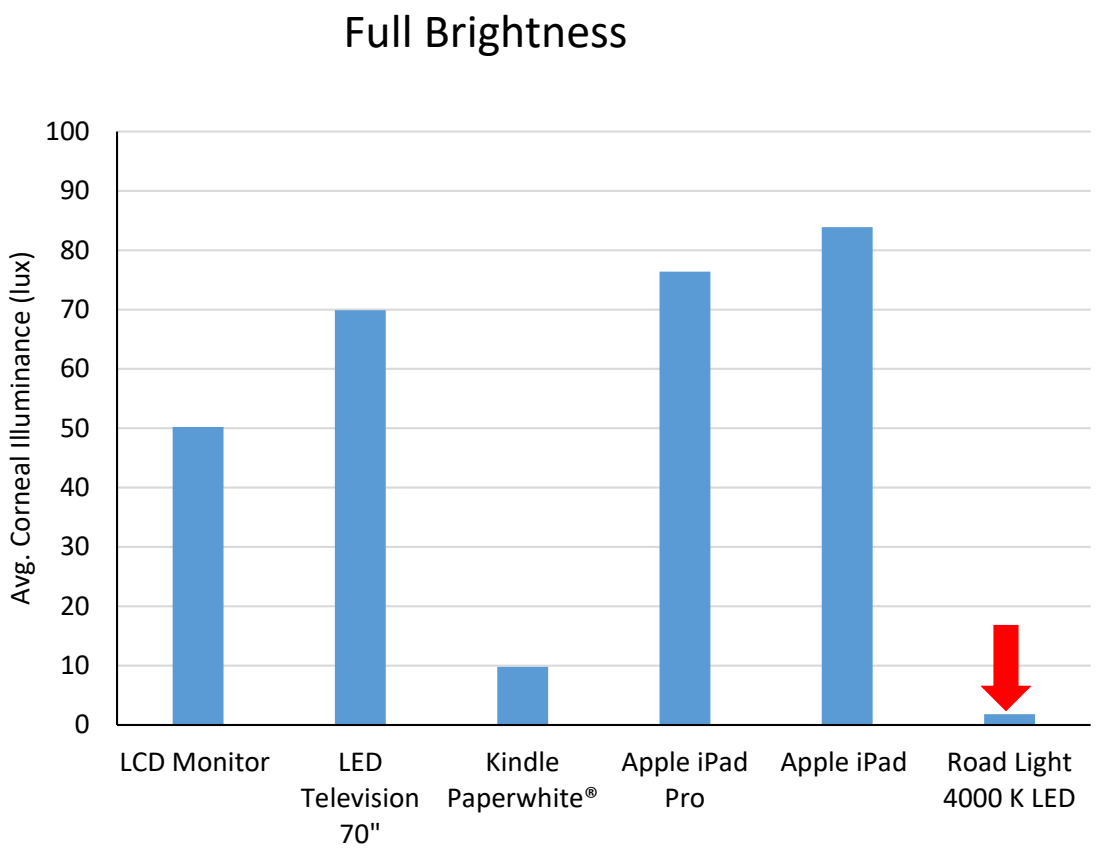
Light Type	2200 K LED	3000 K LED	4000 K LED	5000 K LED	2100 K HPS	No Light
Road Luminance (cd/m^2)	0.8	1	1	1	1	<0.05

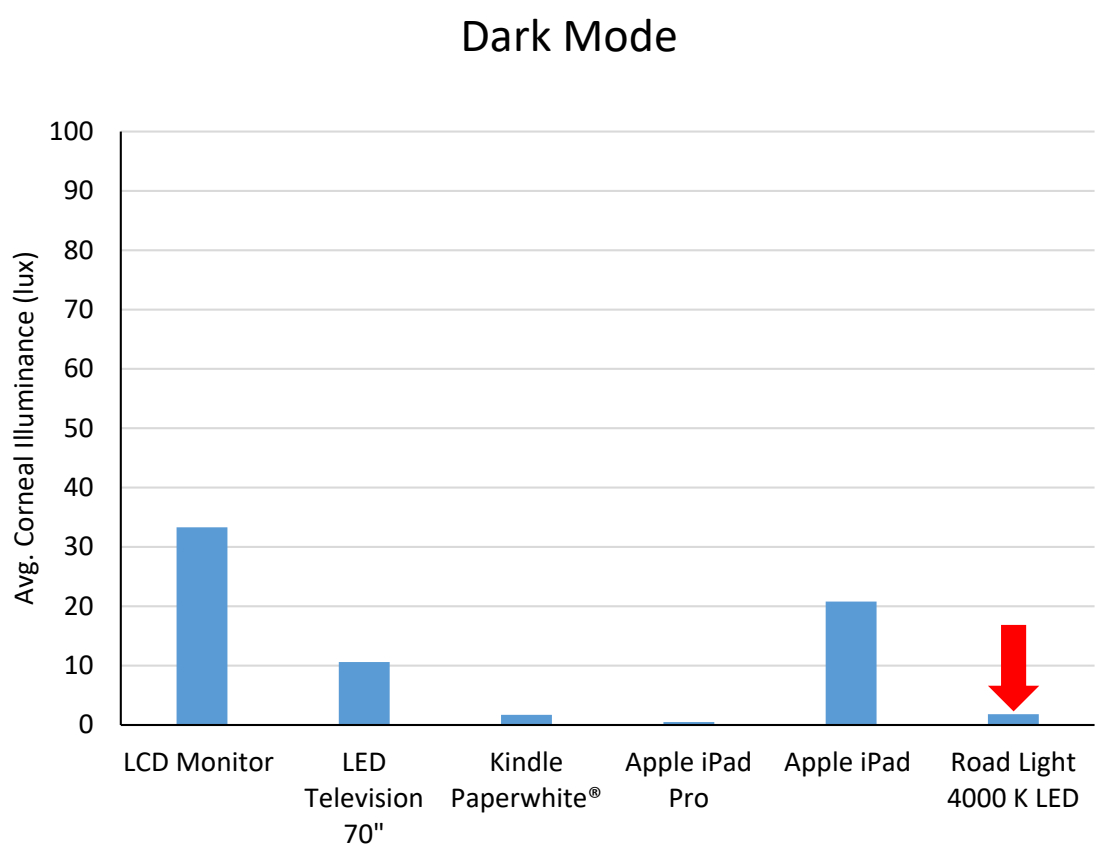
Results – Public Road Illuminance Measurement

- Measurement on real roads
- Not controlled for vehicles headlamps in the opposing direction
- Vertical Illuminance not same as corneal Illuminance

Functional Classification	Avg. Luminance (cd/m^2)	Avg. Vertical Illuminance (lux)
Interstate	0.8	4.3
Major Collector/Local	1.4	2.8
Minor Arterial	1.1	3.2
Principal Arterial	1.1	3.3

Comparison of Consumer Electronic Devices to LED Lighting on Smart Road





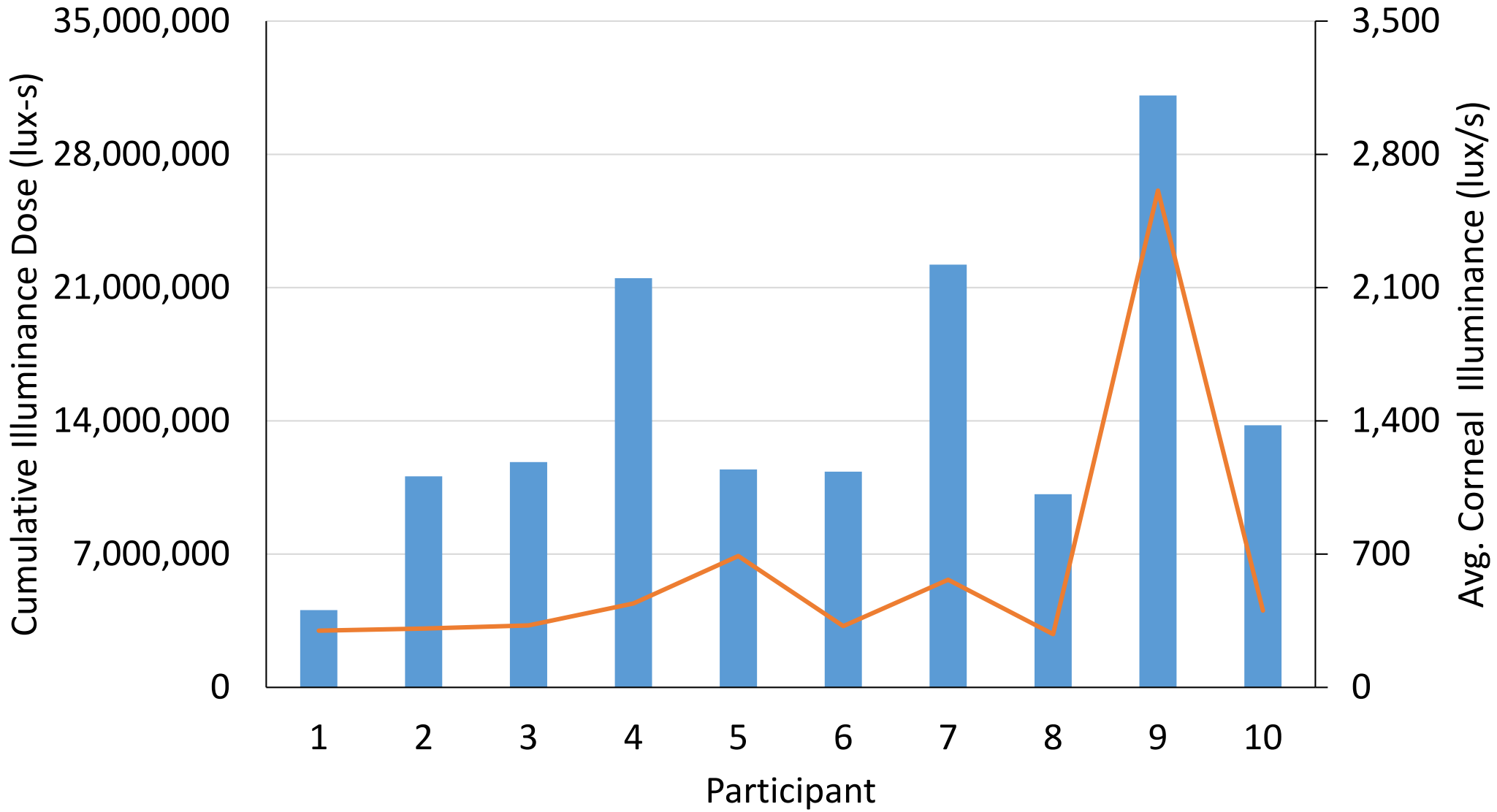
Potential for melatonin suppression from consumer electronic devices is greater than street lighting at IES recommended levels

- 4000 K LED at 1.5 cd/m^2 (higher than IES RP-8) → 1.9 lux
- E-Readers – 31.73 lux – Suppressed melatonin and reduced alertness next morning

  Chang, A.-M., Aeschbach, D., Duffy, J. F., & Czeisler, C. A. (2015). Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. *Proceedings of the National Academy of Sciences, 112*(4)
- LED Computer Monitor – 100 lux – Suppressed melatonin and increased alertness

  Cajochen, C., Frey, S., Anders, D., Späti, J., Bues, M., Pross, A., . . . Stefani, O. (2011). Evening exposure to a light-emitting diodes (LED)-backlit computer screen affects circadian physiology and cognitive performance. *Journal of Applied Physiology, 110*(5), 1432-1438.

HOW MUCH LIGHT DOES AN OFFICE WORKER EXPERIENCE IN 24 HOURS?



DRIVER SLEEP PHYSIOLOGY AND ALERTNESS EXPERIMENT

VARIABLES EVALUATED

Independent Variable	Levels
Light Condition	2100 K HPS – High (1.5 cd/m^2) 4000 K LED – High (1.5 cd/m^2) 4000 K LED – Medium (1.0 cd/m^2) 4000 K LED – Low (0.7 cd/m^2) No Roadway Lighting – (less than 0.05 cd/m^2)
Exposure Time	1 AM to 3 AM.

LIGHT LEVELS IN THE NATURALISTIC DRIVING EXPERIMENT

	Time of Exposure	Road Luminance	Corneal Illuminance	Light Condition
Conditioning	11 PM to 1 AM		200 lux	4000 K LED
Road Exposure	1 AM to 3 AM	1.5 cd/m^2	1.8 lux	2100 K HPS - High
		1.5 cd/m^2	1.9 lux	4000 K LED - High
		1.0 cd/m^2	1.4 lux	4000 K LED - Medium
		0.7 cd/m^2	1.1 lux	4000 K LED - Low
		<0.05 cd/m^2	0.8 lux	No roadway lighting

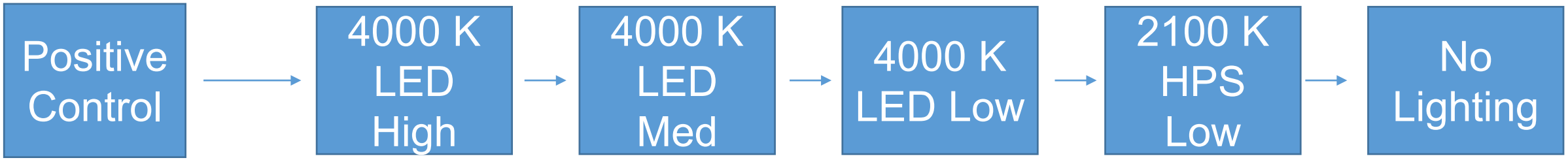
RADIOMETRIC AND PHOTOMETRIC MEASURES WITH CALCULATED A-OPIC LUX VALUES

2018 CIE DS 026 STANDARD, CIE USER GUIDE MARCH 2020

		α-opic equivalent daylight (D65) illuminance, lux				
Light Condition	Photopic Illuminance (lux)	S-cone-opic	M-cone-opic	L-cone-opic	Rhodopic	Melanopic
Conditioning	200 lux	66.4	173.0	194.5	112.4	87.1
2100 K HPS - HIGH	1.8 lux	0.3	1.2	1.9	0.5	0.3
4000 K LED - HIGH	1.9 lux	0.6	1.6	1.8	1.1	0.8
4000 K LED - MED	1.4 lux	0.5	1.2	1.4	0.8	0.6
4000 K LED - LOW	1.1 lux	0.4	1.0	1.1	0.6	0.5

EXPERIMENTAL APPROACH

- At least one week between each exposures
- Presentation of light sources and levels were counterbalanced



POSITIVE CONTROL

- Predicted to strongly suppress melatonin secretion
- 2 hours of conditioning
  - 11 pm to 1 am
- 2 hours of exposure
  - 1 am to 3 am
- Maintain an upright posture with feet on the floor while remaining wakeful.
- No devices that emit light were permitted

INSTRUMENTED VEHICLES

DATA ACQUISITION SYSTEMS

- Differential GPS (for detection distance)
- Road Scout (for SDLP)
- Video of Driver (for PERCLOS)
- Headrest mounted illuminance meter
- Vehicle sensors
  - Brakes
  - Steering position
  - Acceleration
  - Speed etc.

PARTICIPANTS
REQUIREMENTS

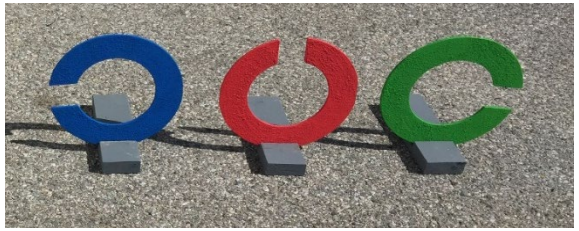
- Steady and regular sleep cycles
  - No alcohol or caffeine after midday
  - No napping after 6pm
  - Non smoking
- Valid US driver's license
- At least 20/40 (6/12) visual acuity
- Normal color vision

- 10 participants (18 to 30 years)
  - Sleep-wake cycles were surveyed for a week prior to participation
  - Sleep logs and actigraphy
- Worn throughout the experiment by the participant
- Participants were picked up and dropped off for each session
- 2 participants per session

DEPENDENT MEASURES

ALERTNESS

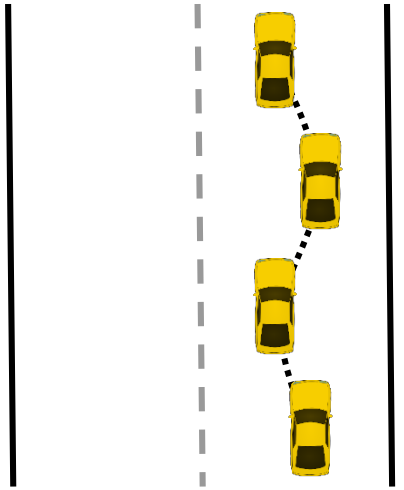
- Reaction Time at 35 mph
  - **Detection Distance:** distance at which drivers can detect an object
  - **Color Recognition Distance:** distance at which drivers can detect the color of the object
  - Both measures decrease with decrease in alertness



- PERCLOS
  - Percentage of time a driver's eyelids are closed over a 3 minute segment
  - Reliable indicator of drowsiness
  - Increase in PERCLOS is associated with increase in drowsiness

DEPENDENT MEASURES

ALERTNESS



- Standard deviation of lane position (SDLP)
  - Measure of vehicle control
  - Objective measure of driver drowsiness
  - More Drowsy → Control over the vehicle's lateral position decreases and SDLP increases
- Karolinska Sleepiness Scale
  - Self report measure of drowsiness
  - Administered every 30 minutes

Rating	Description
9	Extremely sleepy, fighting sleep
8	Sleepy, some effort to keep alert
7	Sleepy, but no difficulty remaining awake
6	Some signs of sleepiness
5	Neither alert nor sleepy
4	Rather alert
3	Alert
2	Very alert
1	Extremely alert

DEPENDENT MEASURES

MELATONIN SUPPRESSION

- Melatonin secretion is a component of circadian regulation
- Evening and nocturnal melatonin promotes sleep
- Evening light exposure can delay the normal onset of pineal melatonin secretion
- Nighttime light exposure can suppress high levels melatonin secretion
- Melatonin suppression and circadian phase delay can make it more difficult to fall asleep

EFFECTS OF ROADWAY LIGHTING

ECOLOGY

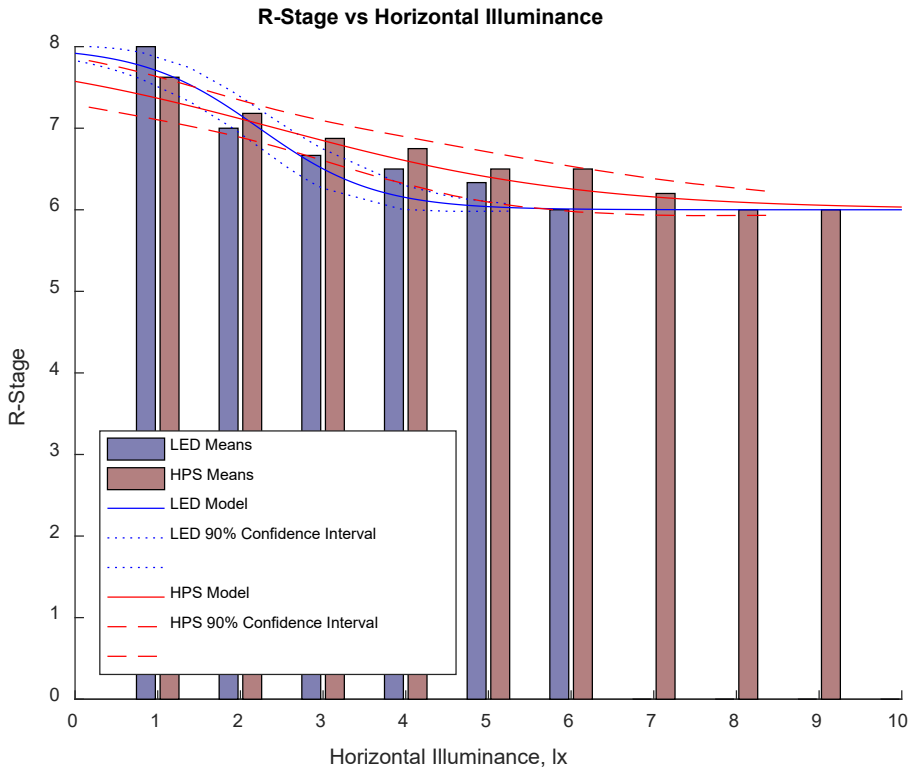
TRAFFIC SAFETY

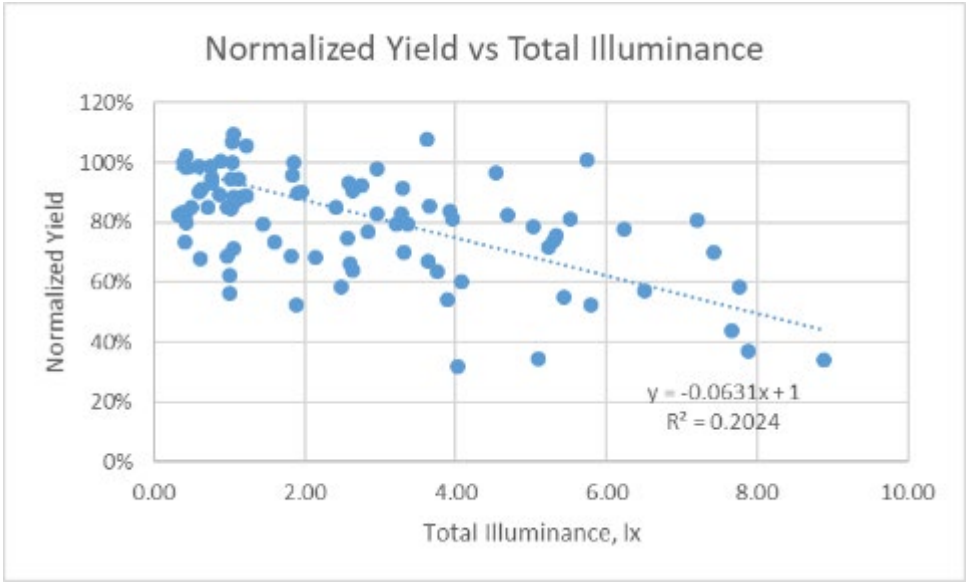
Ideal Light for Roadways

- So what is “Ideal Light”?
- We judge this by a variety of Dimensions
  - Roadway User Safety
    - Crash Reduction
      - Detection
      - Glare
  - Energy Consumption
  - Impact on User Health
  - Public Perception and Acceptance
  - Impact on Light Pollution
    - Trespass
    - Skyglow
  - Impact on the Environment
    - Flora
    - Fauna

Impact on Soybean Growth

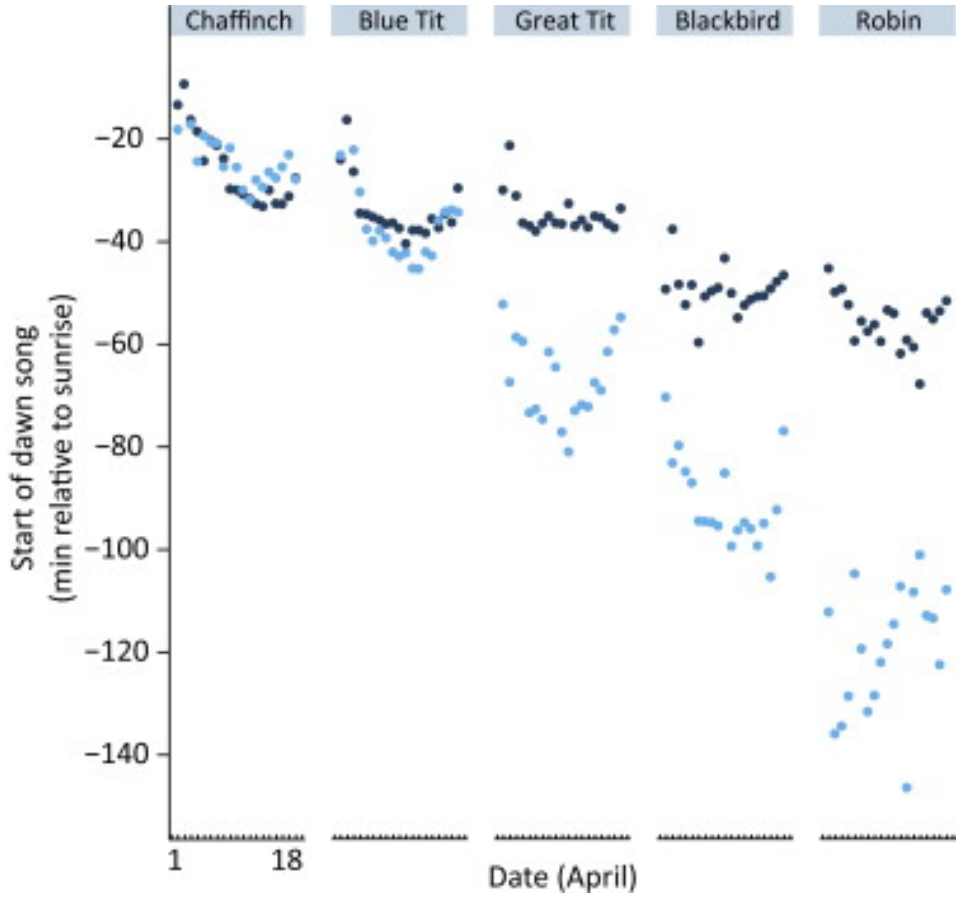
Yield and Moisture





Maximum Values	
Illuminance	Maximum, lx
Horizontal	2.2
Vertical	1.8

Birds, Bass, Bears and Bees



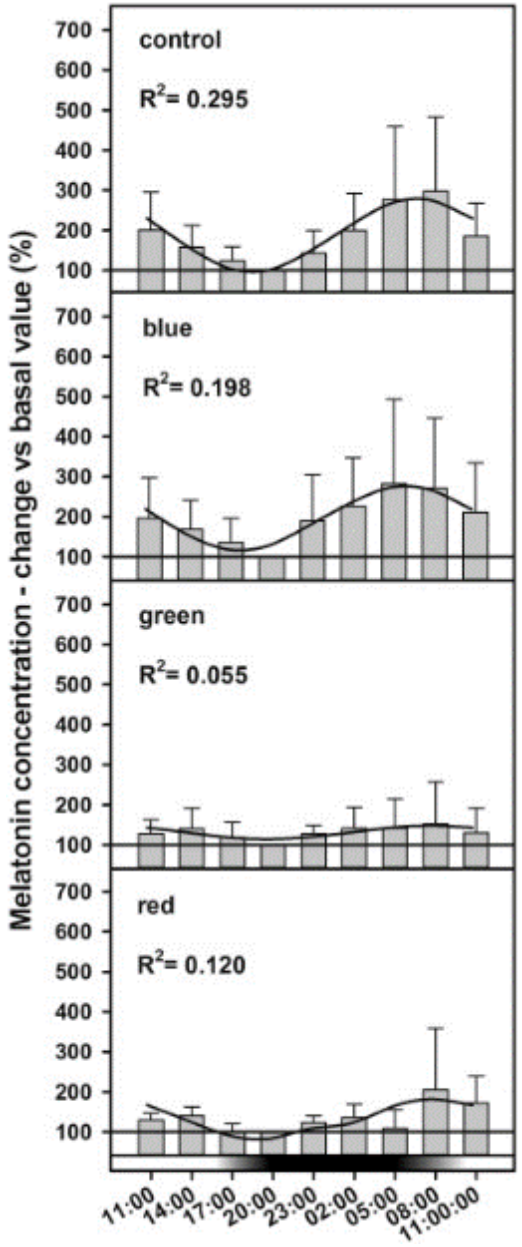
Lighting influences anything with eyes that are sensitive to visible light

- Eg. Robin Song will start as much as 2 hours early in areas adjacent to Roadways (Kempenaers et al, 2010)

Light Impact on Perch

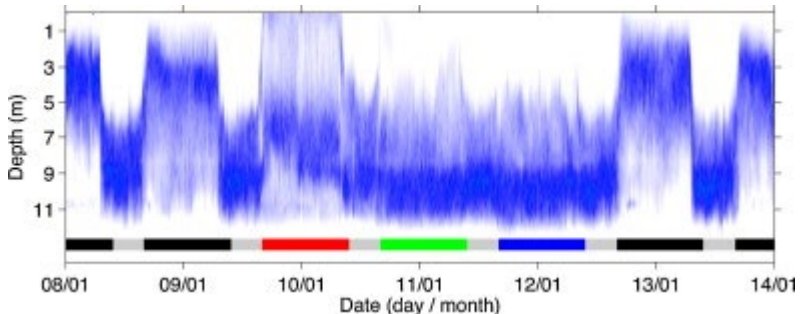
(Bruning et al)

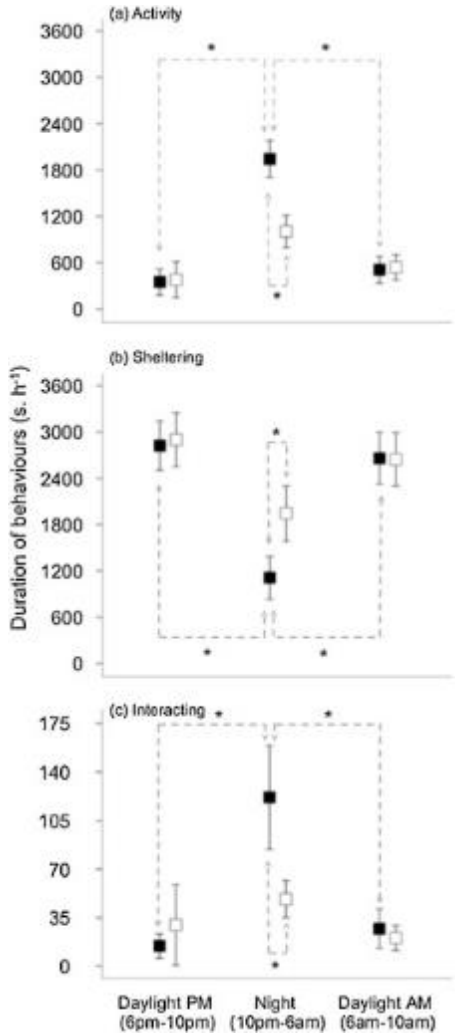
- Melatonin is suppressed by red light
  - Opposite impact of humans

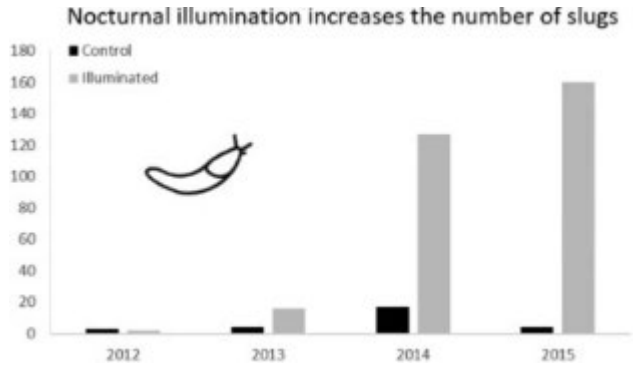


We are changing the Ecology

- Crayfish hide and do not interact as significantly under roadway lighting
- Bats now hunt under light fixtures
- Slugs are on the rise
- Salmon change their swimming depth



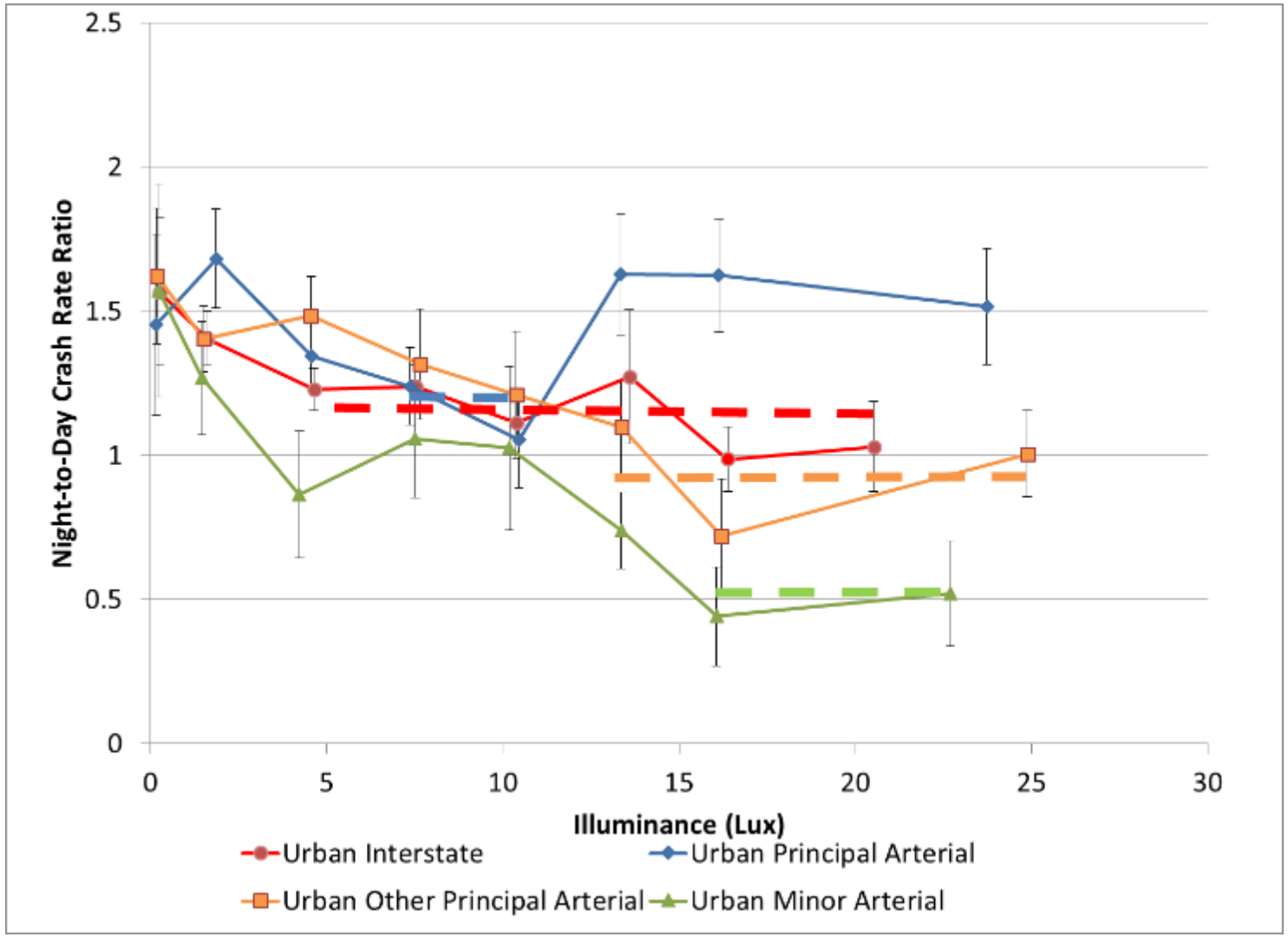




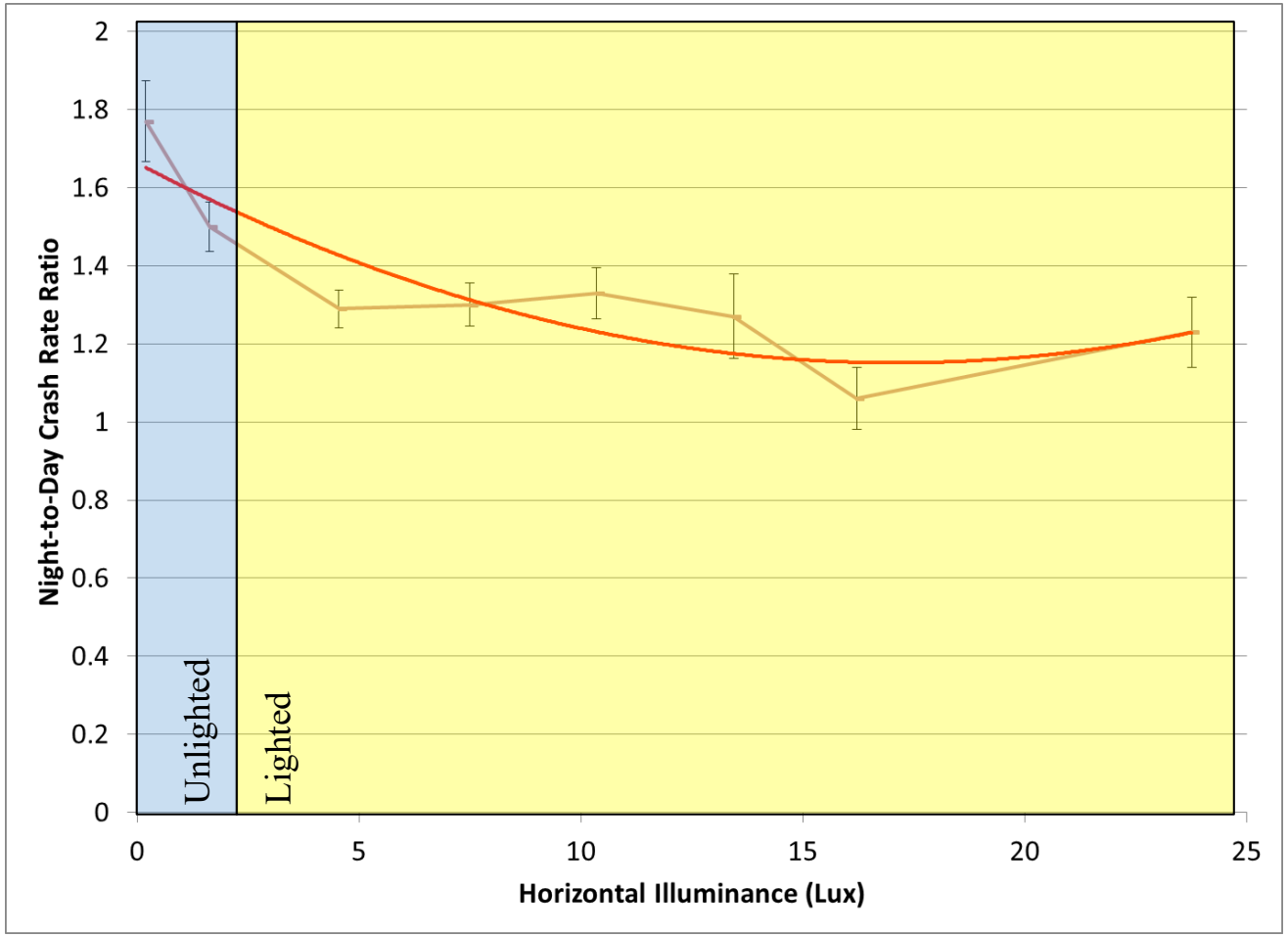
FHWA Strategic Initiative for Reduced Lighting on Roadways

- We linked the lighting level to crash rate for a variety of roadway designs and conditions
  - Developed a statistically accurate link between lighting design and crash safety

Results by Road Type

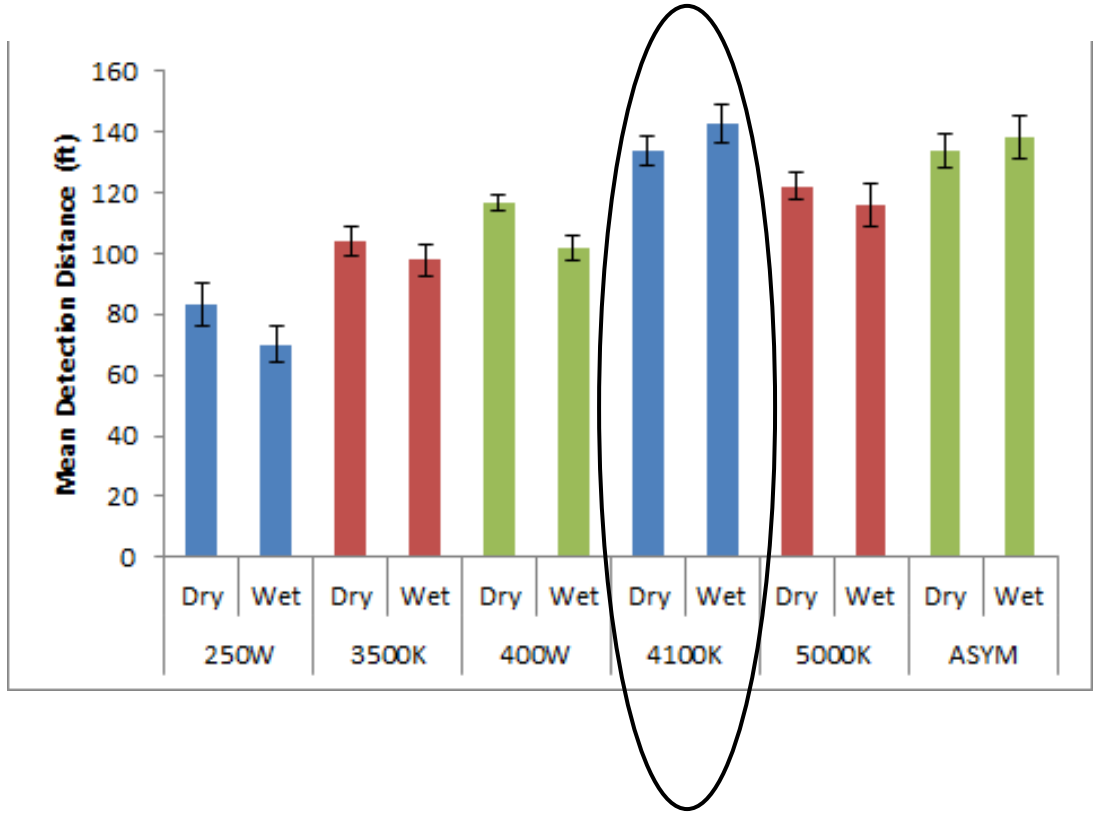


Roadway Light Also Affects Traffic Safety – Decrease in Crashes On Interstates



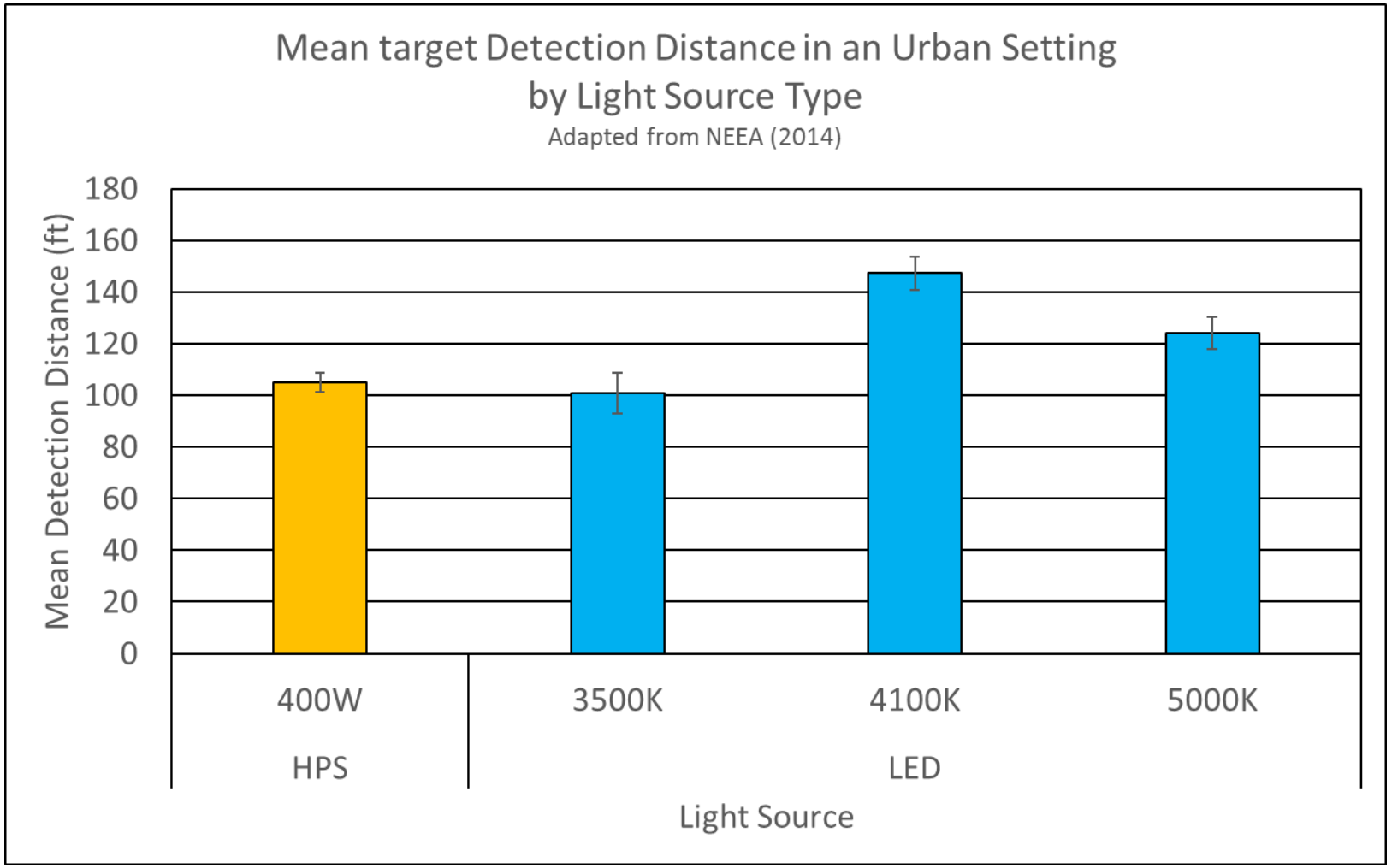
Gibbons, Ronald B., et al. *Guidelines for the Implementation of Reduced Lighting on Roadways*. No. FHWA-HRT-14-050. United States. Federal Highway Administration, 2014.

Target Detection and Color Temperature



Note: CCT is horrible Metric for this

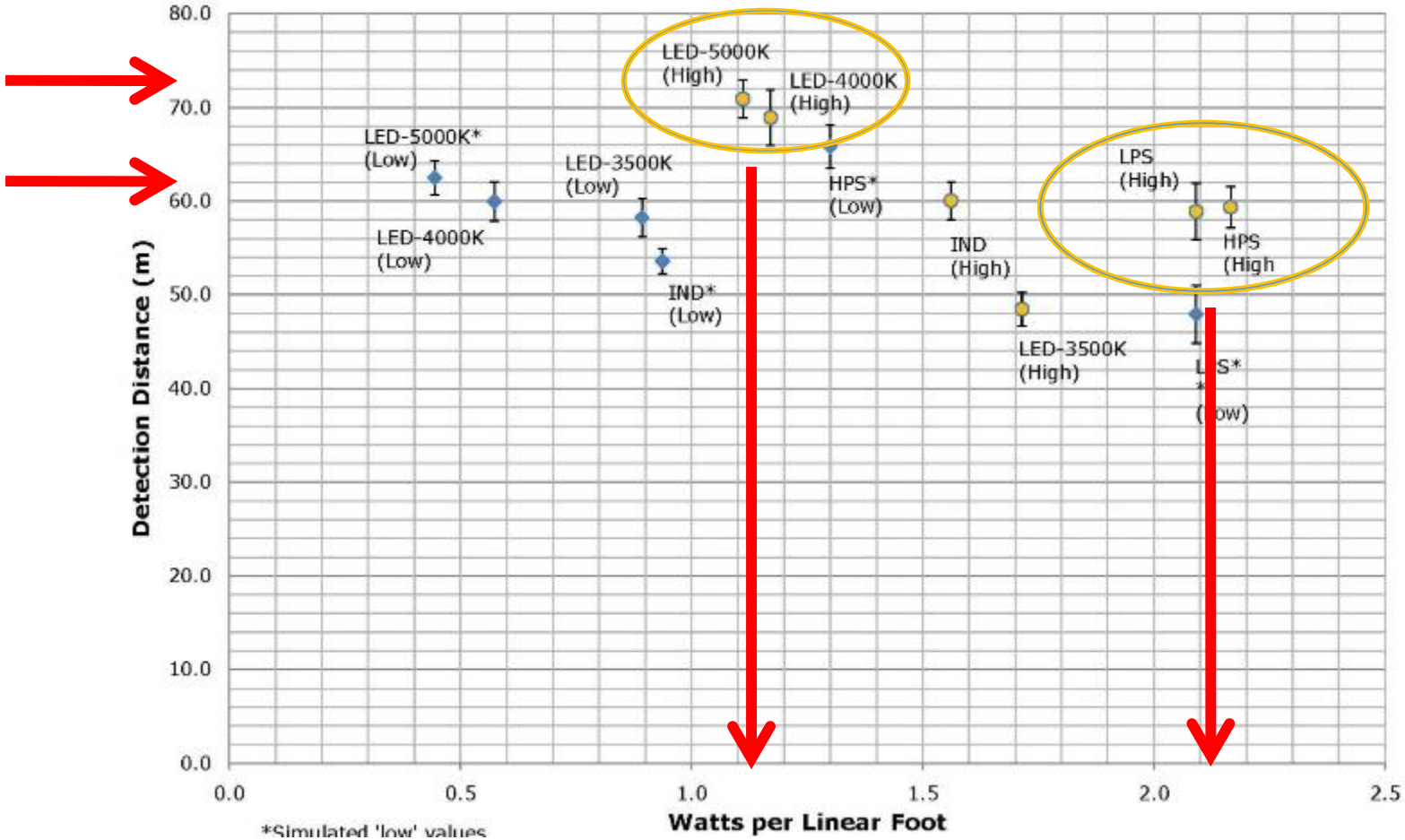
Light Source and Detection



https://neea.org/docs/default-source/reports/seattle-led-adaptive-lighting-study.pdf?sfvrsn=4

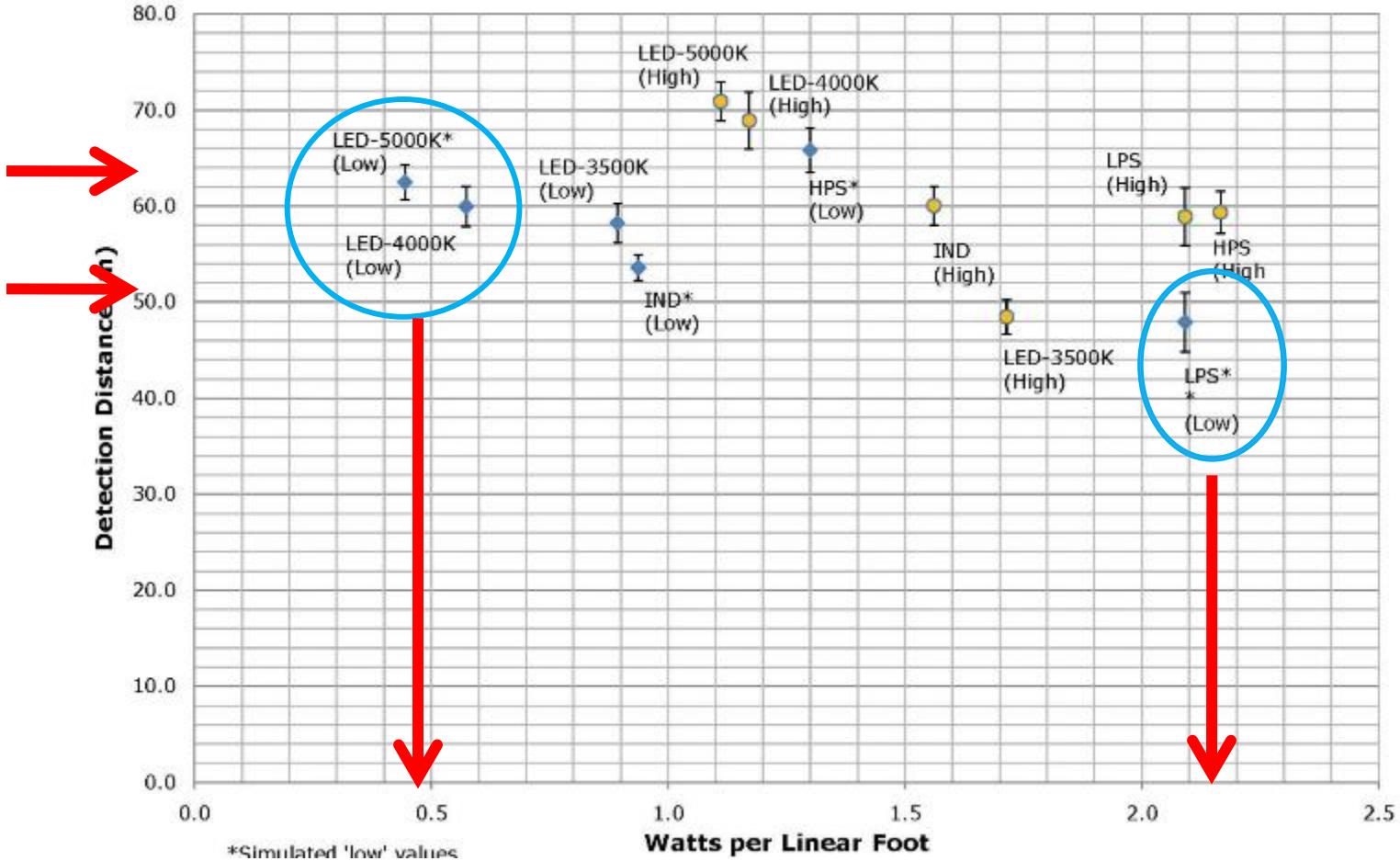
San Jose – Detection distance

vs watts per linear foot HIGH (100%)



San Jose – Detection distance

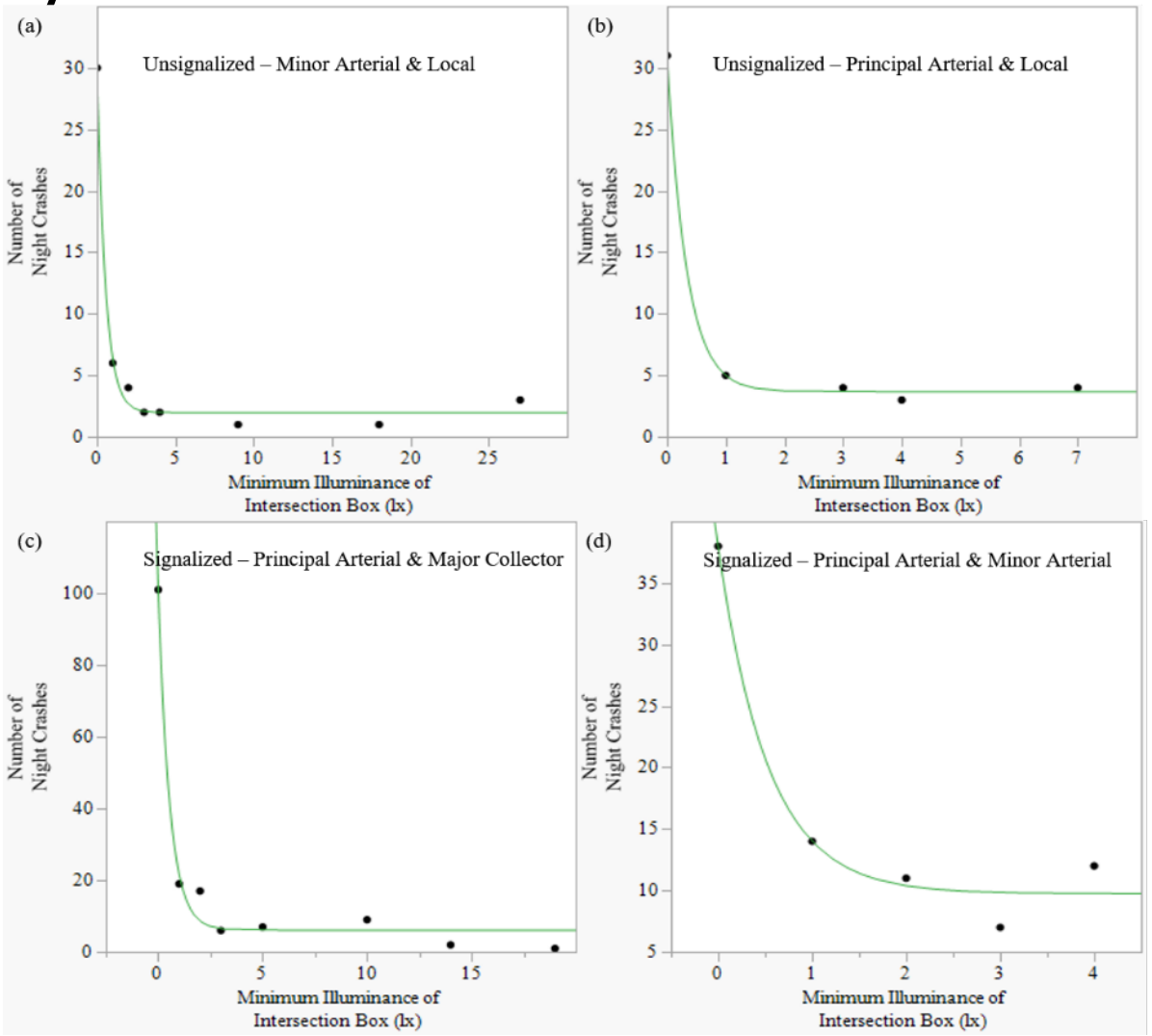
vs watts per linear foot LOW (50%) setting



Roadway Lighting & Safety – Decrease in Crashes at Intersections

235 intersections in Virginia

Increase in light level by 1 Lux is associated with decrease in Night to Day Crash Ratio by 2.9 %

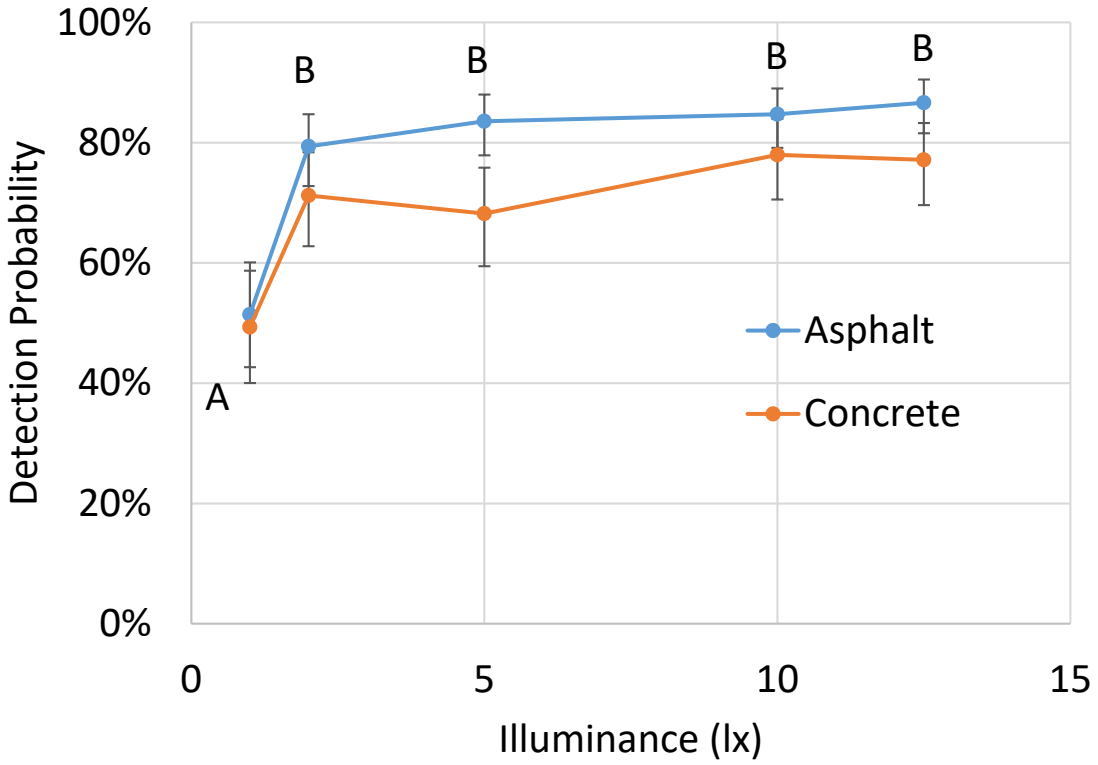


Li, Y. E., Bhagavathula, R., Terry, T. N., Gibbons, R. B., & Medina, A. (2020). *Safety Benefits and Best Practices for Intersection Lighting* (No. FHWA/VTRC 20-R31).

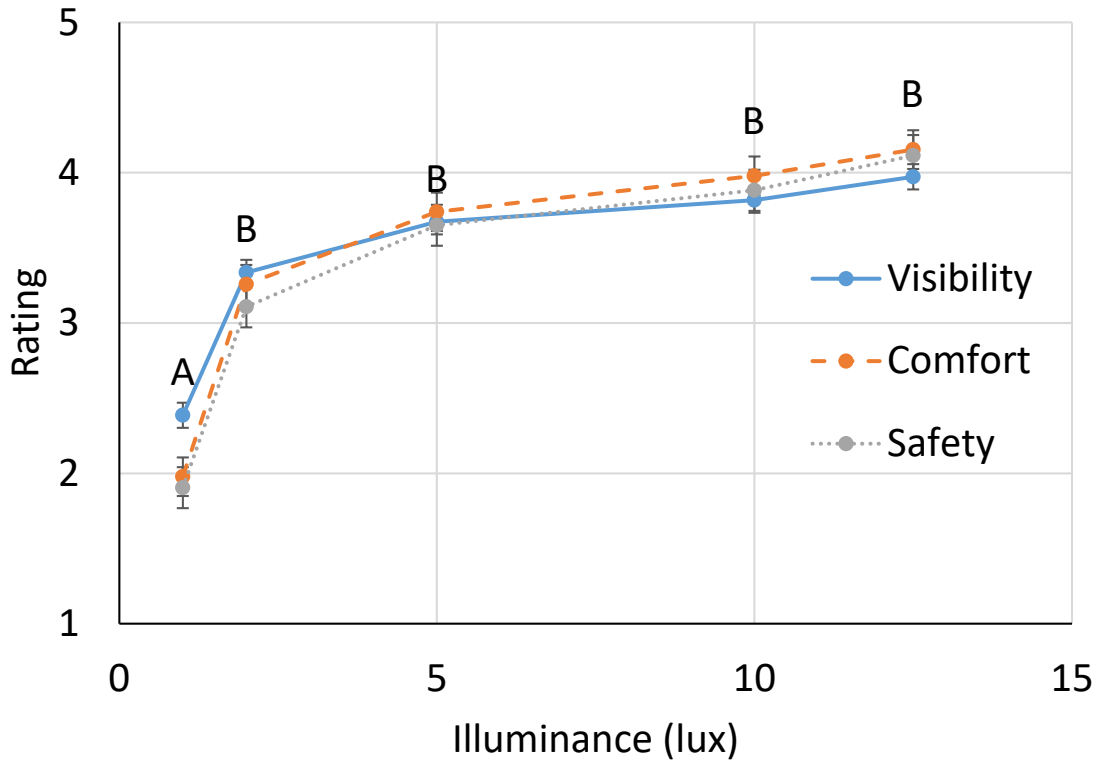
LIGHTING ALSO INCREASES SAFETY FOR PEDESTRIANS

PERFORMANCE AND PERCEPTIONS

- Detection of Tripping and Falling Hazards



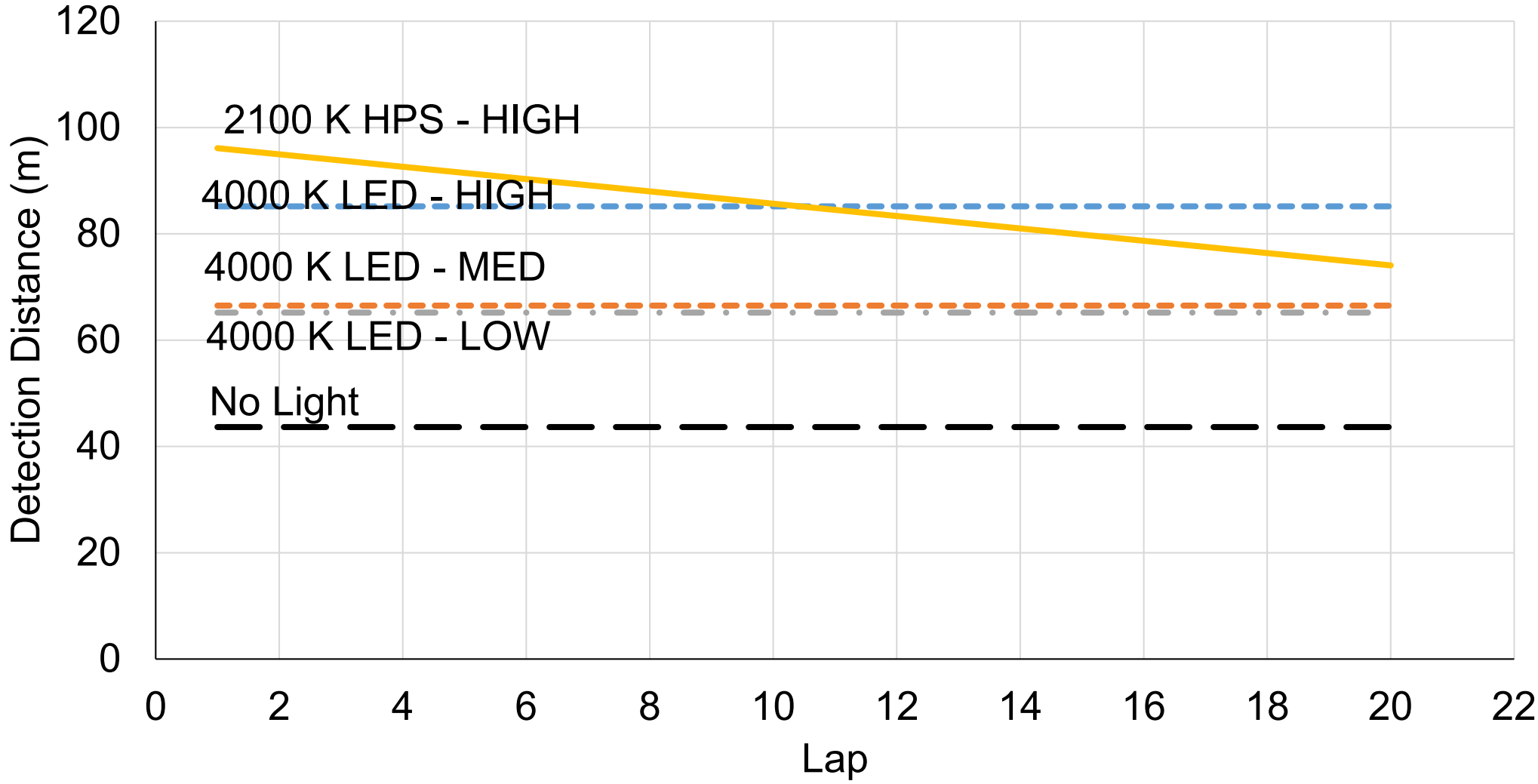
- Subjective Ratings



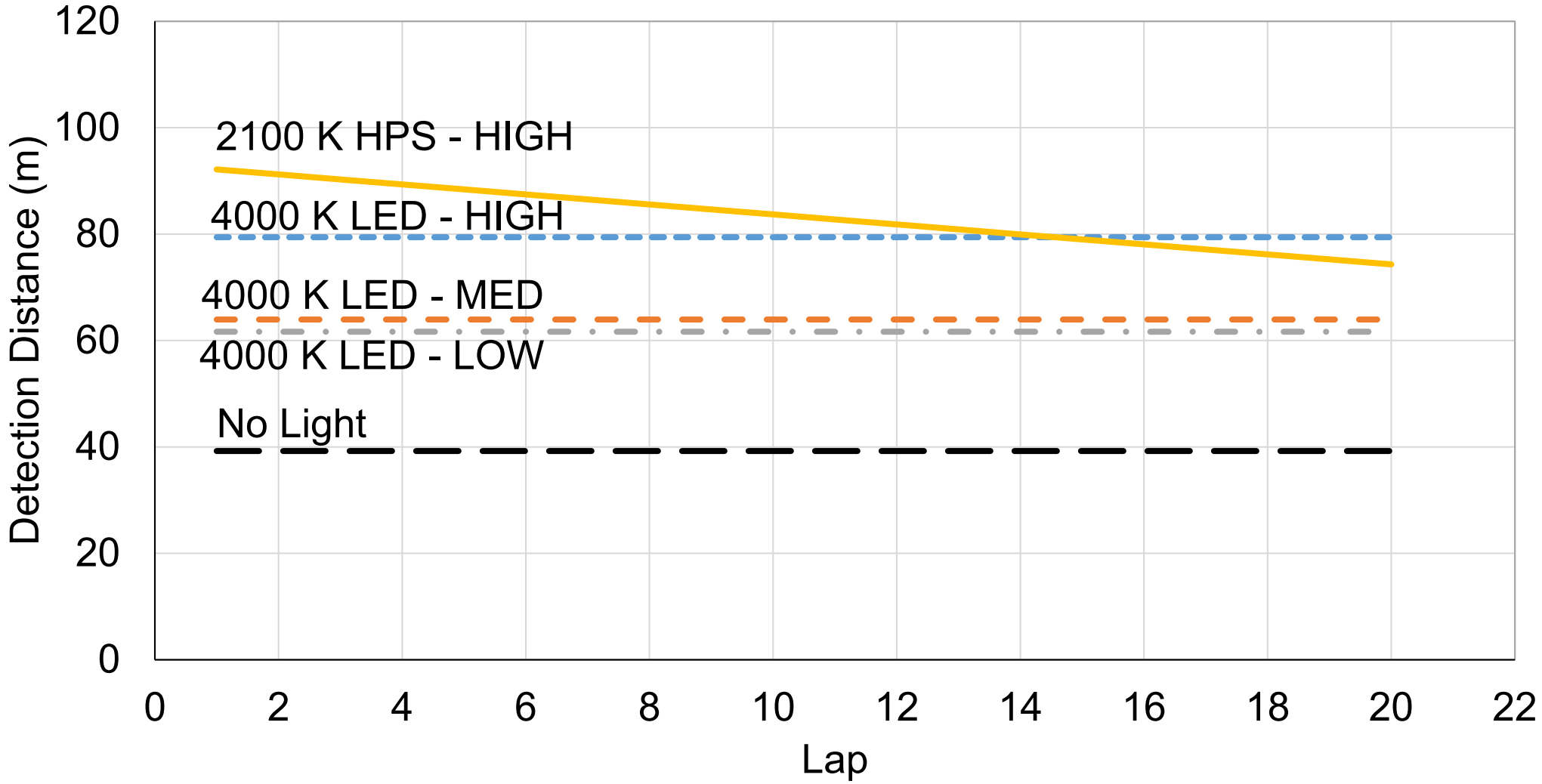
Bhagavathula, R., & Gibbons, R. B. (2020). Light levels for parking facilities based on empirical evaluation of visual performance and user perceptions. *Leukos*, *16*(2), 115-136.

Results of Street Lighting Exposures on Salivary Melatonin of Drivers

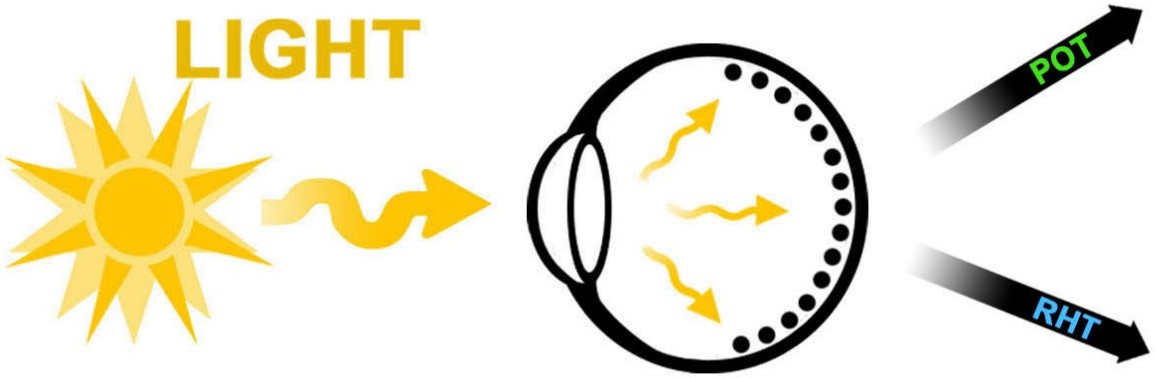
Results – Detection Distance
HPS detection distances decreases over time



Results – Color Recognition Distance
HPS recognition distances decreases over time

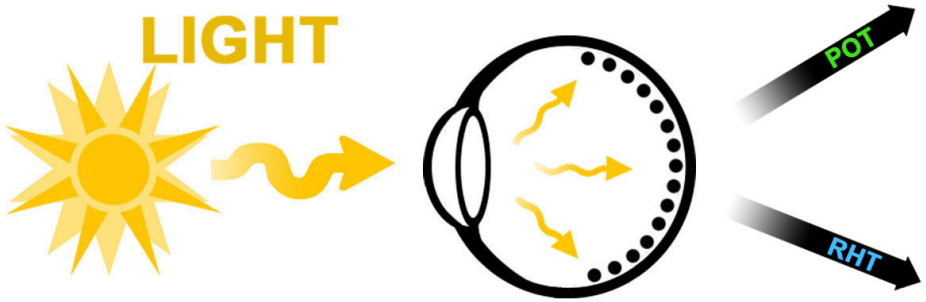


EFFECT OF LIGHT ON SLEEP HEALTH



VISUAL EFFECTS
VISUAL REFLEXES

BIOLOGICAL REGULATION
BEHAVIORAL EFFECTS



VISUAL EFFECTS
VISUAL REFLEXES

BIOLOGICAL/BEHAVIORAL

Acute Effects

- Melatonin Secretion
- Body Temperature
- Cortisol Secretion
- Pupillary Regulation
- Heartrate
- Alertness
- Brain Bloodflow
- EEG Responses
- Clock Gene Expression
- Cognitive Performance
- Psychomotor Performance

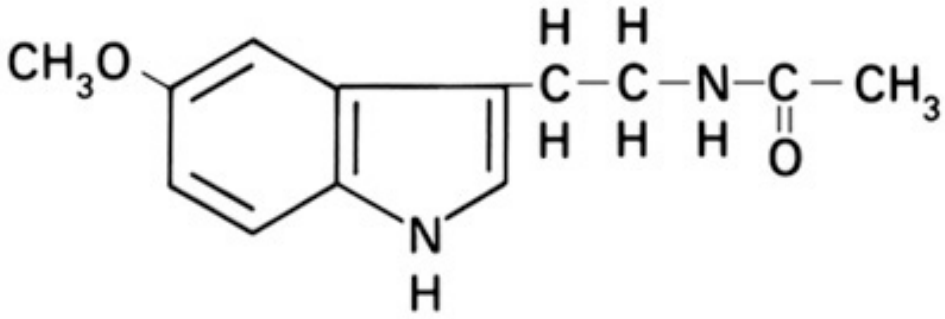
Longer Term Effects

- Circadian Phase-Shift
- Circadian Entrainment
- Sleep Physiology
- Light Therapy (eg SAD)

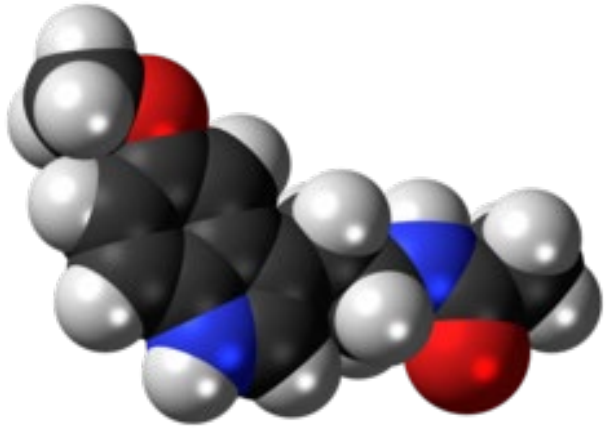
One Biological Measure for Two Major Systems

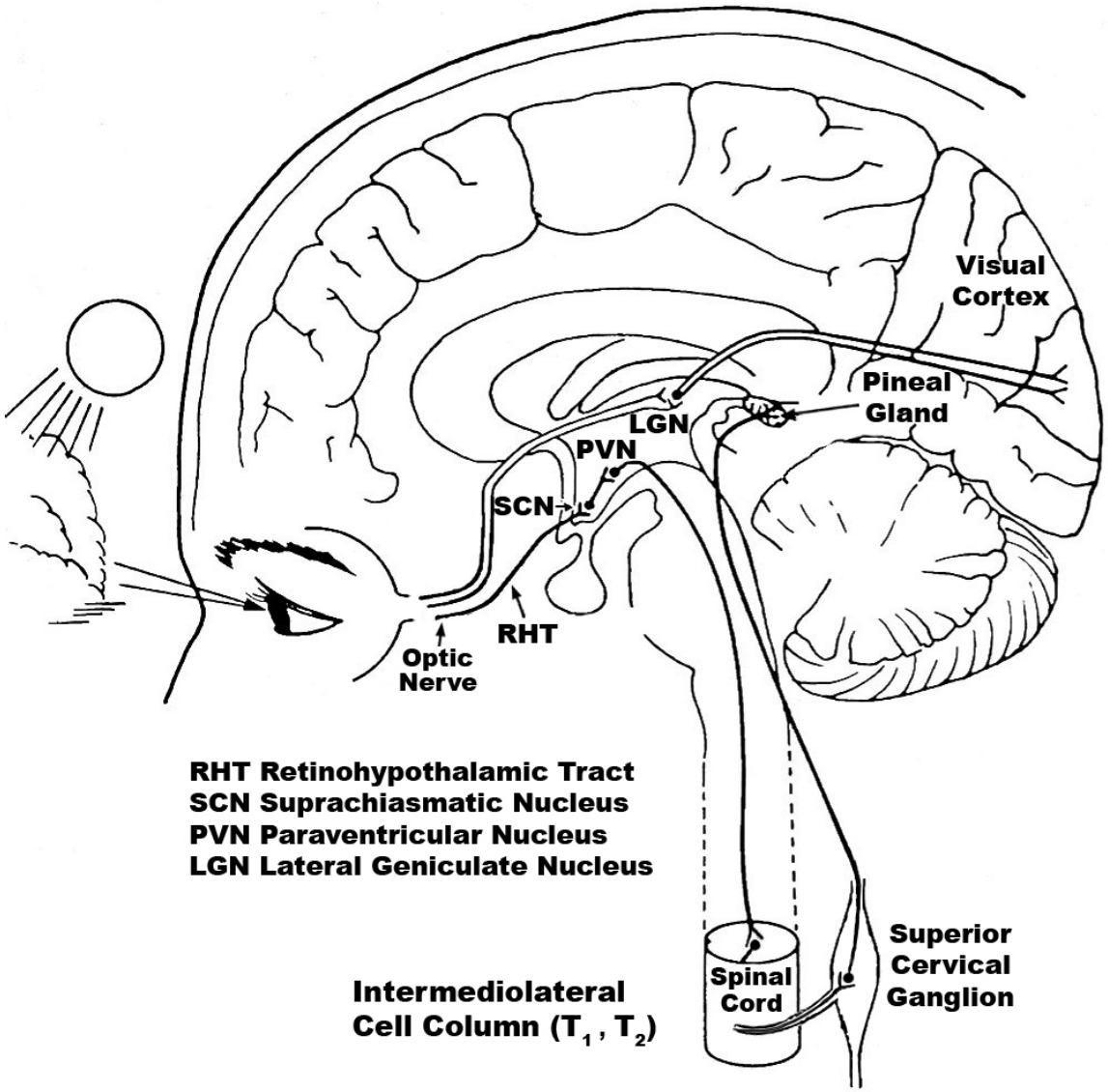
Neuroendocrine
- Acute suppression
- Photoperiodism

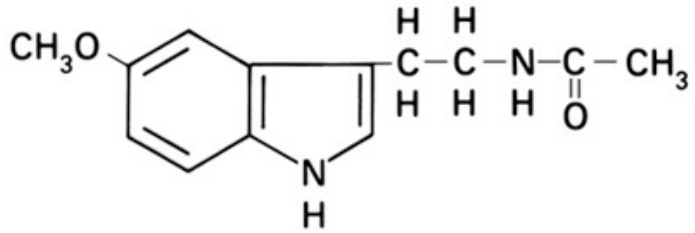
Circadian
- Phase-shift
- Entrainment



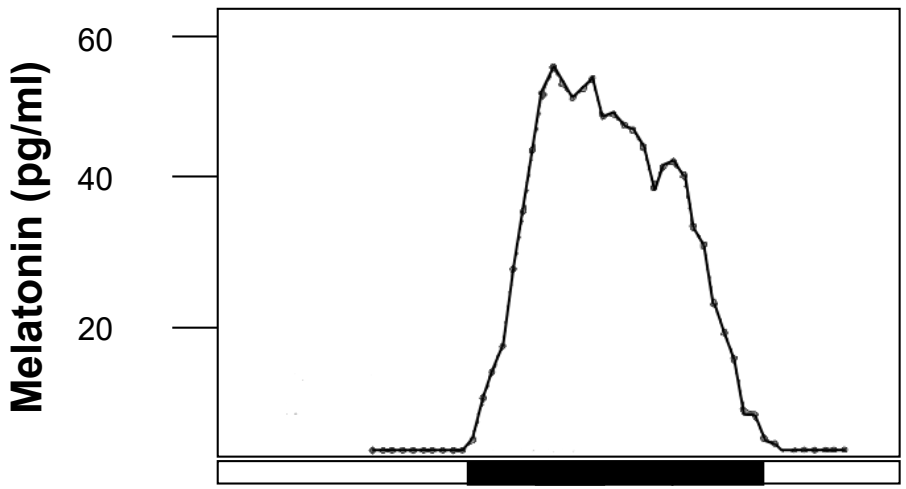
MELATONIN







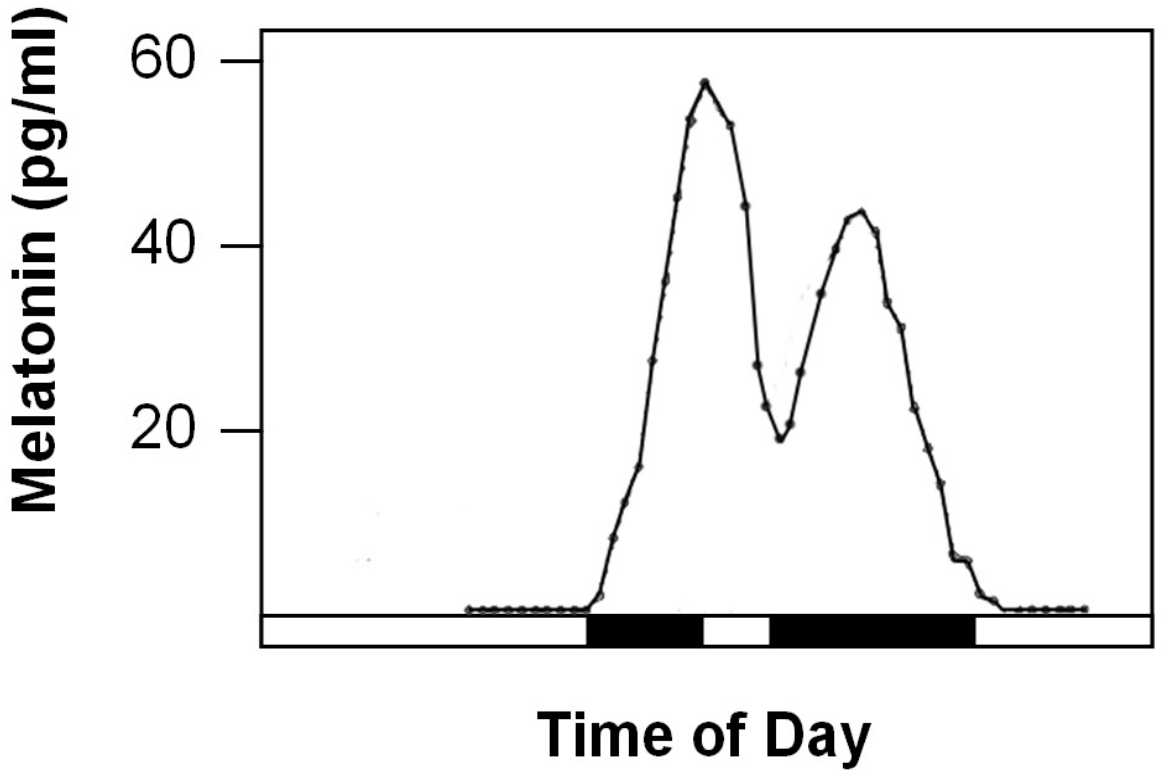
MELATONIN



Time of Day

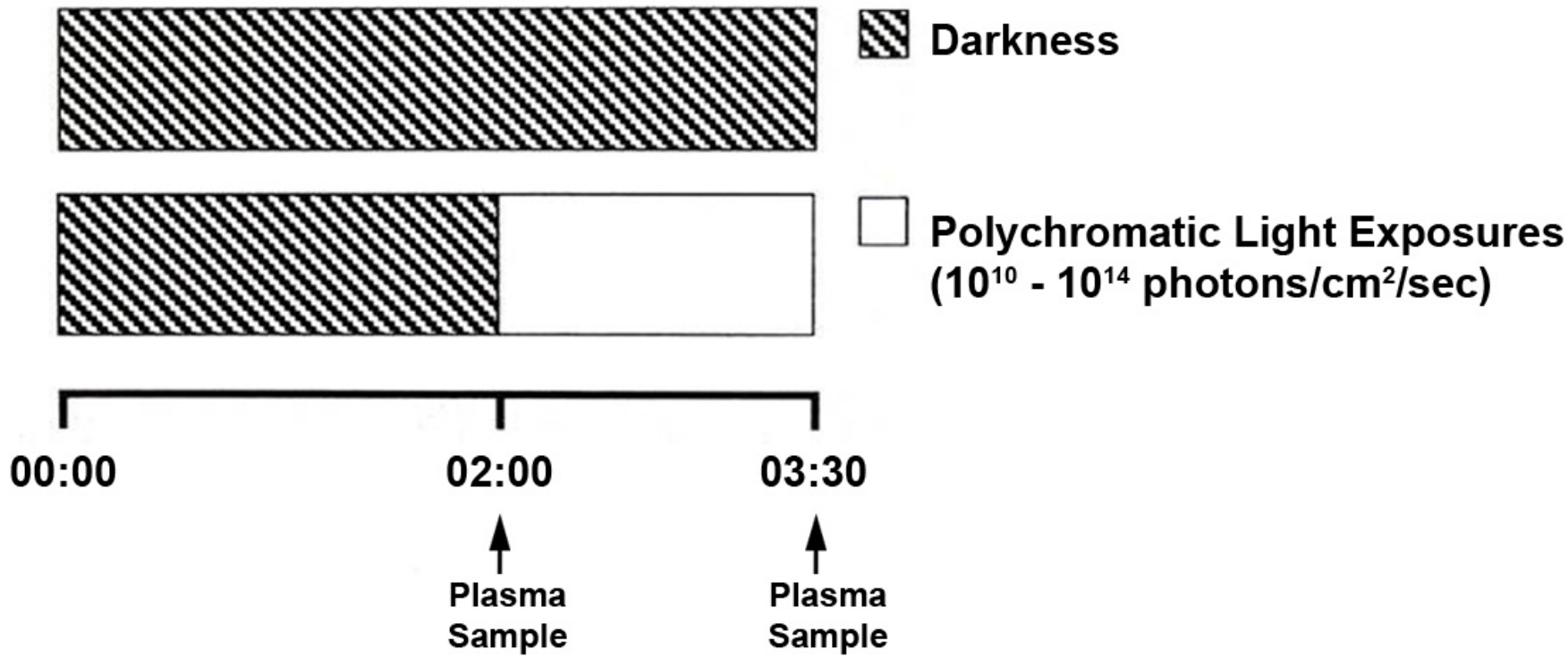
Brain/head image modified from NY Times, 1980.

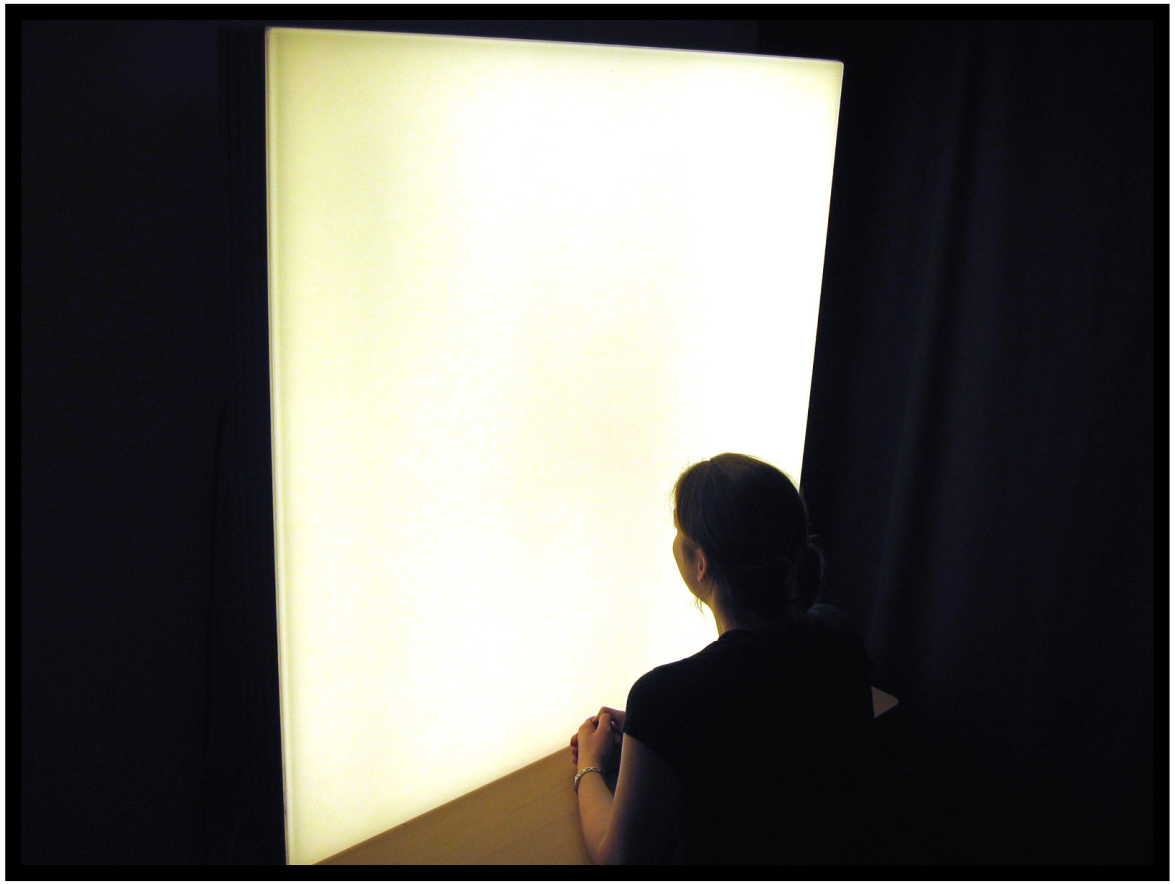
Bright light (2500 lux) suppresses nighttime plasma melatonin in healthy humans

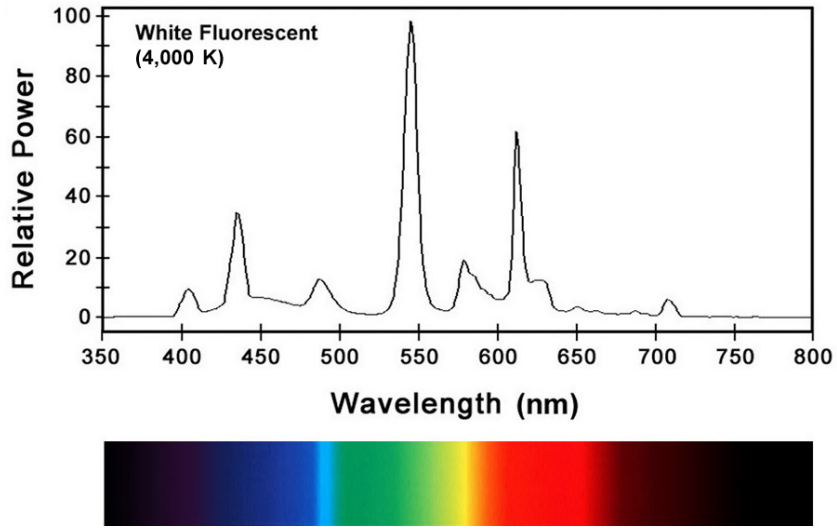


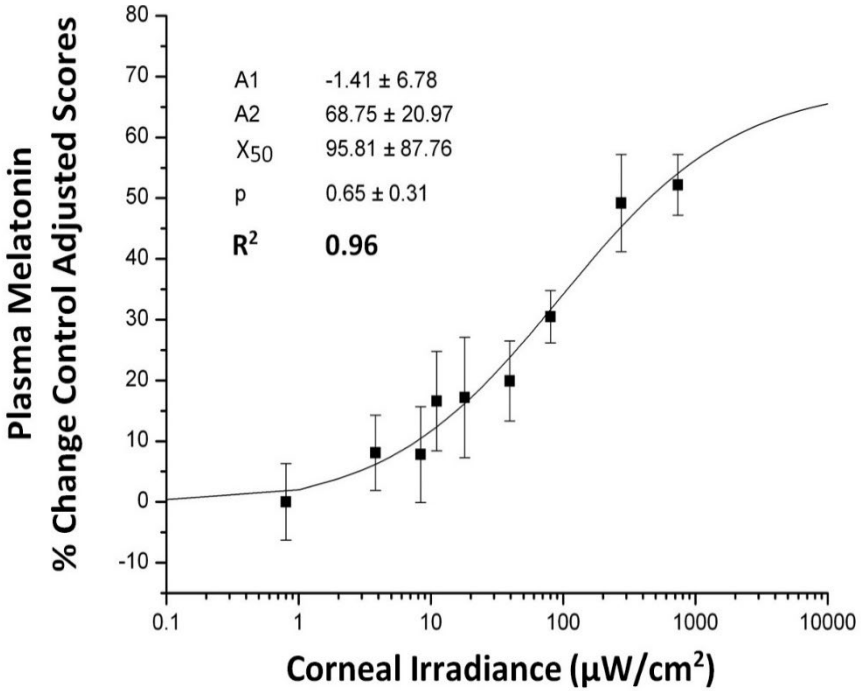
AJ Lewy, TA Wehr, FK Goodwin, DA Newsome, SP Markey
December 12, 1980, Science 210: 1267-1269

Full Dose-Response Protocol for Polychromatic Light





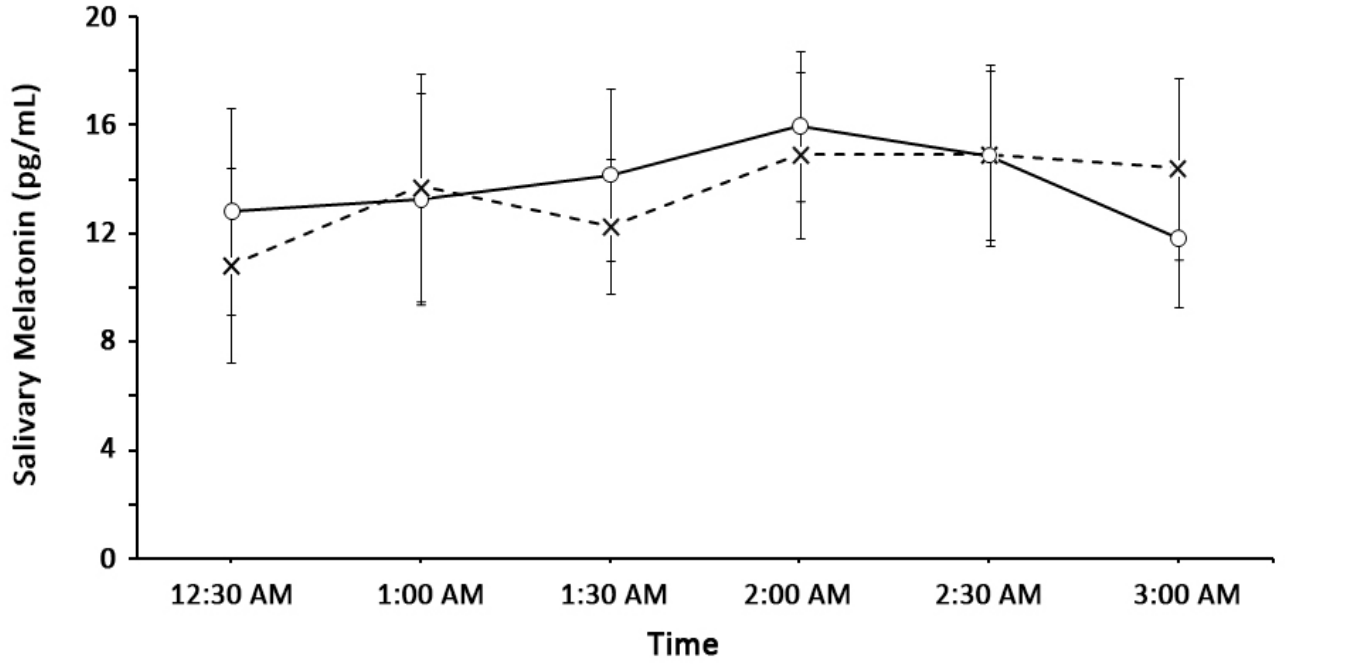

White Fluorescent
(4,000 K)
Relative Power
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)


Plasma Melatonin
% Change Control Adjusted Scores
A1 -1.41 ± 6.78
A2 68.75 ± 20.97
X50 95.81 ± 87.76
p 0.65 ± 0.31
R2 0.96
80
70
60
50
40
30
20
10
0
-10
0.1
1
10
100
1000
10000
Corneal Irradiance (µW/cm2)

Results of Street Lighting Exposures on Salivary Melatonin of Drivers

Drivers: 2100 K HPS

F=0.04
P=0.85
df=1



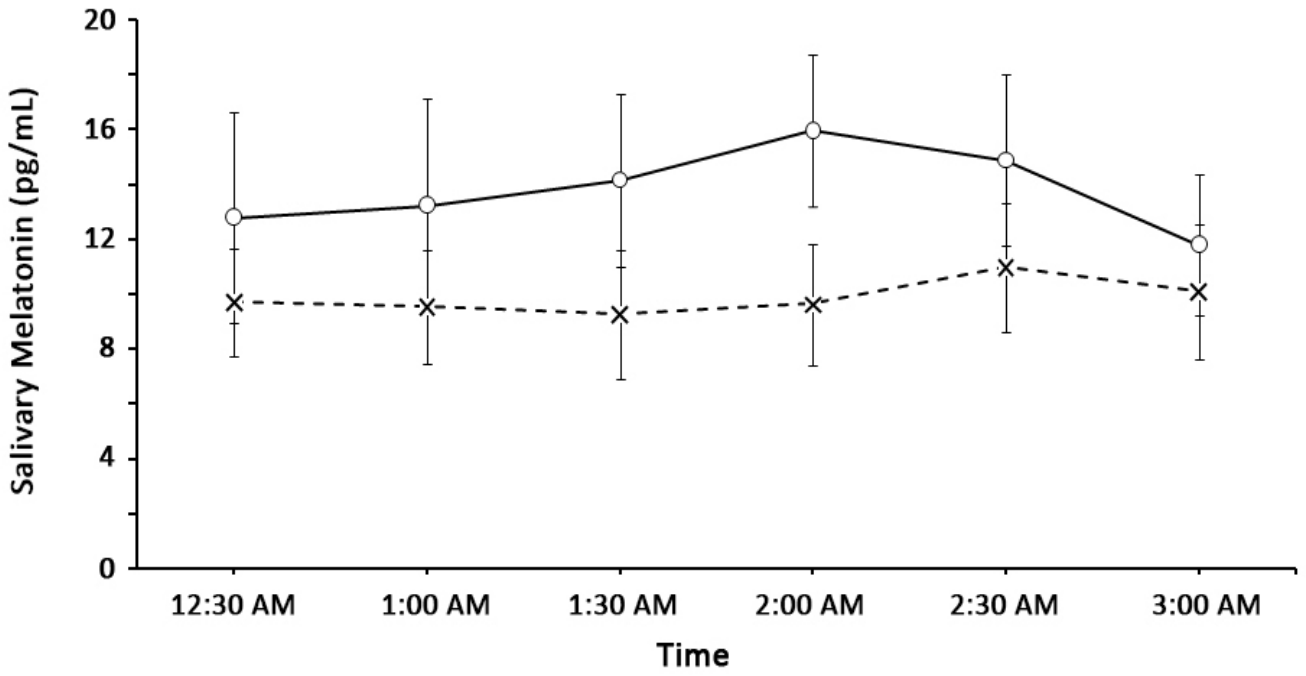
200 lux	0.8 lux 0.3 Melanopic EDI
200 lux	1.8 lux 0.3 Melanopic EDI

—○— No Light
—×— HPS

Drivers: 4000 K LED Low

Exposure Time: 1:00AM – 3:00AM

F=1.34
P=0.26
df=1



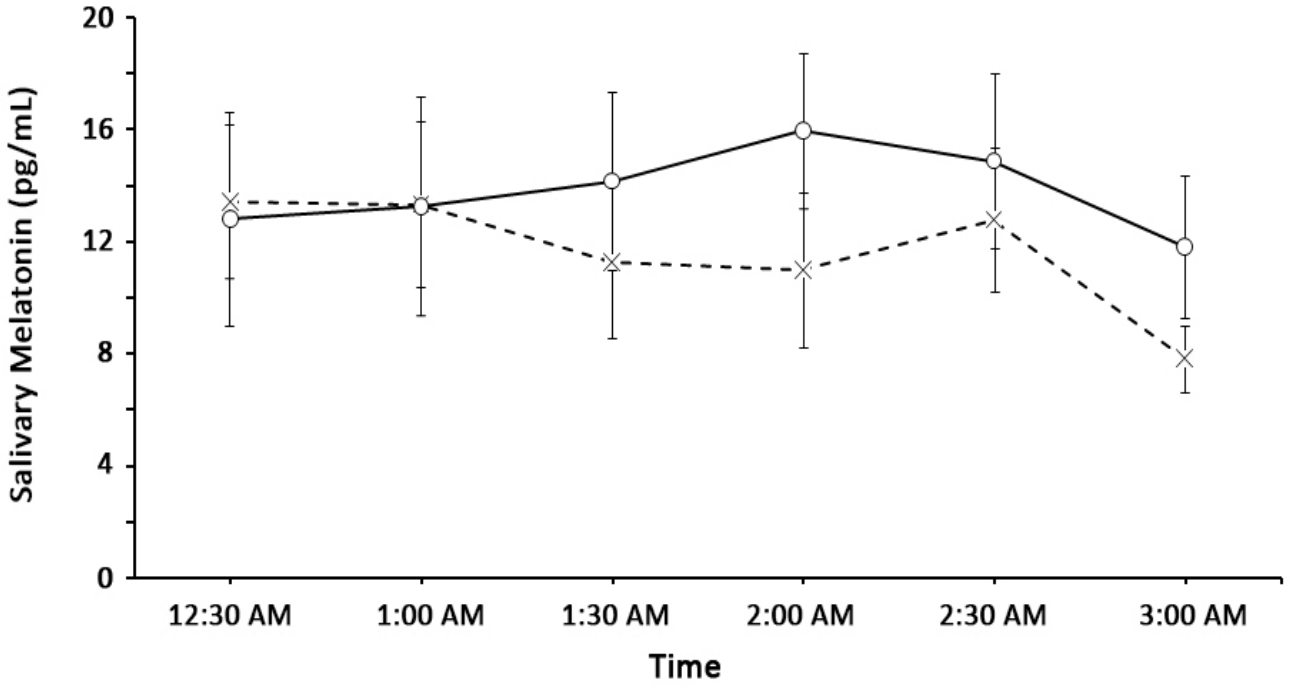
200 lux	0.8 lux 0.3 Melanopic EDI
200 lux	1.1 lux 0.5 Melanopic EDI

No Light
Drivers 4K Low

Drivers: 4000 K LED Medium

Exposure Time: 1:00AM – 3:00AM

F=0.42
P=0.53
df=1



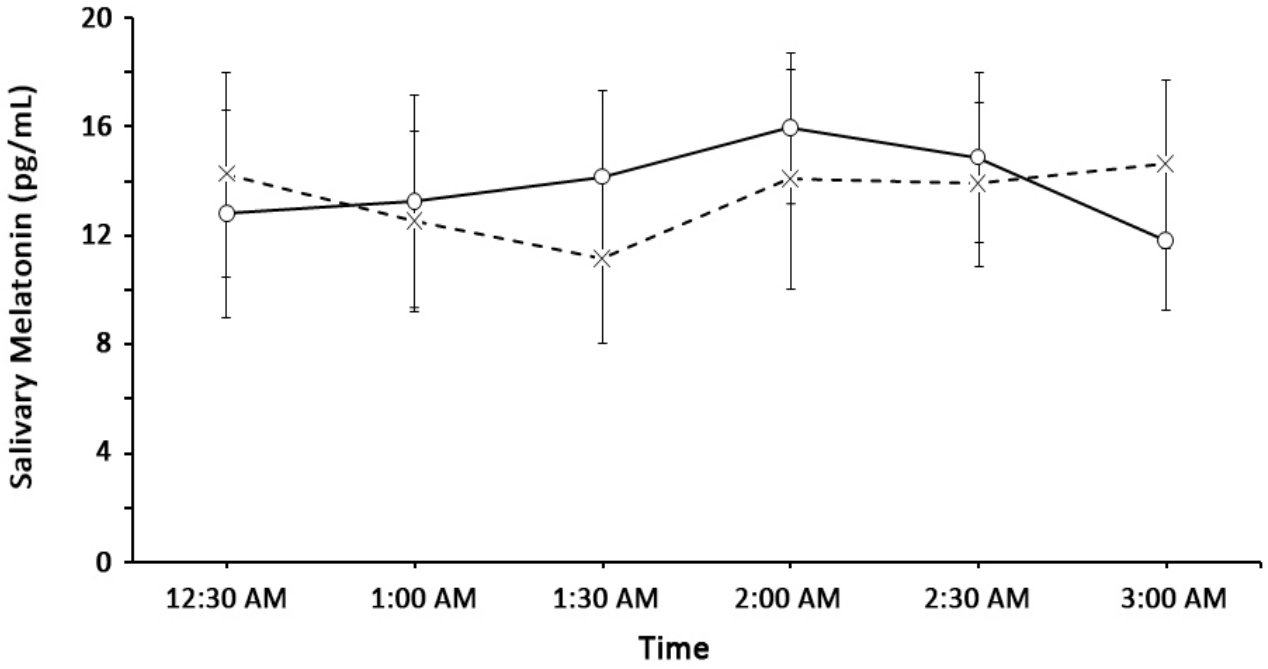
200 lux	0.8 lux 0.3 Melanopic EDI
200 lux	1.4 lux 0.6 Melanopic EDI

No Light
Drivers 4K Medium

Drivers: 4000 K LED High

Exposure Time: 1:00AM – 3:00AM

F=0.03
P=0.86
df=1



200 lux	0.8 lux 0.3 Melanopic EDI
200 lux	1.9 lux 0.8 Melanopic EDI

No Light
Drivers 4K High

Light Condition	2100 K HPS	4000 K LED	4000 K LED	4000 K LED	No Light	Positive Control
Light Level (lux)	1.8	1.9	1.4	1.1	0.8	3500
Melanopic EDI*	0.3	0.8	0.6	0.5	0.3	1474

Naturalistic On-Road

Laboratory

AMA Adopts New Policies, June 19, 2012

The American Medical Association (AMA), the nation's largest physician organization, voted today during its annual policy-making meeting to adopt the following new policy:

Adverse Health Effects of Nighttime Lighting

The AMA adopted the policy recognizing that exposure to excessive light at night can disrupt sleep, exacerbate sleep disorders and cause unsafe driving conditions. The policy also supports the need for developing lighting technologies that minimize circadian disruption and encourages further research on the risks and benefits of occupational and environmental exposure to light at night.

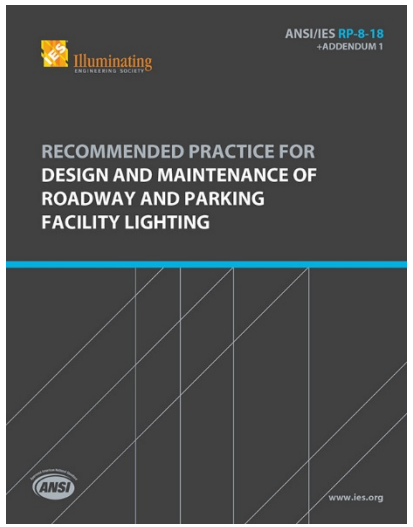
AMA Adopts New Recommendations, June 14, 2016

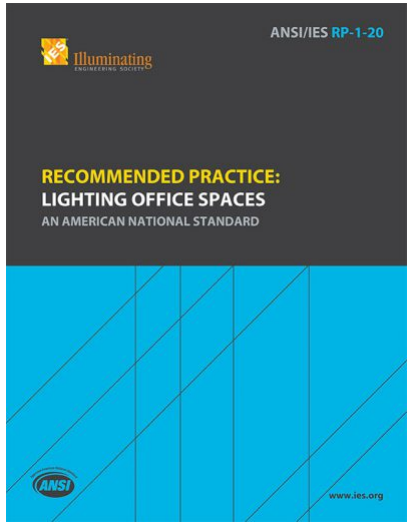
The American Medical Association (AMA), the nation's largest physician organization, voted today to adopt the following new recommendations:

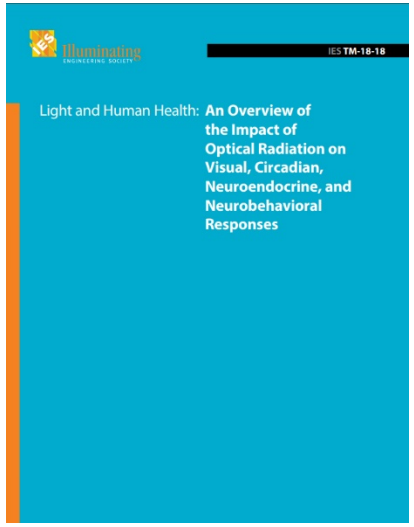
1) That our American Medical Association (AMA) support the proper conversion to community-based Light Emitting Diode (LED) lighting, which reduces energy consumption and decreases the use of fossil fuels.

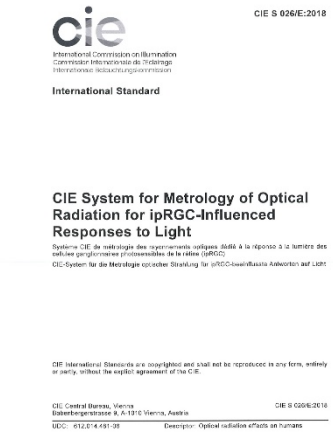
2) That our AMA encourage minimizing and controlling blue-rich environmental lighting by using the lowest emission of blue light possible to reduce glare.

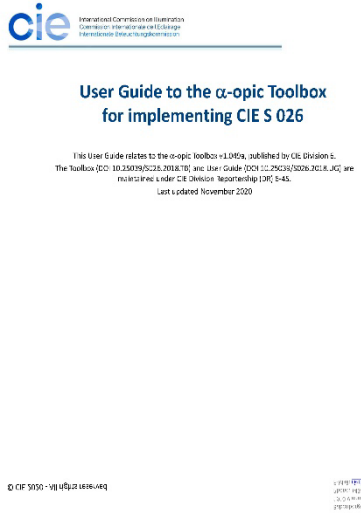
3) That our AMA encourage the use of 3000K or lower lighting for outdoor installations such as roadways. All LED lighting should be properly shielded to minimize glare and detrimental human and environmental effects, and consideration should be given to utilize the ability of LED lighting to be dimmed for off-peak time periods.


Illuminating
ANSI/IES RP-8-18
+ADDENDUM 1
RECOMMENDED PRACTICE FOR
DESIGN AND MAINTENANCE OF
ROADWAY AND PARKING
FACILITY LIGHTING
ANSI
www.ies.org


Illuminating
ANSI/IES RP-1-20
RECOMMENDED PRACTICE:
LIGHTING OFFICE SPACES
AN AMERICAN NATIONAL STANDARD
ANSI
www.ies.org


Illuminating
IES TM-18-18
Light and Human Health: An Overview of the Impact of Optical Radiation on Visual, Circadian, Neuroendocrine, and Neurobehavioral Responses

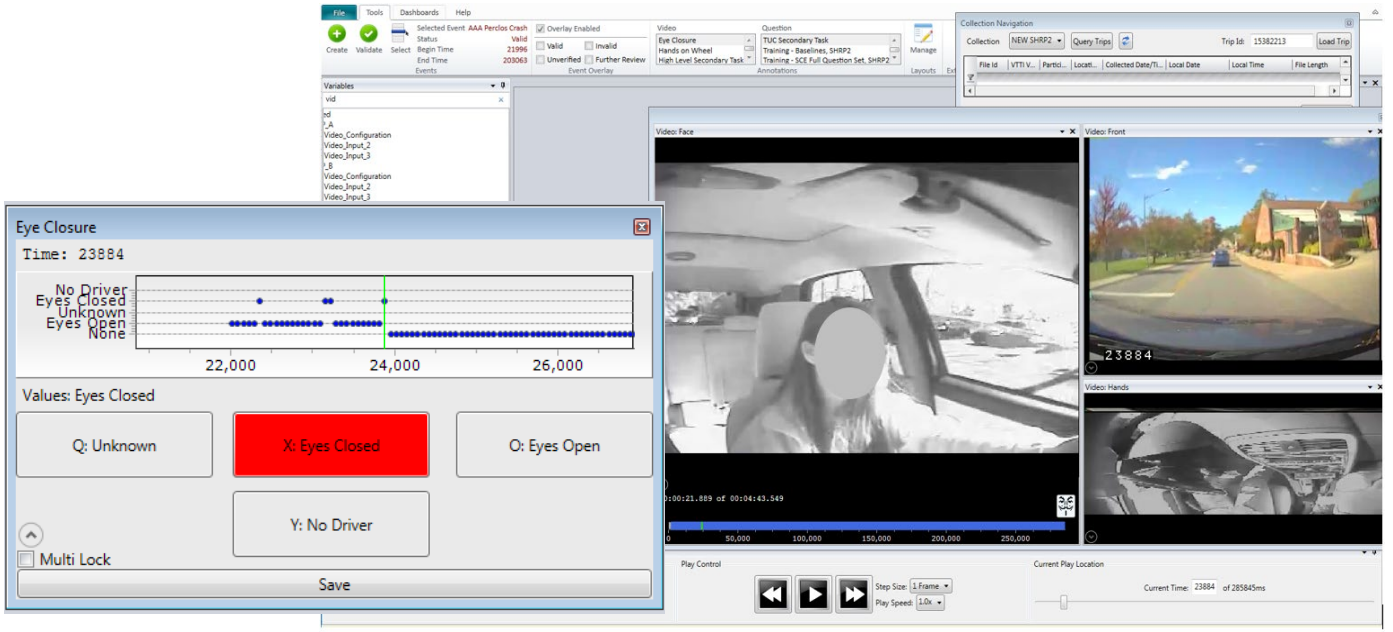

cie
CIE S 026/E:2018
International Standard
CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light


cie
User Guide to the α-opic Toolbox for implementing CIE S 026
This User Guide relates to the α-opic Toolbox v1.049a, published by CIE Division 1.
Last updated November 2020

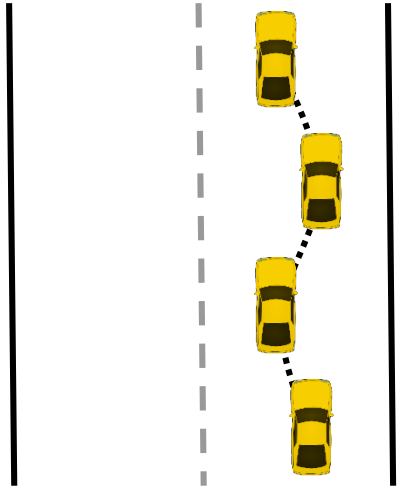
EFFECT OF LIGHT ON ALERTNESS

Karolinska Sleepiness Scale (KSS)

Extremely alert	1
Very alert	2
Alert	3
Rather alert	4
Neither alert nor sleepy	5
Some signs of sleepiness	6
Sleepy but no effort to keep awake	7
Very sleepy, great effort to keep awake, fighting sleep	9
Extremely sleepy, can't keep awake	10



PERCLOS

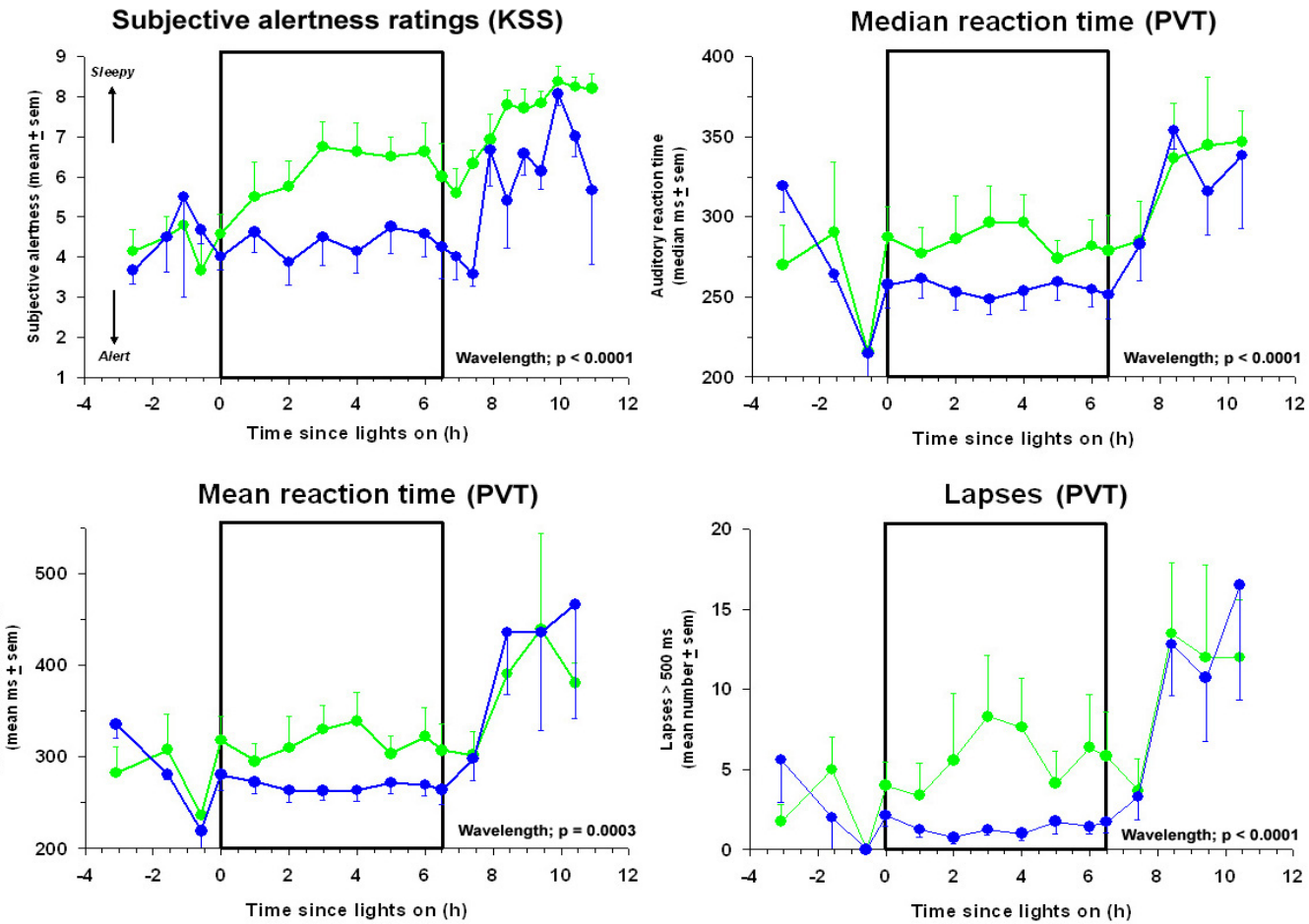


SDLP

Short-Wavelength Sensitivity for the Direct Effects of Light on Alertness, Vigilance, and the Waking Electroencephalogram in Humans

Steven W. Lockley, PhD[1,2]; Erin E. Evans, BS, RPSGT[1]; Frank A.J.L. Scheer, PhD[1,2]; George C. Brainard, PhD[3]; Charles A. Czeisler, PhD, MD[1,2]; Daniel Aeschbach, PhD[1,2]

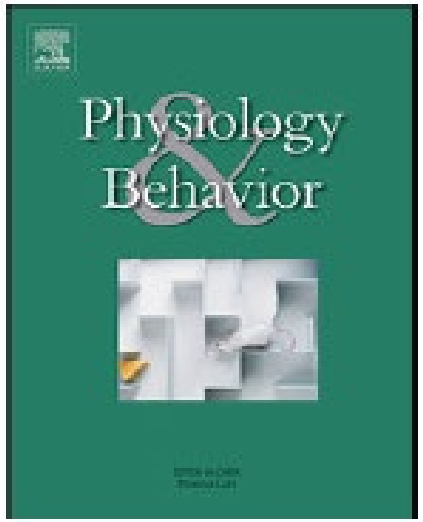
[1]Division of Sleep Medicine, Brigham and Women's Hospital, Boston, MA; [2]Division of Sleep Medicine, Harvard Medical School, Boston, MA; [3]Department of Neurology, Jefferson Medical College, Thomas Jefferson University, Philadelphia, PA

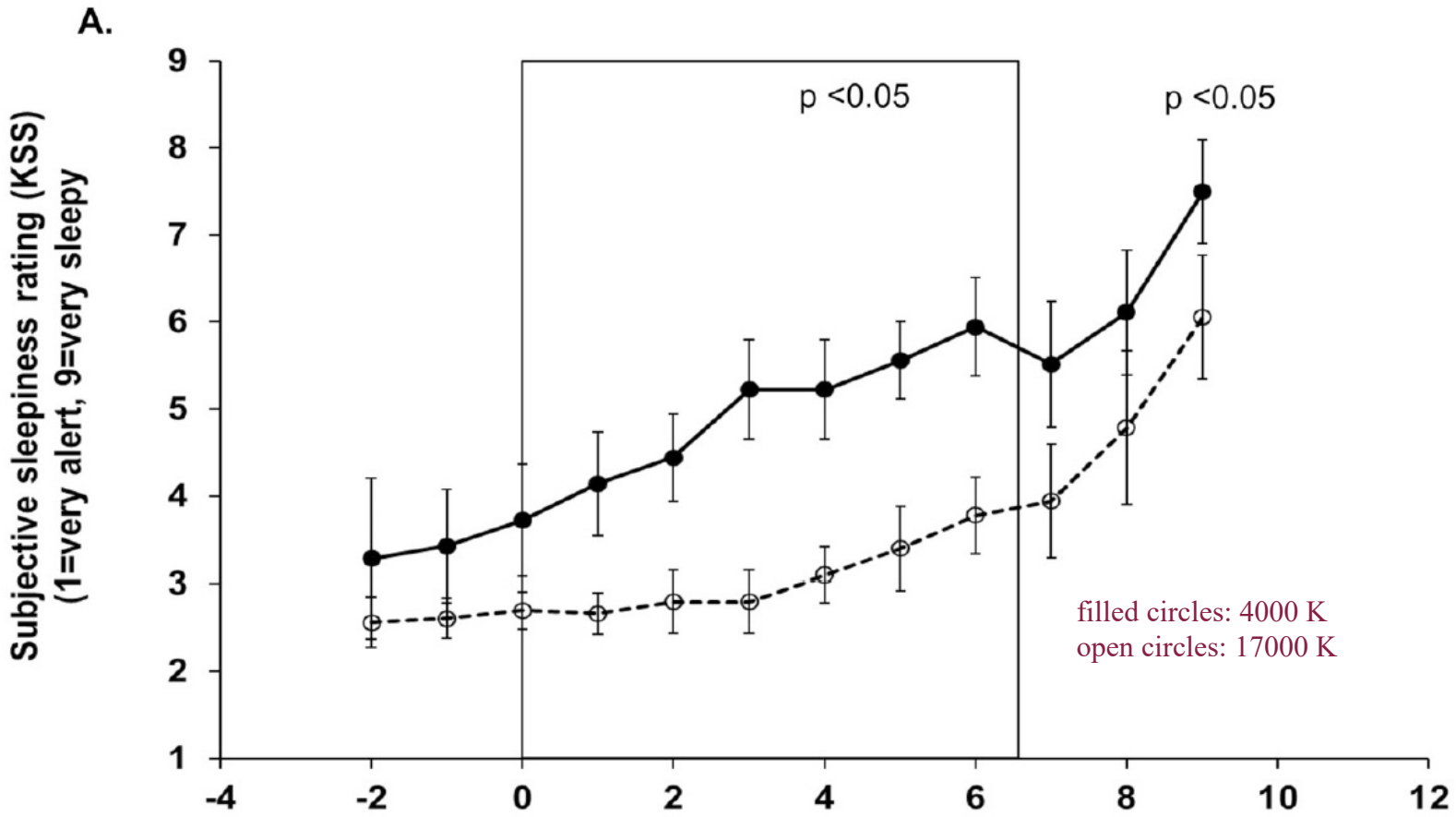


Randomized trial of polychromatic blue-enriched light for circadian phase shifting, melatonin suppression, and alerting responses

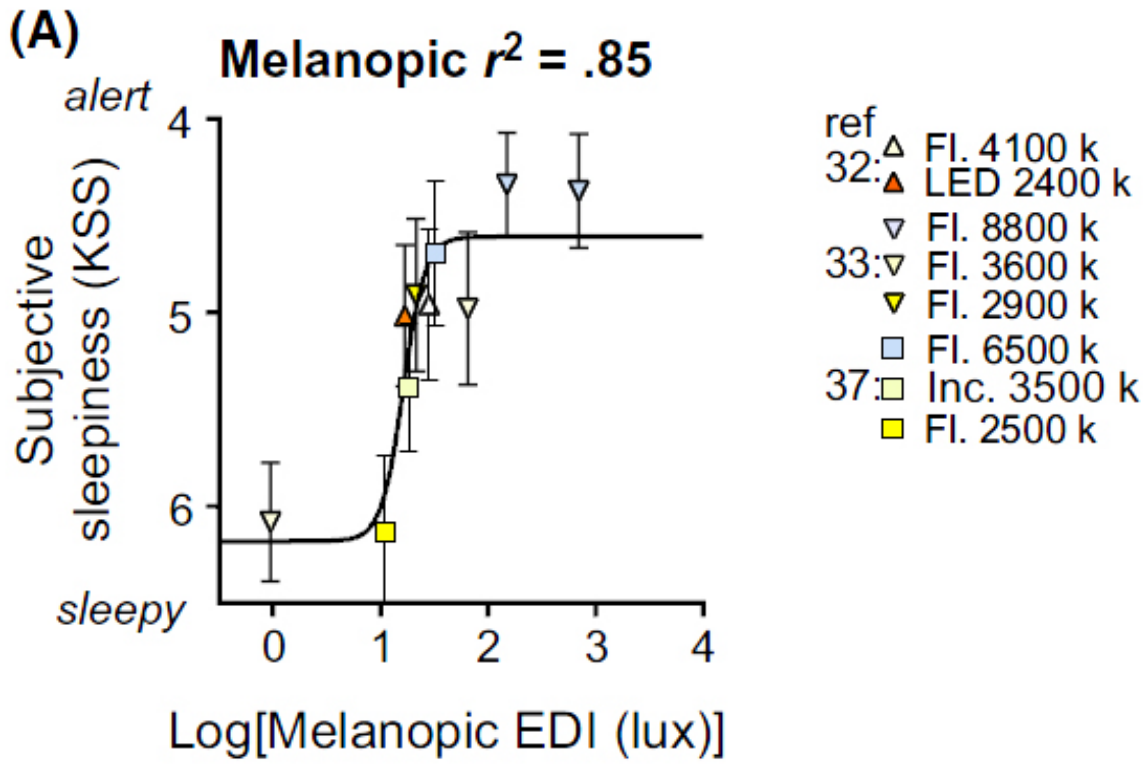
J.P. Hanifin[a,*], S.W. Lockley[b], K. Cecil[a], K. West[a], M. Jablonski[a], B. Warfield[a], M. James[a], M. Ayers[a], B. Byrne[a], E. Gerner[a], C. Pineda[a], M. Rollag[a], G.C. Brainard[a]

[a] *Department of Neurology, Thomas Jefferson University, Philadelphia, PA 19107, USA*
[b] *Division of Sleep and Circadian Disorders, Departments of Medicine and Neurology, Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02115, USA*





SPECTRAL SENSITIVITY OF ALERTING RESPONSES TO LIGHT



Spectral sensitivity of alerting responses to light. A, Data from (32,33,37) showing subjective sleepiness (as measured by KSS scores obtained 70-90 min prior to scheduled sleep) across subjects exposed to various broadband sources for >1 h, quantified as melanopic, photopic and S-cone opic illuminance. Curves show best-fit 4-parameter sigmoid.

EFFECT OF LIGHT ON ALERTNESS AT NIGHT

- Maximum response at 1000 lux and half-maximum 90-180 lux*
- Lab studies
- Shift work studies
  - Blue enriched fluorescent light (17000 K) – never used for roads
- Some research on blue light and driver alertness at night

*Cajochen, C, Zeitzer, JM, Czeisler, CA, Dijk, D-J (2000) Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness. Behav Brain Res 115(1):75–83.

BLUE LIGHT AND DRIVER ALERTNESS

- Driving simulator – Blue (460 nm ~ 1lux), Red (640 nm ~ 1lux), & Ambient white light (~0.2 lux) – 6 hours

Phipps-Nelson, J., Redman, J. R., Schlangen, L. J., & Rajaratnam, S. M. (2009). Blue light exposure reduces objective measures of sleepiness during prolonged nighttime performance testing. *Chronobiology International*, *26*(5), 891-912.

  - Blue Light
    - Faster reaction times
    - Reduced slow eye movements
    - Suppressed EEG slow wave delta and theta activity
    - No effects on sleepiness or salivatory melatonin levels
- Field Study with Truck Drivers – 30 mins of bright light – 9 hours of night driving

Landström, U., Åkerstedt, T., Byström, M., Nordström, B., & Wibom, R. (2004). Effect on truck drivers' alertness of a 30-min. exposure to bright light: a field study. *Perceptual and motor skills*, *98*(3), 770-776.

  - No effect of light
  - Sleepiness increased

BLUE LIGHT AND DRIVER ALERTNESS

- Field Study – Blue light (468 nm ~ 20 lux) box placed on the dashboard – 4 hours (1 am to 5:15am) – Highway Driving (80 mph)
  - Coffee (normal and decaf)

Taillard, J., Capelli, A., Sagaspe, P., Anund, A., Akerstedt, T., & Philip, P. (2012). In-car nocturnal blue light exposure improves motorway driving: a randomized controlled trial. PloS one, 7(10), e46750.

  - Lane deviations were lower than decaf coffee
  - Coffee was better than blue light
  - No effect on sleep quality for coffee or blue light or decaf coffee
- Driving Simulator – 60 mins of blue light (440 nm – 469 lux) – 8:30 am to 9:30 am.

Rodríguez-Morilla, B., Madrid, J. A., Molina, E., Pérez-Navarro, J., & Correa, Á. (2018). Blue-enriched light enhances alertness but impairs accurate performance in evening chronotypes driving in the morning. *Frontiers in psychology*, *9*, 688.

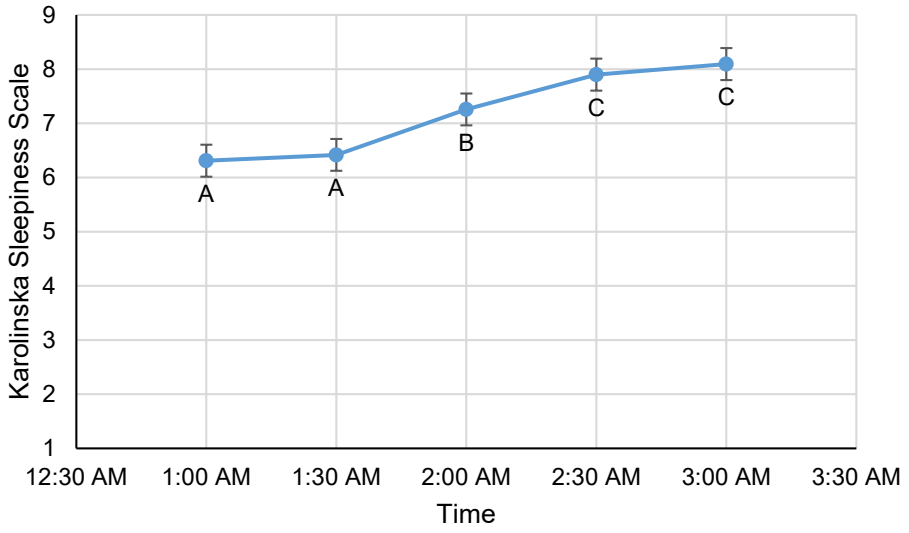
  - Blue light increased alertness (faster reaction times)
  - Reduced accuracy of driving performance

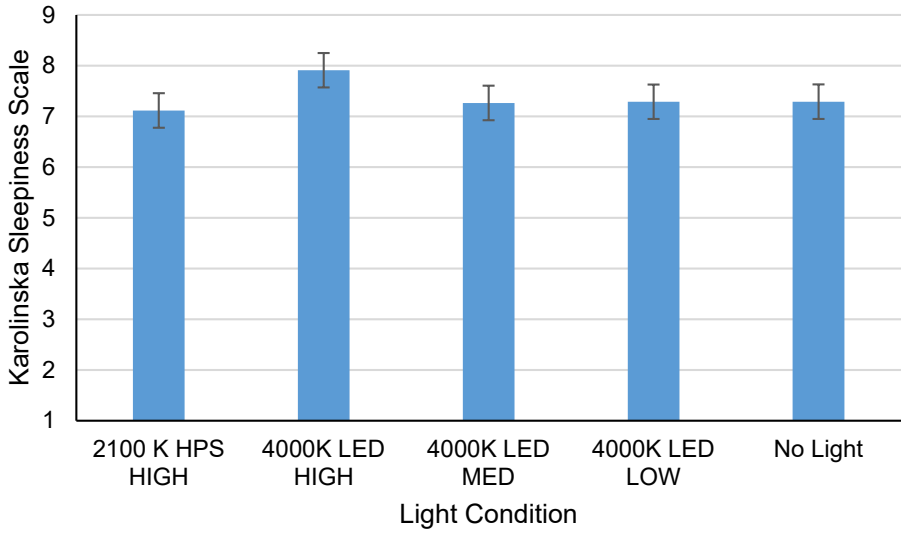
Results of Street Lighting Exposures on Alertness of Drivers

Results – Self Report Measures of Drowsiness

Drivers were sleepy in all conditions

Rating	Description
9	Extremely sleepy, fighting sleep
8	Sleepy, some effort to keep alert
7	Sleepy, but no difficulty remaining awake
6	Some signs of sleepiness
5	Neither alert nor sleepy
4	Rather alert
3	Alert
2	Very alert
1	Extremely alert

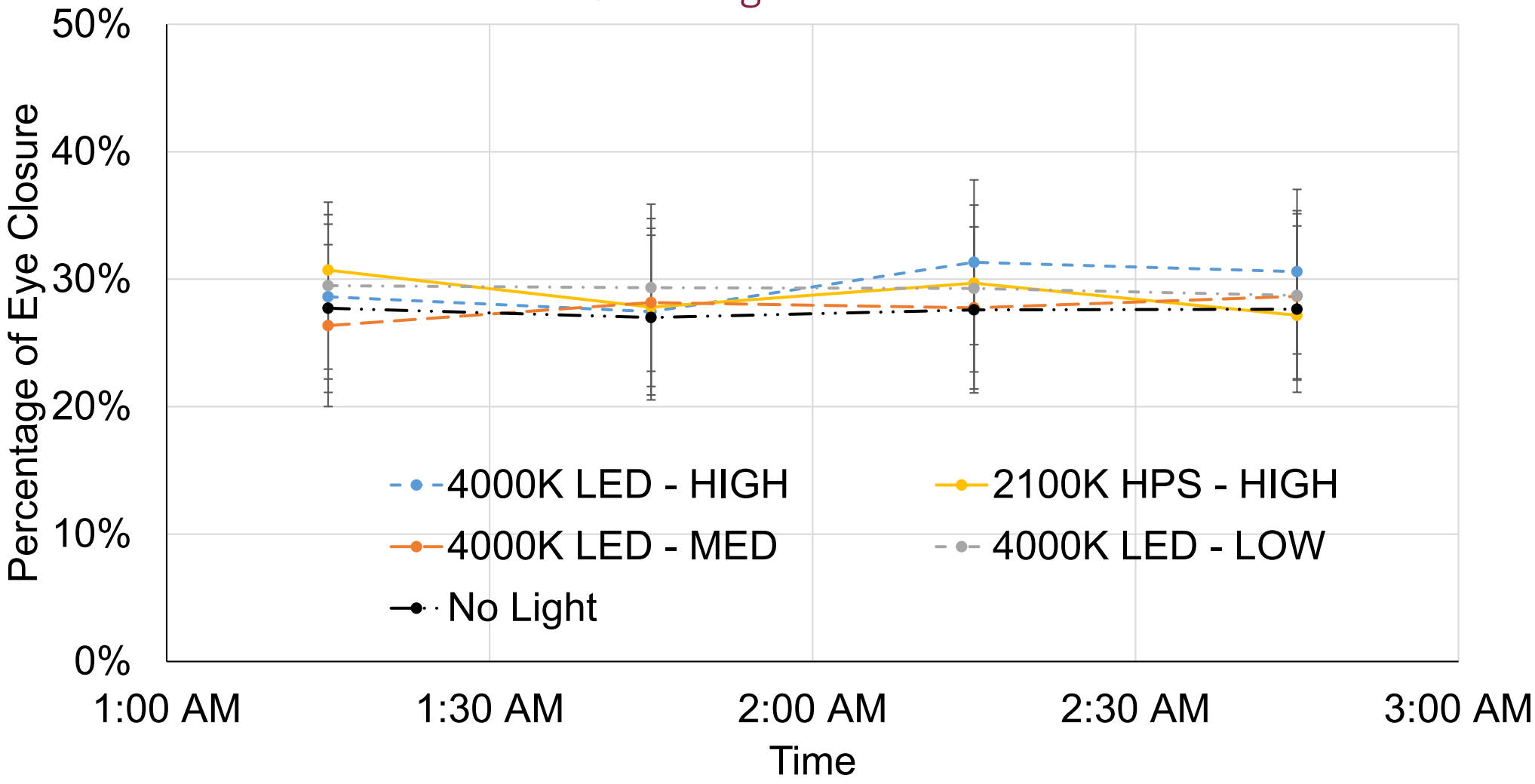




Results – Alertness – PERCLOS

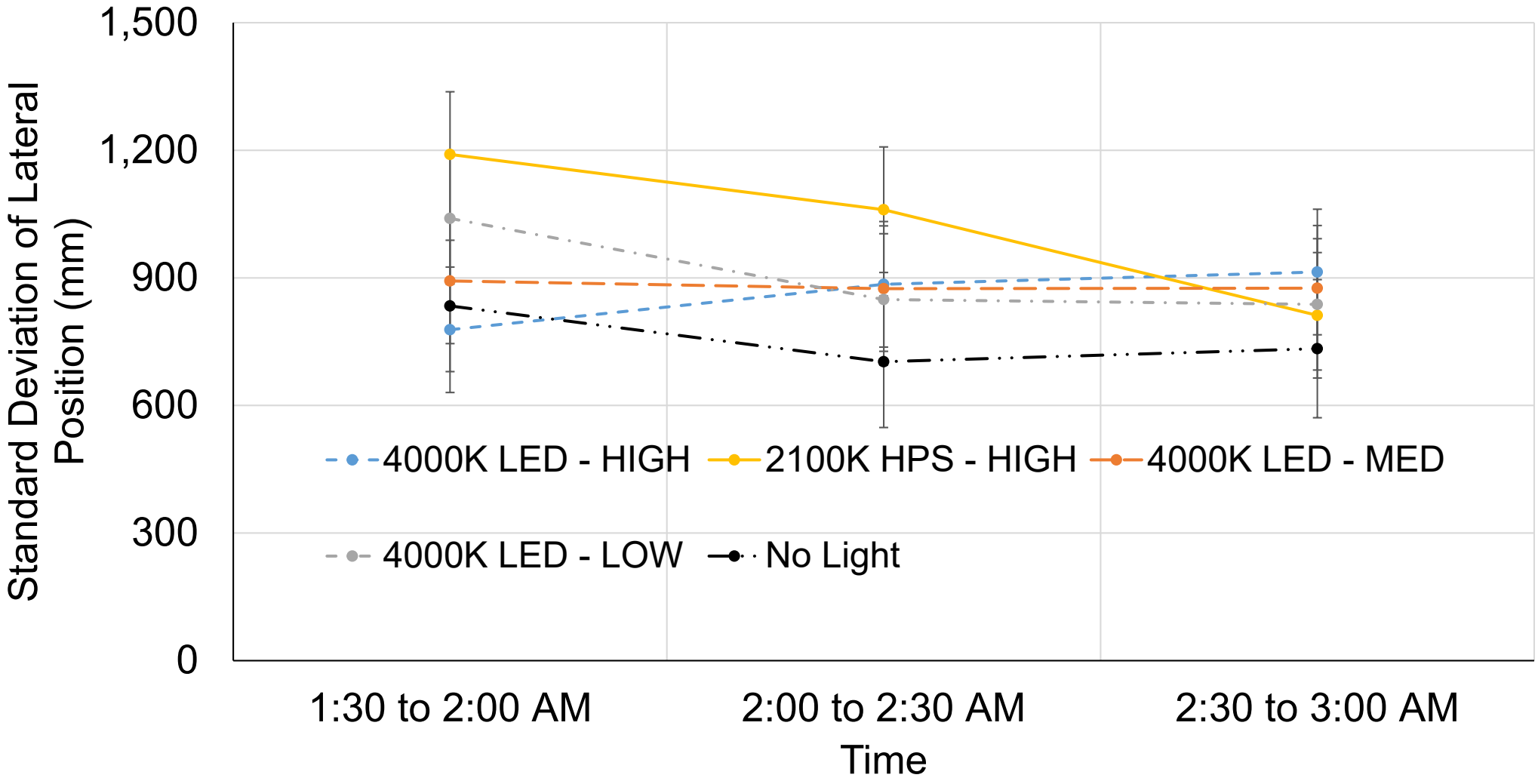
No differences across all light conditions

PERCLOS > 12% is a sign of drowsiness



Results – Vehicle Control – Standard Deviation of Lateral Position

No statistical differences across all conditions



CONCLUSIONS

MELATONIN SUPPRESSION

- LED roadway lighting even does not significantly suppress salivary melatonin between 1:00 AM to 3:00 AM in healthy drivers.
  - At levels that are higher than specified in the IES RP-8-18
- No statistical differences in between LED and HPS roadway lighting
  - At the same light level (roadway luminance of 1.5 cd/m^2 or a corneal illuminance of 1.9 lux).
- No statistical differences between any LED and HPS roadway lighting condition and the roadway without roadway lighting

ALERTNESS

- Under HPS lighting visual performance decreased over time
  - Not observed in LED or no lighting
- No increase in alertness in any lighting conditions (HPS, LED or No light)
  - PERCLOS
  - Sleepiness
- Potential for melatonin suppression from consumer electronic devices is considerably higher than LED roadway lighting

IMPORTANT CONSIDERATIONS

- Roadway lighting (LED and HPS) does have a detrimental effect on sky glow, light pollution, flora and fauna → Minimize the impacts
- This study assessed only salivary melatonin suppression under roadway lighting conditions → Future studies should assess plasma melatonin
- Other metrics such as sleep efficiency, duration, and quality should be measured relative to roadway lighting conditions
- Future studies should include higher street lighting levels observed in some urban communities
- Only acute effects measured - long term effects unknown

CONSIDER LIGHT AS A MEDICINE

- Right Amount
- Right Time
- Right Location
- Adaptive Lighting
  - Dimming during periods of low use

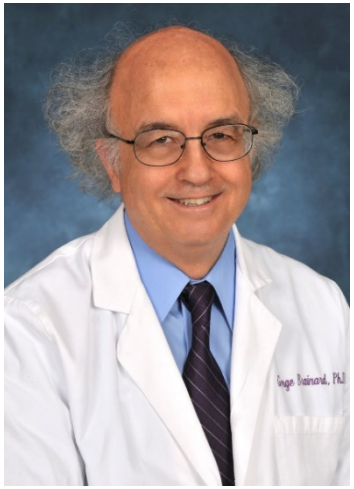
THANK YOU!

QUESTIONS?

RAJ@VTTI.VT.EDU

Today's Panelists

Moderator: Ron Gibbons,
Virginia Tech Transportation Institute



George Brainard,
Thomas Jefferson University

Rajaram Bhagavathula,
Virginia Tech Transportation Institute

John Hanifin,
Thomas Jefferson University

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