

Investigating the Health Impacts of Outdoor Lighting

A Partnership of
The Virginia Tech Transportation Institute and
Thomas Jefferson University

Background

- There is a strong link between light and melatonin level
 - Impacting sleep, alertness, general health
- Highly Dependent on Dosage
 - Spectral
 - Quantity / Timing

The Question

- What is the impact of Roadway Lighting on the Melatonin Levels?
 - There is a threshold where the Melatonin (DLMO) is no longer impacted
 - Laboratory based measurements (Full Field View)
 - This has never been measured in a Naturalistic Lighting Environment

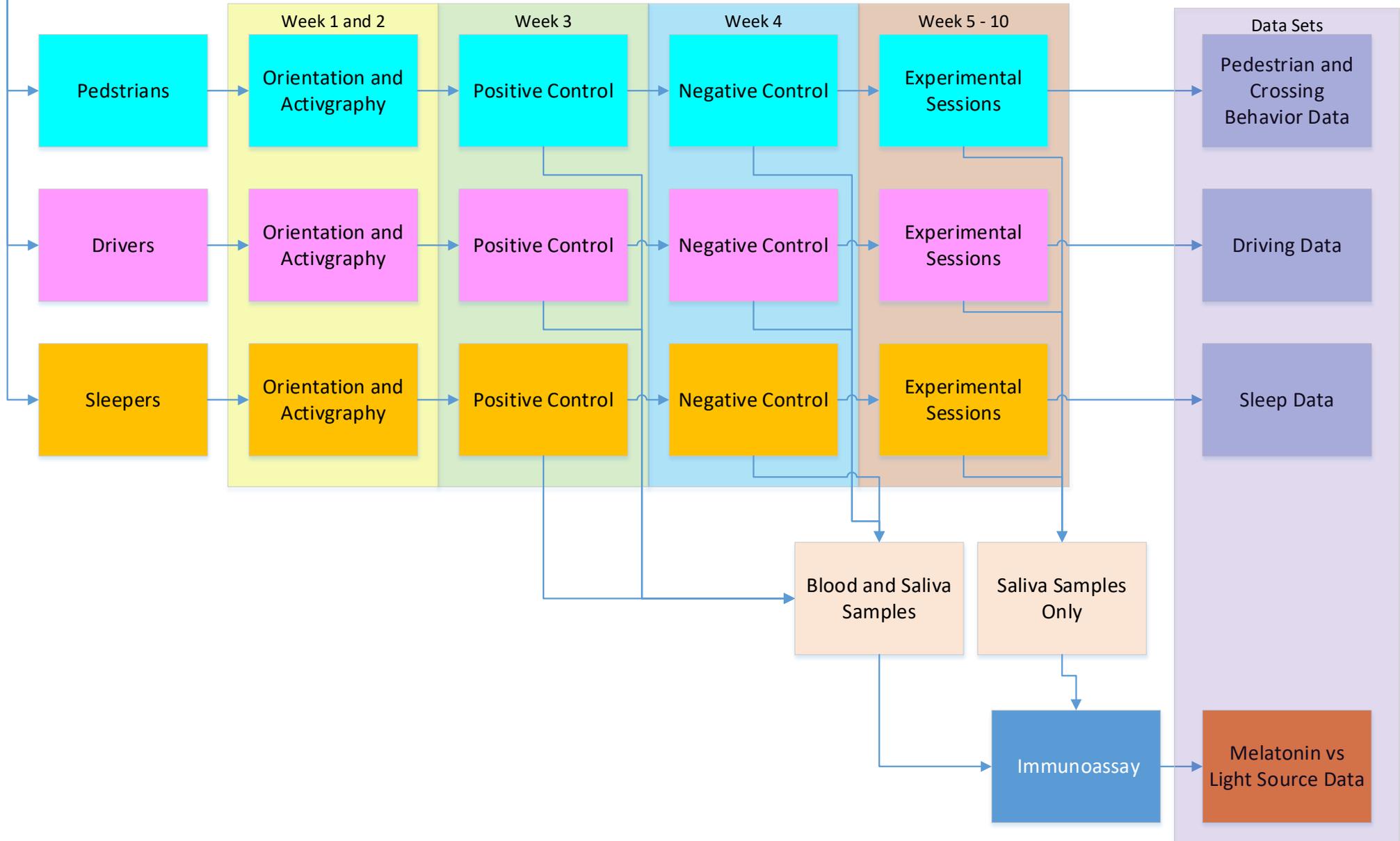
Who is impacted?

- All roadway Users:
 - Drivers on a roadway
 - Pedestrians
 - those living close to the lighted area (Sleepers)

Project Objective

- This project will measure the impact of different lighting types on melatonin in the blood of users of a lighted space at dosage levels appropriate to that space.
 - Not full field
 - No fixed observation point

Initial Screening



Experimental Design

Independent Variable	Luminaires to be tested
Lighting Type	No roadway lighting, 2100K HPS 2700K LED 4000K LED 5000K LED 6500K LED
Exposure Time	Between 1.5 and 6 hours, depending on the task

Independent Variables

- Luminaires:
 - Five different light sources will be tested each of differing spectral content.
 - Luminaires will be evaluated in terms of the circadian and neuroendocrine phototransduction of the intrinsically photosensitive retinal ganglion cell (ipRGC) system (melanopic, rhodopic, cyanopic, chloroptic and erythopic as per Lucas et al., 2014) and CCT using custom-developed software
- Activities:
 - Driver
 - Will be Driving a vehicle on the Smart Road for 2 hours
 - Pedestrian
 - Will be performing a crossing task and enjoying the outdoor space for 4 hours
 - light trespass
 - Will be Sleeping in a building for 2 hours

Dependent Variables

- Primary Data set:
 - Concentration of melatonin for the participant in each of the lighting conditions.
 - measured over an exposure time based on the participant type.
- Secondary Data sets :
 - For drivers, the detection distances of a series of visibility objects will be recorded as part of a visibility experiment.
 - For pedestrians, the perception of how safe it is for a person to cross the road in front of an opposing vehicle will be measured.
 - For sleepers, the sleep time will be recorded (using Actigraphy)

Controlled Variables

- Roadway Luminance will be maintained at (1.0 cd/m²)
- The experimental time, start time, duration and light exposure times will be controlled
- The participant age, sleep cycle, and daily activity will be monitored and controlled.
- The on-road and in experiment activities will be controlled while the participants are in the experiment area.
- Light exposure from the beginning to the end of the experimental period will be measured and controlled.

Participants

- 11 participants will be recruited to participate in each of the study's three exposure experiments (a total of 33 participants).
 - Between the ages of 18 and 30 years, gender balanced, non-smokers
 - Maintain a normal sleeping schedule monitored using logs and actigraphy
 - Avoid substances containing alcohol (24 hours) and caffeine (after midday)
 - No napping after 6:00 p.m.
 - Use an eyeglass frame mounted light measurement system to record exposure

Experimental Setup

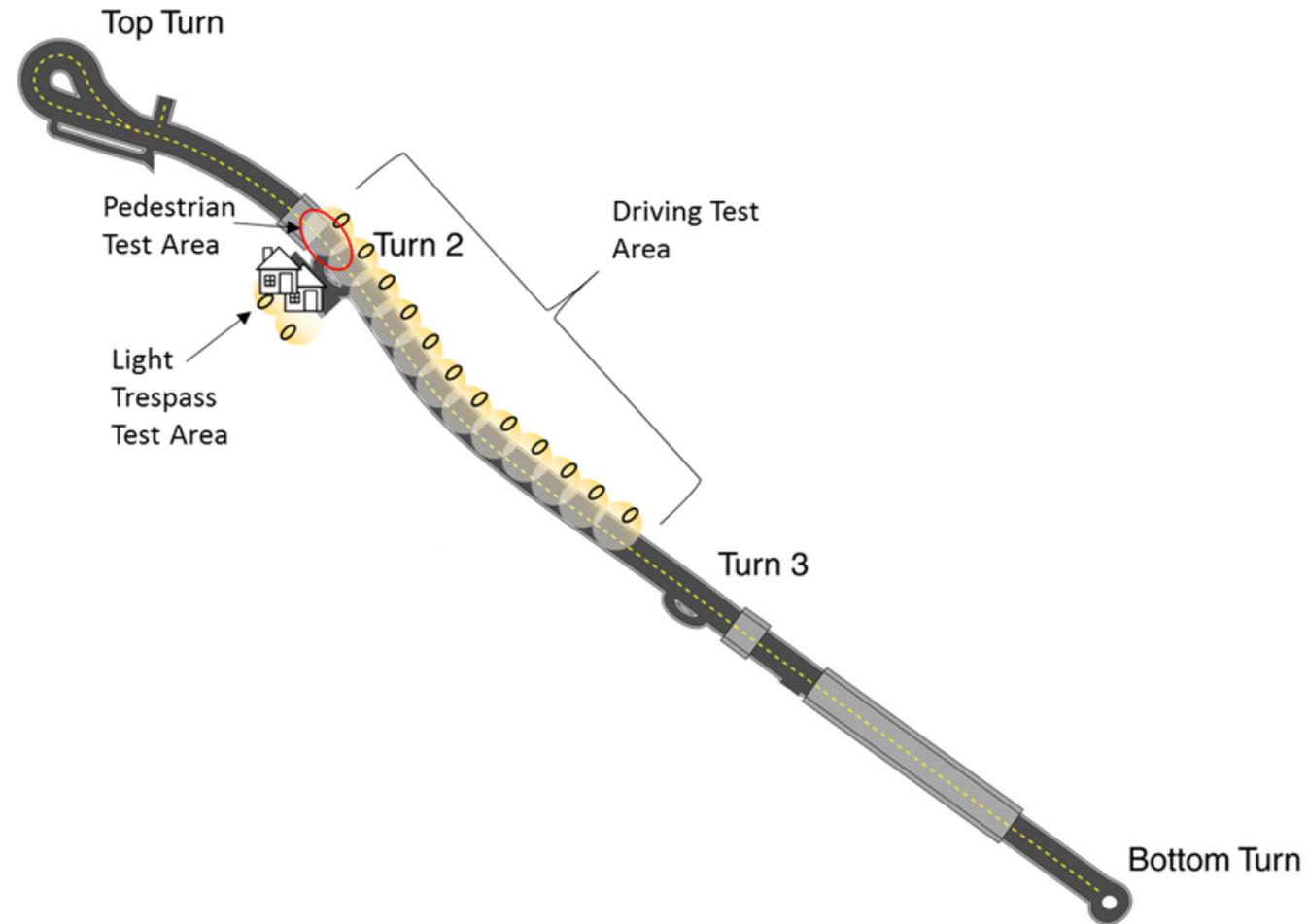
- Project will have three focus areas :
 - Conducted on the Virginia Smart Road.
- The primary purpose of this task is to develop the experimental conditions on the Smart Road.
 - Installing new roadway lighting luminaires at the facility,
 - Photometrically characterizing the installations to ensure compliance to standards (Middle of the IES Range)
 - Exemplar housing structure with a bedroom will be constructed within 40 feet of the Smart Road.
 - Bedroom light level will be measured and controlled
- Development and submission of the Institutional Review Board (IRB) application for this project.
 - Milestone: Smart Road lighting setup (8 months after contract award)
 - Go/No-Go Decision Point: Complete Smart Road setup and IRB approval (8 months after contract award)

Smart Road

- Variable lighting section
 - 39 light towers
 - ~95% of lighting configurations found on U.S. highways
 - Differential spacing
 - Height adjustable
 - Intelligent Transportation Systems (ITS) equipment
 - 3 luminaires/poles
 - Varying intensities



Smart Road Test Areas



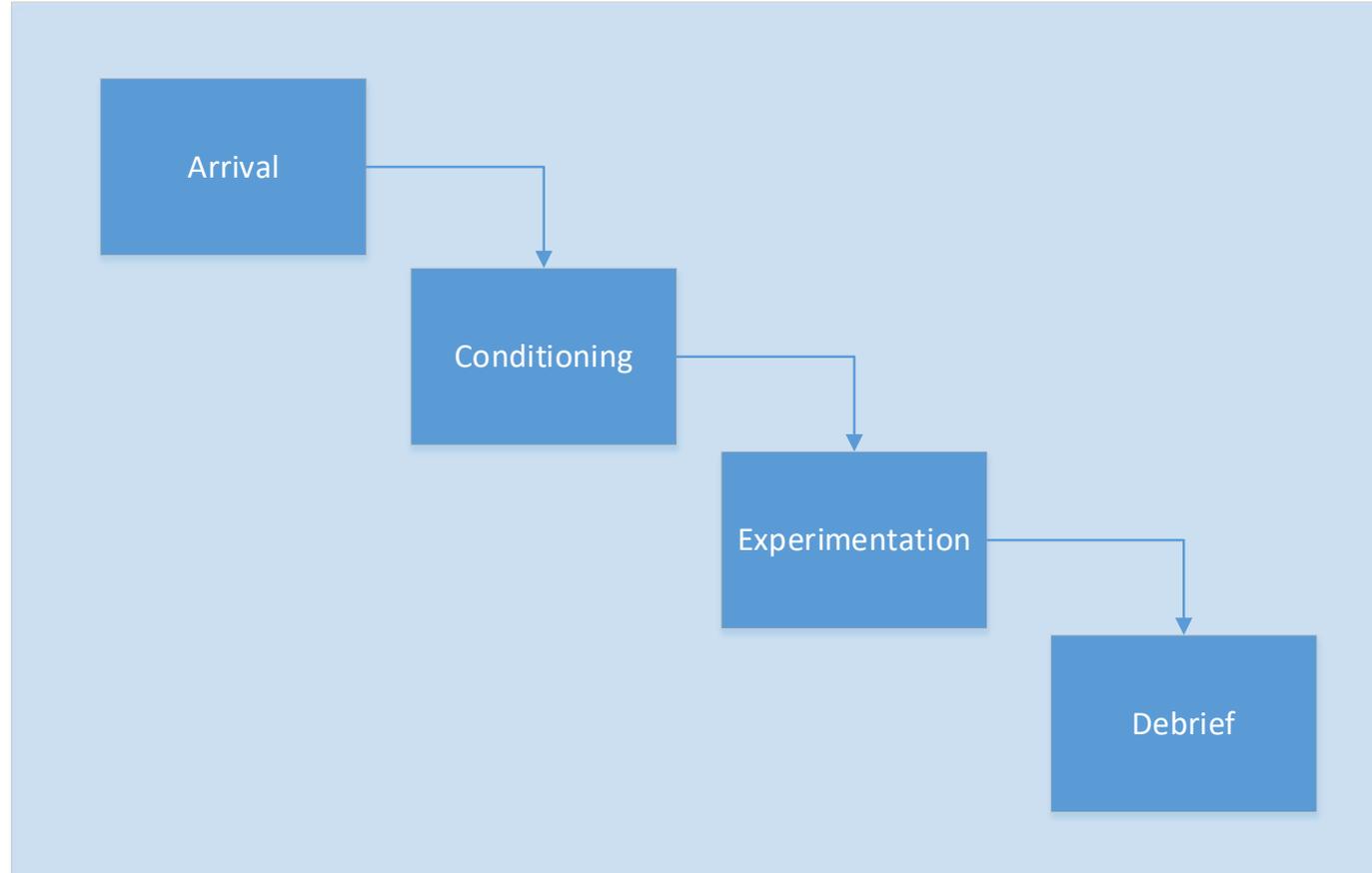
Test Methods

- 2 Test Methods will be performed
 - Positive and Negative Control
 - Positive and negative controls of melatonin secretion will serve as reference points to compare the melatonin levels in the three experimental scenarios
 - Positive control is to strongly suppress the dim light melatonin onset (DLMO) and peak melatonin secretion.
 - Negative control is to allow the normal onset of DLMO in the evening and the first half of peak melatonin secretion.
 - Naturalistic Exposure Testing
 - Testing of light performance under a variety of Blue Content Lighting systems

Testing Methods

- Two approaches to melatonin sampling will be undertaken. Blood and saliva.
- Plasma and saliva sampling
 - In control studies:
 - blood samples (2–3 ml) will be collected every 30–60 minutes through an indwelling intravenous catheter located in a forearm vein.
 - In control studies, saliva samples (1–2 ml) will be taken at the same time as blood draws to serve as backup for the measurement of plasma melatonin should indwelling intravenous lines fail to flow.
 - Naturalistic testing conditions:
 - only saliva samples will be collected.
 - It should be noted that blood sampling is a by far more responsive evaluation of melatonin however saliva is much easier to sample.
 - Only saliva samples will be used in the exposure experiments to minimize the potential for issues in the field test environment.
- Melatonin assay
 - Blood and saliva samples will be analyzed for melatonin by radioimmunoassay

Experimental Session



Controls for Driving Experiment

Control	Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling
Positive	11 p.m. to 1 a.m.	2 hours	200 lux	Incandescent	No sampling
	1 a.m. to 3 a.m.	2 hours	1000 $\mu\text{W}/\text{cm}^2$	4000 K LED	Blood and saliva at 30-minute intervals
Negative	11 p.m. to 1 a.m.	2 hours	5 lux	4000 K LED	No sampling
	1 a.m. to 3 p.m.	2 hours	No light – Participants blindfolded		Blood and saliva at 30-minute intervals

Controls for Pedestrian Experiment

Control	Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling
Positive	8 p.m. to 10 p.m.	2 hours	200 lux	Incandescent	No sampling
	10 p.m. to 2 a.m.	4 hours	1000 $\mu\text{W}/\text{cm}^2$	4000 K LED	Blood and saliva at 40-minute intervals
Negative	8 p.m. to 10 p.m.	2 hours	5 lux	4000 K LED	No sampling
	10 p.m. to 2 a.m.	4 hours	No light – Participants blindfolded		Blood and saliva at 40-minute intervals

Controls for “Sleeper” Experiment

Control	Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling
Positive	10 p.m. to 12 a.m.	2 hours	200 lux	Incandescent	No sampling
	12 a.m. to 2 a.m.	2 hours	1000 $\mu\text{W}/\text{cm}^2$	4000 K LED	Blood and saliva at 40-minute intervals
Negative	10 p.m. to 12 a.m.	2 hours	5 lux	4000 K LED	No sampling
	12 a.m. to 2 a.m.	2 hours	No light – Participants blindfolded		Blood and saliva at 40-minute intervals

Naturalistic Testing

- Once the control sessions have been completed, the exposure sessions in which the effects of lighting are measured in a naturalistic environment
 - one lighting condition will be experienced each night
 - At least one week will pass between exposure sessions.

Driving Exposure Experiment

- Participants will drive the experimental vehicle from 1:00 a.m. to 3:00 a.m. at a speed of 35 mph. with Low-beam headlamps
- Participants will be given detection tasks (detection of small wooden targets of 18 cm × 18 cm or detection of pedestrians) to keep them engaged.
- Two participants at once.

Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling	Tasks
11 a.m. to 1 a.m.	2 hours	200 lux	Incandescent	No sampling	
1 a.m. to 3 a.m.	2 hours	1.0 cd/m ²	No roadway lighting 2100K HPS 2700K LED 4000K LED 5000K LED 6500K LED	Saliva at 30-minute intervals	Visibility assessment tasks

Pedestrian Exposure Experiment

- Participants will perform typical outdoor Tasks
 - sitting at a picnic table,
 - sitting on a bench on the side of the road, walking, and enjoying an outdoor café. Participants will perform these tasks for three hours
 - Perform a gap acceptance crossing estimation task

Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling	Tasks
8 p.m. to 10 p.m.	2 hours	200 lux	Incandescent	No sampling	
10 p.m. to 2 a.m.	4 hours	1.0 cd/m ²	No roadway lighting 2100K HPS 2700K LED 4000K LED 5000K LED 6500K LED	Saliva at 40-minute intervals	Gap acceptance tasks, walking, sitting at a table, etc.

Light Trespass Exposure Experiment

- Participants will experience the road in bed:
 - A housing structure with a bedroom will be constructed within 40 feet of the lighted section of the road with one 5 ft x 3 ft window with no window shades.
 - Two participants at once.
 - The participant will be instructed to face the window in a lying position with their eyes closed.
 - Using Actigraphy, we will record if the participant sleeps

Time of Exposure	Duration of Exposure	Light Level/ Corneal Irradiance	Light Source	Blood/Saliva Sampling	Tasks
10 p.m. to 12 a.m.	2 hours	200 lux	Incandescent	No sampling	
12 a.m. to 2 a.m.	2 hours	Maximum light trespass allowed by IES RP-8-14	No roadway lighting 2100K HPS 2700K LED 4000K LED 5000K LED 6500K LED	Saliva at 40-minute intervals	Participants will lie on the bed in the simulated bedroom.

Analysis

- A linear mixed model analysis will be used to assess the effects of lighting type on melatonin level in each of three experiments.
- The analysis is expected to provide insights into the overall effect of light exposure on the melatonin levels of drivers on the roadway, pedestrians, and homeowners with bedrooms exposed to street lighting.

Expected Results

- A complete reporting of all of the activities in this research effort will be prepared
 - Peer Reviewed Papers
 - Reports