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Tracking human light exposure, health and wellbeing using data-logging sensors and smartwatches—a pilot study

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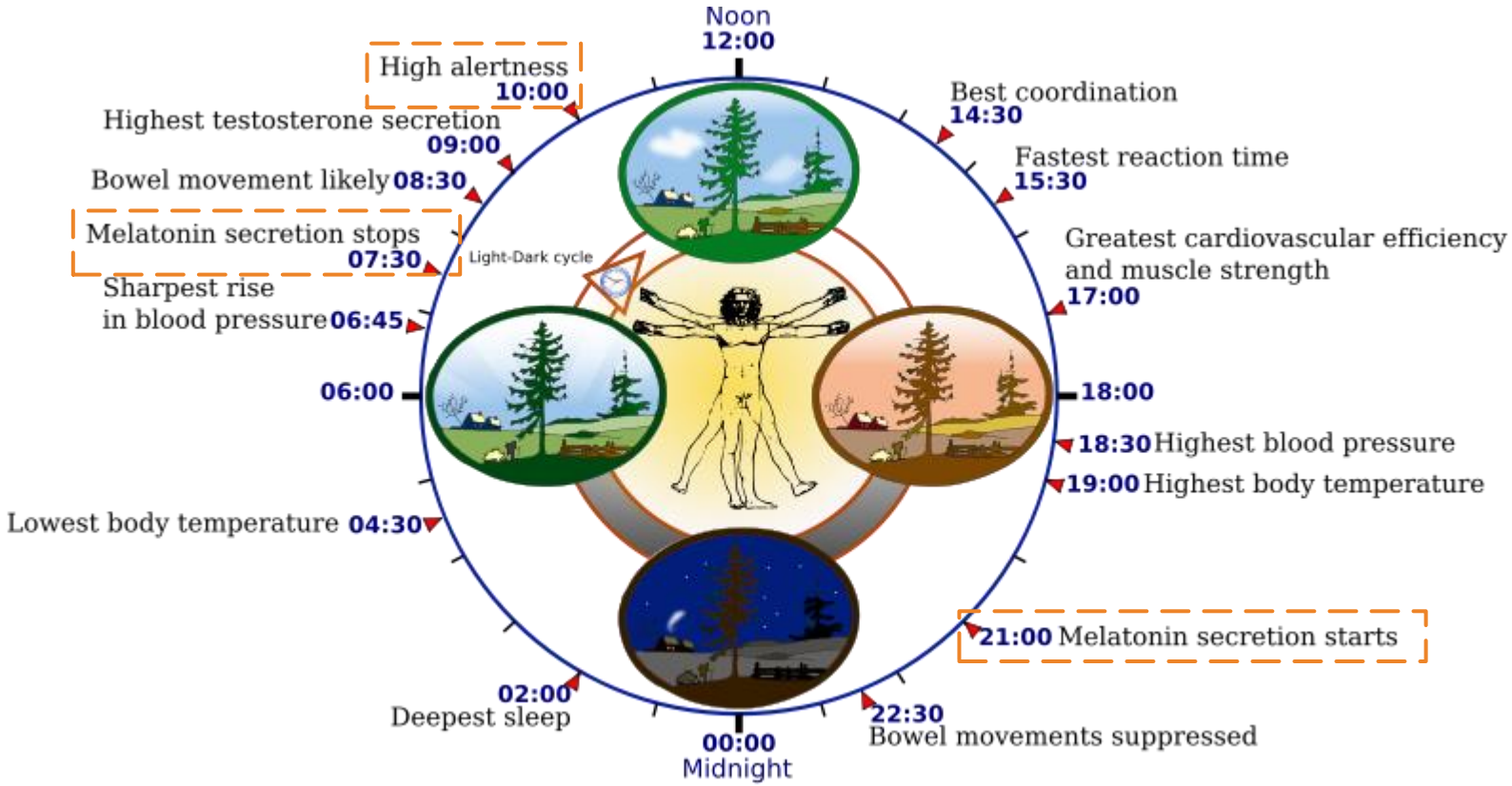
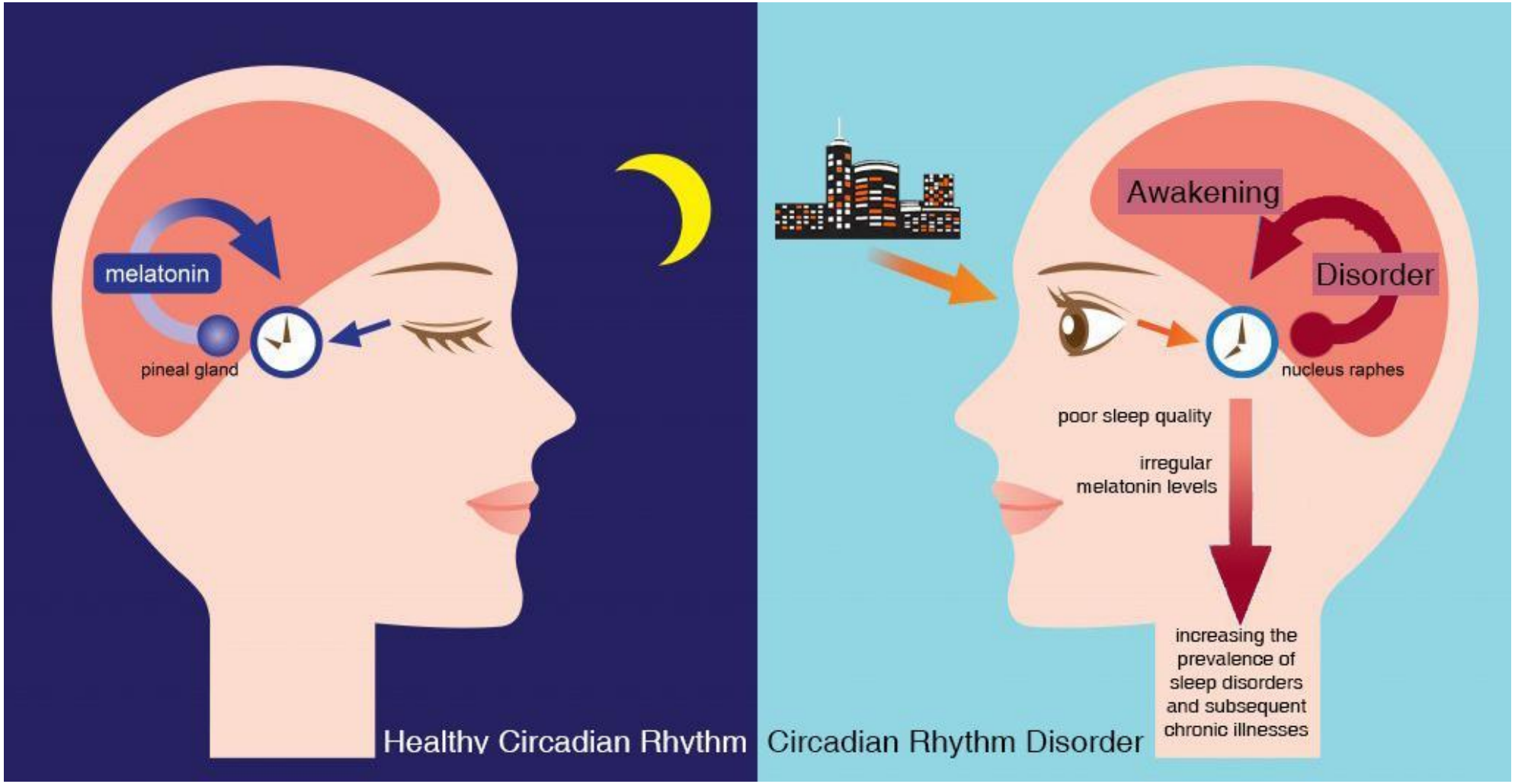
Circadian Rhythms

- A **24-hour cycle** in the biochemical, physiological or behavioural processes.
- Can be entrained by external cues such as **daylight**.
- Important in determining **sleeping** and feeding patterns.
- Plays a role in the measurement and interpretation of day length.
- Linked to core body temperature, brain wave activity, hormone production and cell regeneration.
- Vital in the production of **Melatonin**.



"The Body Clock Guide to Better Health" by Michael Smolensky and Lynne Lamberg; Henry Holt and Company, Publishers (2000)

Impact of Circadian Rhythm on Health

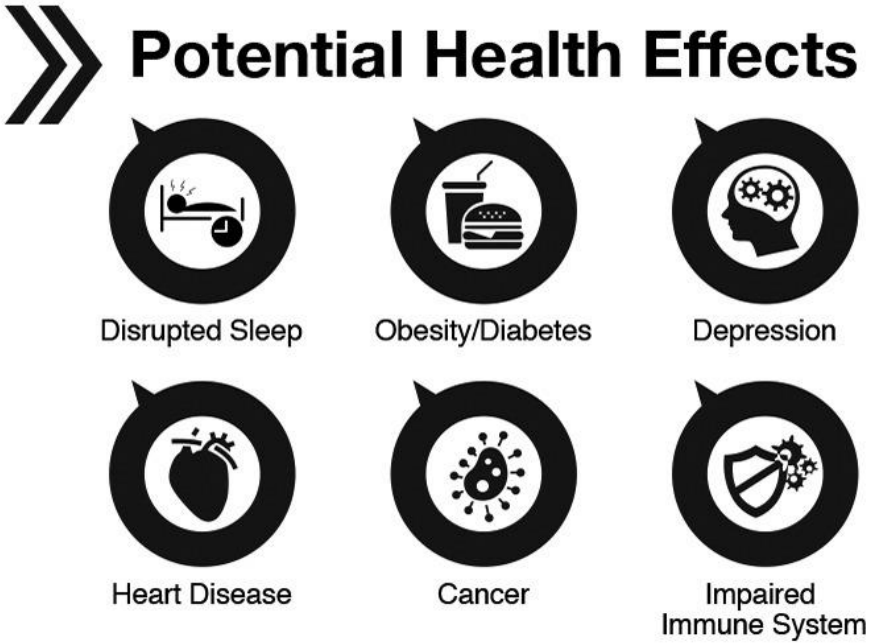


Source: https://sitn.hms.harvard.edu/flash/2020/i-cant-sleep-can-you-turn-off-the-lights/

Health Risks of Disrupted Circadian Rhythms

Greater night light exposure is associated with increased risk for:

- Depressive disorder
- Anxiety disorder
- PTSD
- Psychosis
- Bipolar disorder
- Self-harm behavior



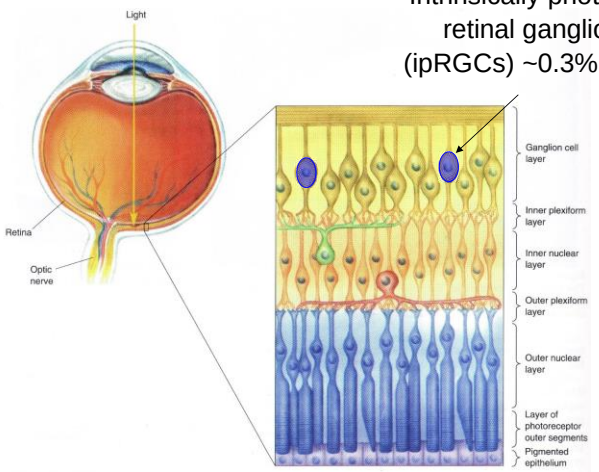
(Source: Lunn et al., 2017)

‘Non-Visual’ Photoreception

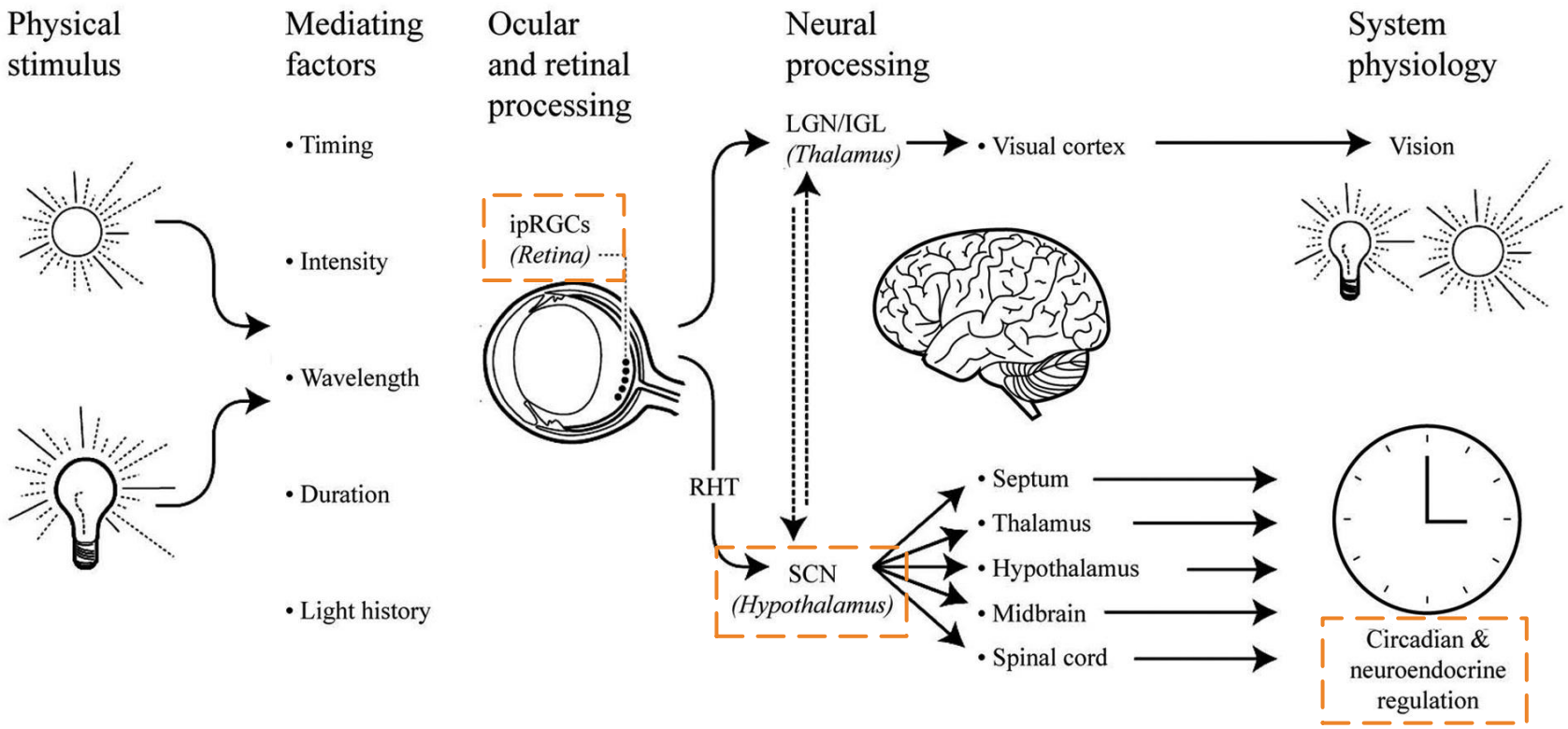
Intrinsically Photosensitive Retinal Ganglion Cells (ipRGCs)

- Discovered in 2002.
- Turns light energy directly into brain signals.
- Important in determining sleeping patterns.
- Contribute to regulation and suppression of Melatonin.
- Absorbs light mainly in the blue wavelength.

Melanopsin – containing Intrinsically photosensitive retinal ganglion cells (ipRGCs) ~0.3% of all GCs



(Source: Hattar et al., Science 2002)

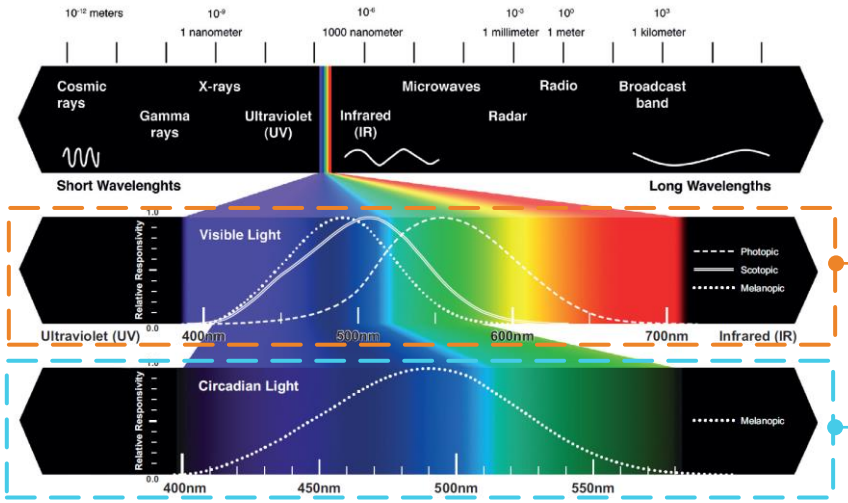


(Vetter et al., 2021)

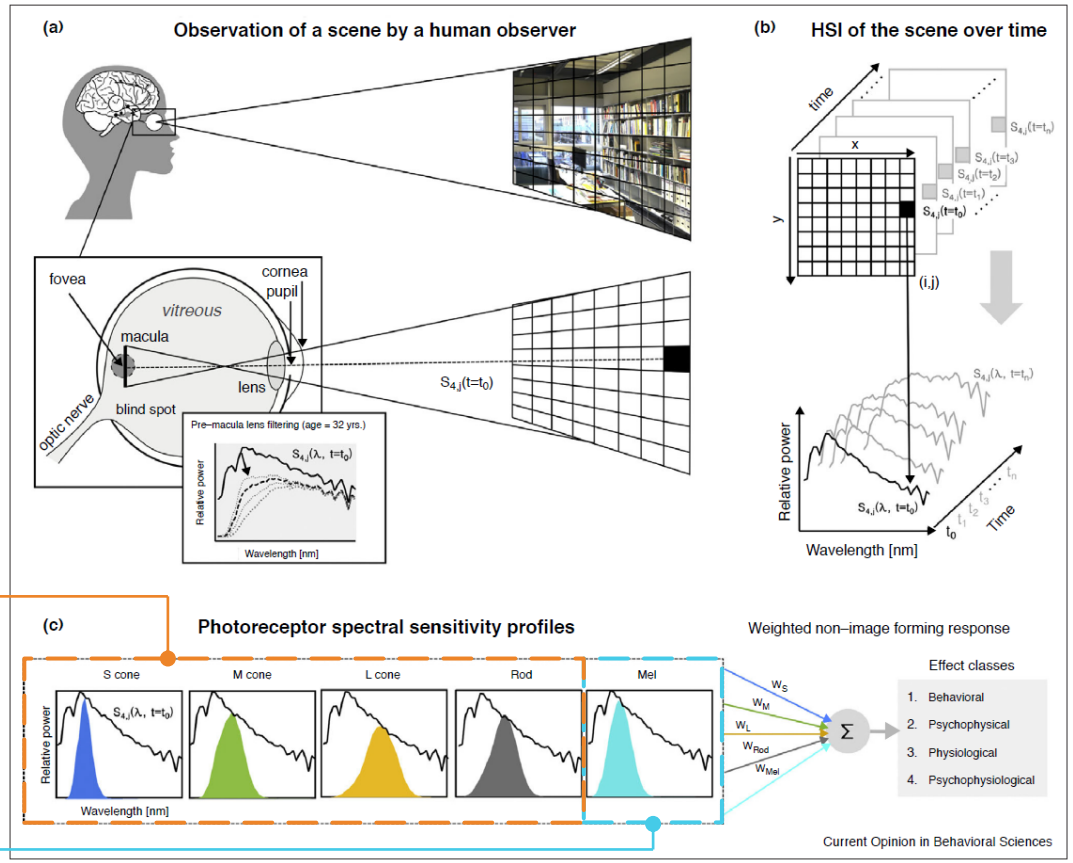
‘Non-Visual’ Photoreception

Properties of light affecting non-visual photoreception

- Intensity
- Timing
- Duration
- Pattern
- Light history
- **Wavelength**



Visible light spectrum vs circadian light spectrum as defined by photopic sensitivity range and melanopic sensitivity range respectively. (Altenberg, 2019)



Overview of the human visual system’s response to a scene over the spectral range and over time. (Webler et al., 2019)

New metrics arise from ipRGC light responses

- Quantifiable metrics to capture light's effects on ipRGC cells:
  - Melanopic irradiance
  - Equivalent melanopic lux (EML)
  - Melanopic-to-photopic light ratios
- Predict daylight's non-visual effects
- Evaluate built environments

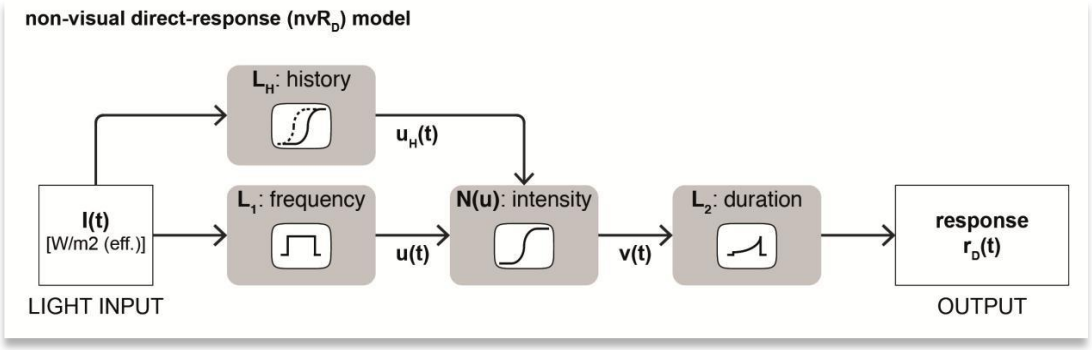
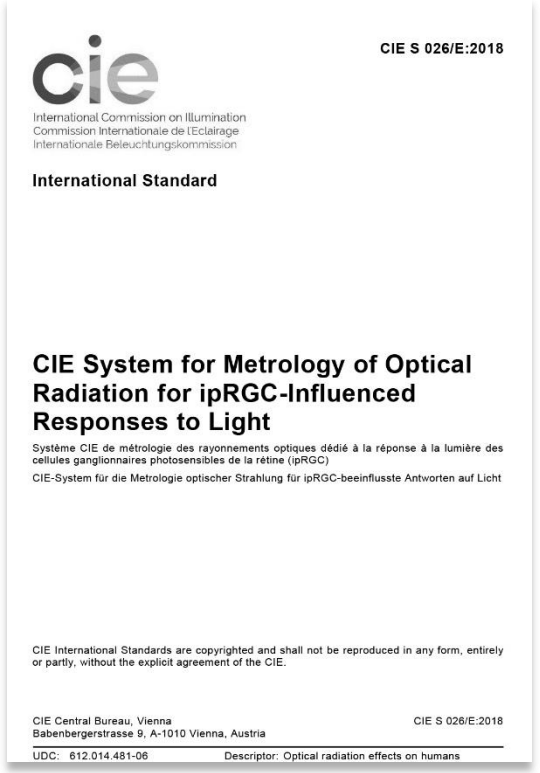


Diagram of the nvRD model. (Amundadottir et al., 2017)


CIE S 026/E:2018

International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

International Standard

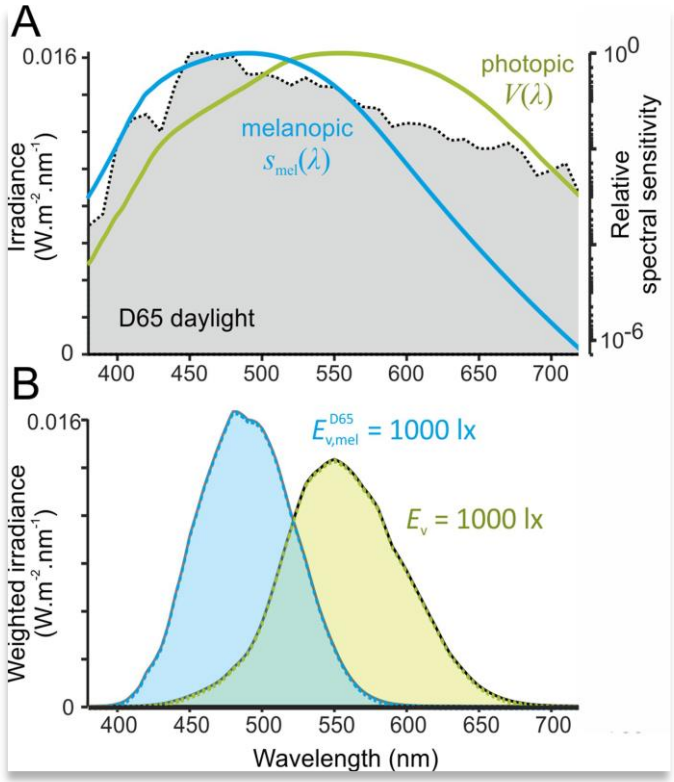
CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light

Système CIE de métrologie des rayonnements optiques dédié à la réponse à la lumière des cellules ganglionnaires photosensibles de la rétine (ipRGC)

CIE-System für die Metrologie optischer Strahlung für ipRGC-beeinflusste Antworten auf Licht

CIE Central Bureau, Vienna
Babenbergerstrasse 9, A-1010 Vienna, Austria
CIE S 026/E:2018
UDC: 612.014.481-06 Descriptor: Optical radiation effects on humans

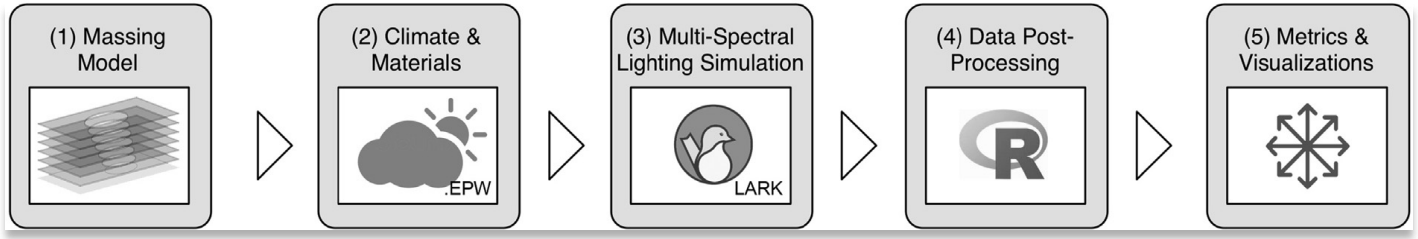
(International Commission on Illumination (CIE), 2018)



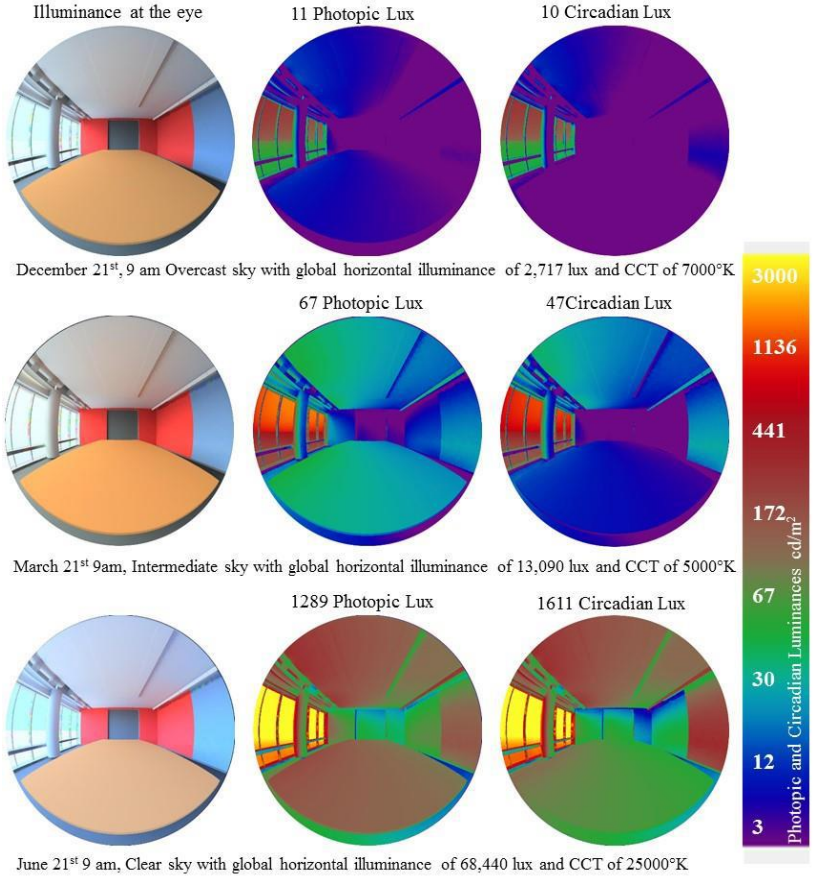
Differences in photopic and melanopic spectral sensitivity formalized in the SI-compliant system for quantifying ipRGC-influenced responses to light. (Brown et al., 2022)

Simulation Tools and Architectural Design for Optimal Lighting

- Enable lighting level adjustment
- Based on user preferences and needs
- Spaces that support circadian health
- Optimal building designs



Conceptual diagram of the design assist tool(CDAT). (Konis, 2019)



Photopic- and circadian-luminance distributions and illuminance values at the scene for 9 am at selected dates (view looking towards East) (Inanici et al., 2015)

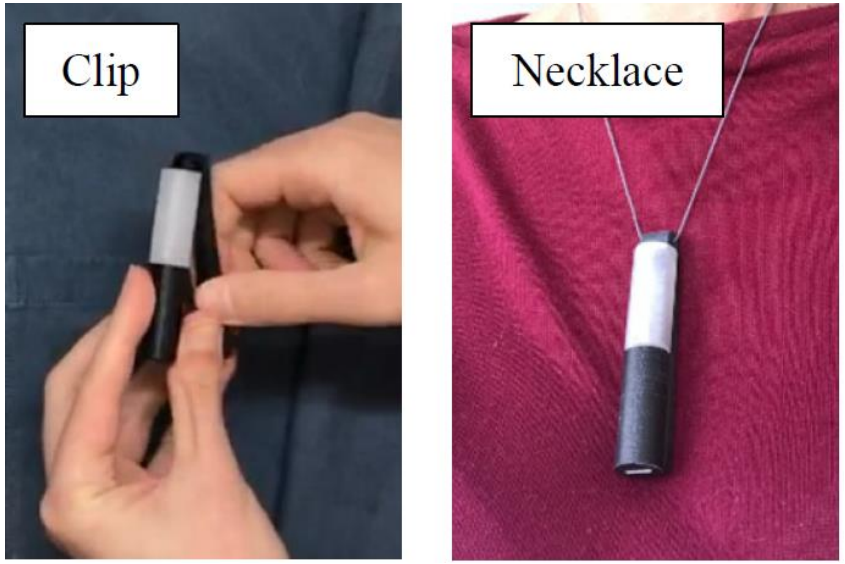
Wearable Sensors - light loggers and dosimeters

- Detailed tracking of personal light exposure in real-time settings
- More precise

LuxBlick light-dosimeter for measurement at eye-level.
(Hubalek et al., 2010)

Wearable corneal-plane α-opic light logger.
(Webler et al., 2021)

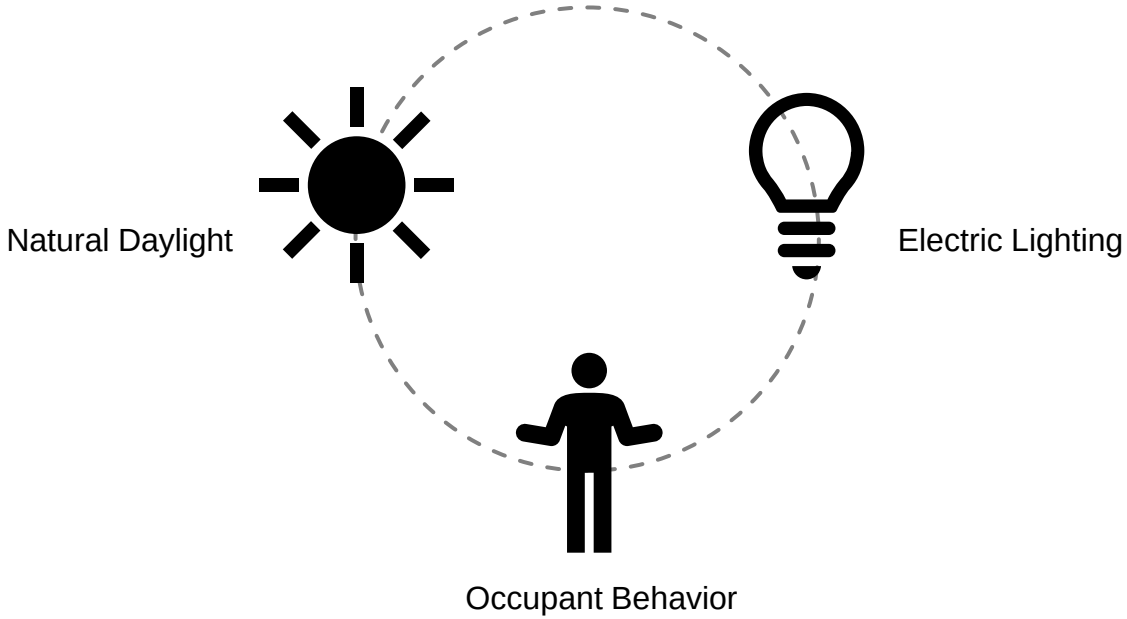
Photos of the watch-face using a Fitbit ionic, with the strap-pack sensor box. (Jayathissa et al., 2019)



Spectrace device components, and wearability options.
(Webler et al., 2021)

Methodology

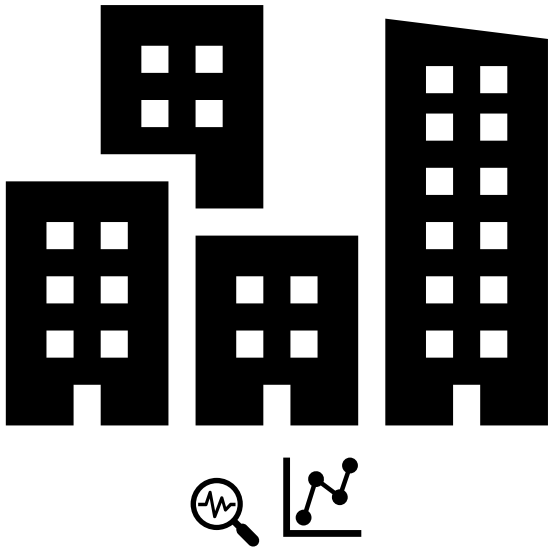
for field measurement of ipRGC-influenced lighting and its effects on humans



Human-Centric Lighting Assessment Methodology

Our Goals:

- Explore the temporal and spatial dimensions of light exposure
- Spaces based on user preferences and needs
- Spaces that support circadian health

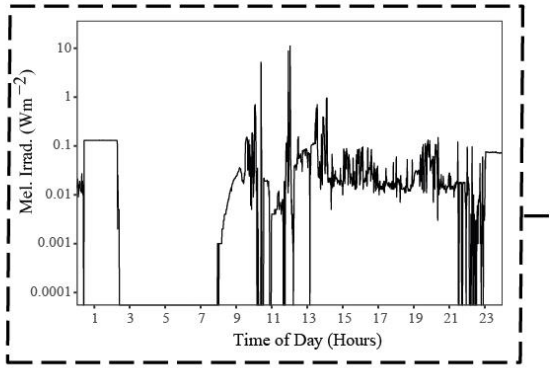


Shifting Lighting Analysis from Building Spaces…

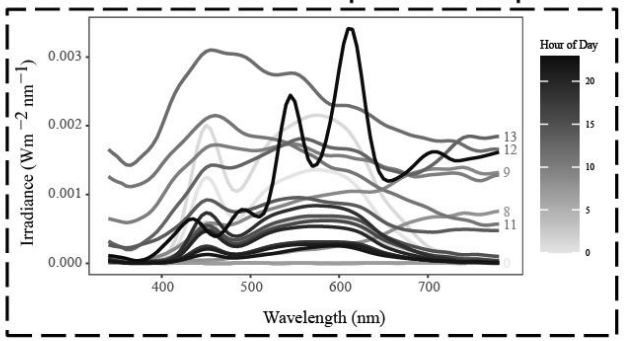
To

Transient Occupants

Continuous Data Collection Process and Methodology



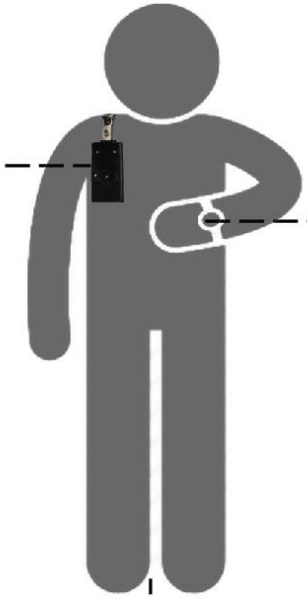
Melanopic Irradiances

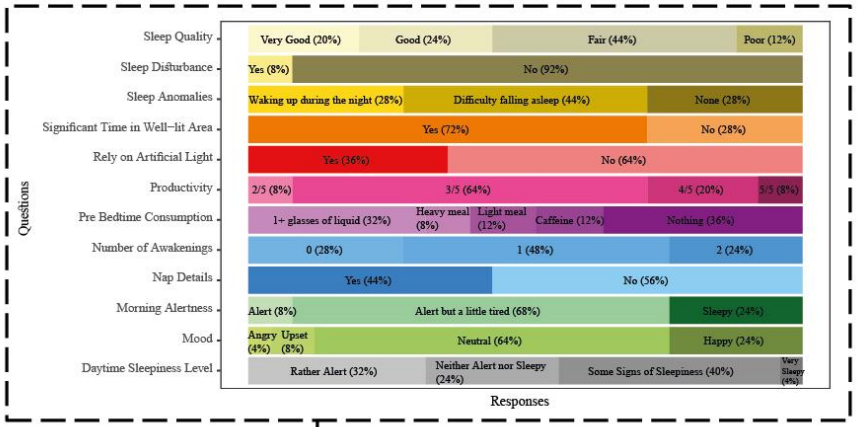


Spectral Irradiances

Survey Responses

Fitbit Smartwatch



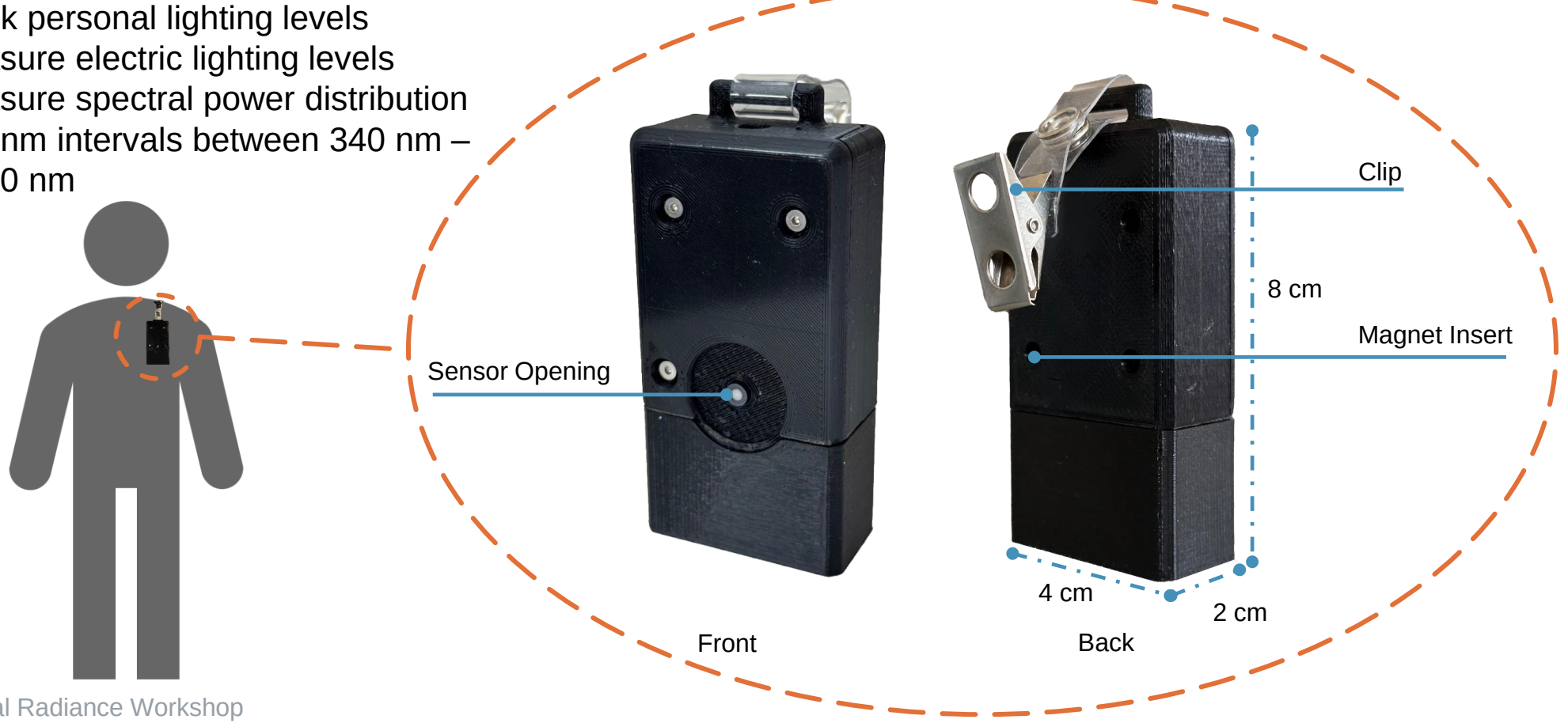


Daily Journal and Activities Schedule

Sensor and Measurement Device

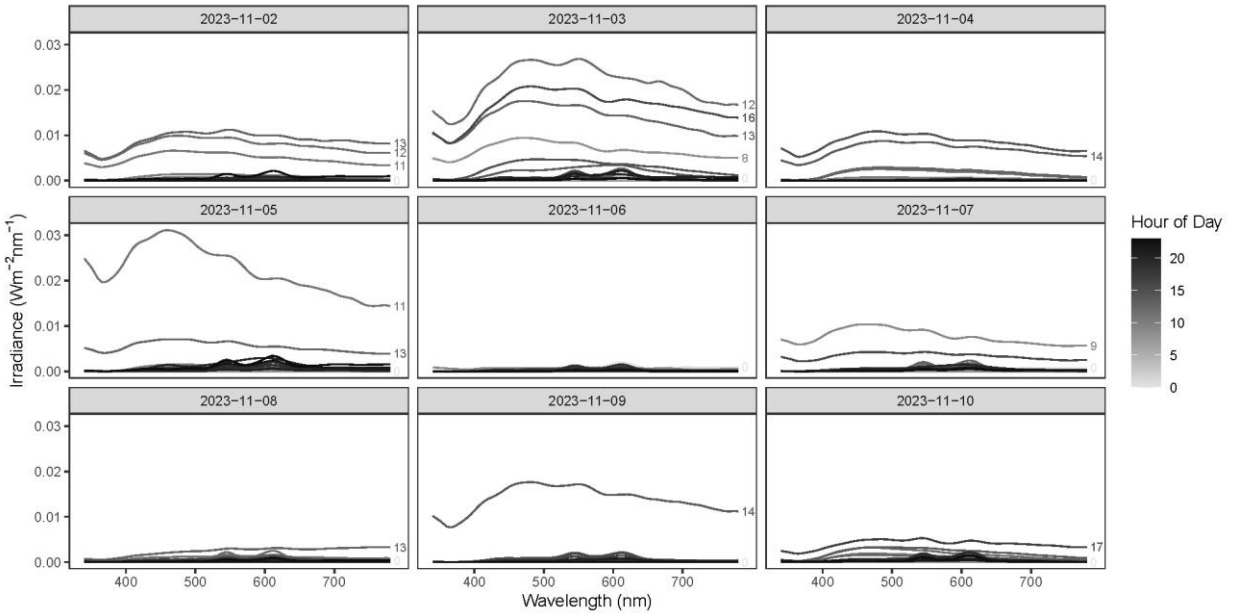
'Open Optical Spectral Irradiance Sensor' (OOSI Sensor)

- Data-logging melanopic irradiance sensor
- Track personal lighting levels
- Measure electric lighting levels
- Measure spectral power distribution at 5 nm intervals between 340 nm – 1,010 nm

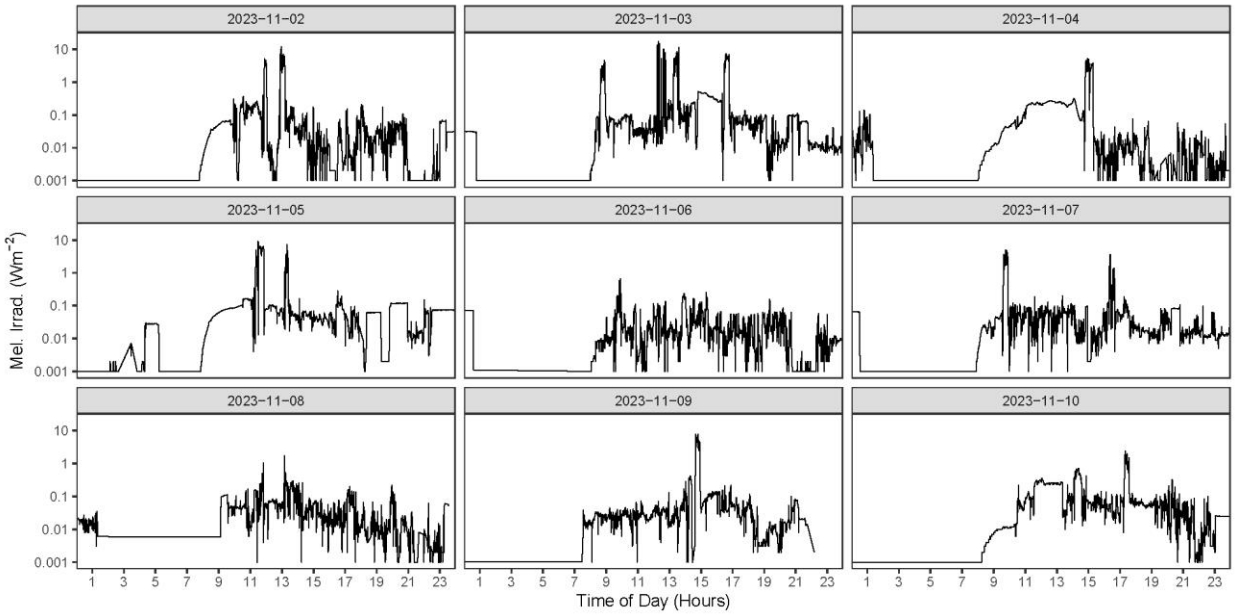


Selected Instantaneous Spectral Irradiances

- The sensor records the spectral light exposure every **1 minute** for **two weeks**.



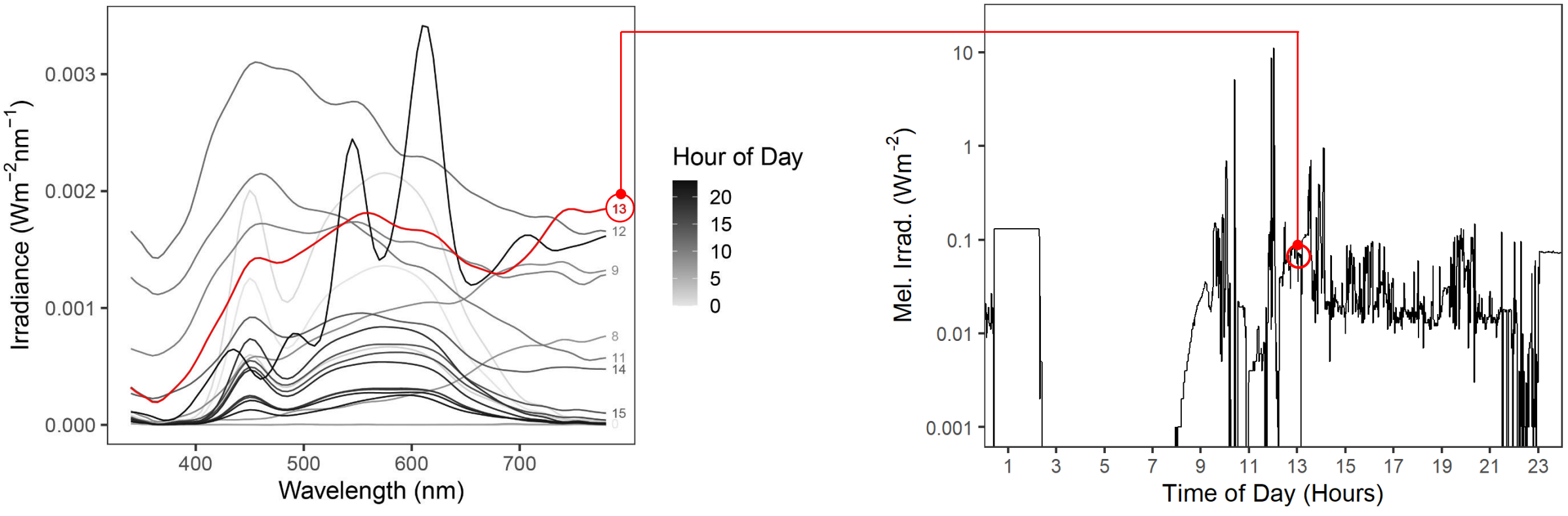
Spectral Irradiances



Melanopic Irradiances

Selected Instantaneous Spectral Irradiances

- How do the **timing**, **intensity**, and **quality** of light interact with human's daily life?

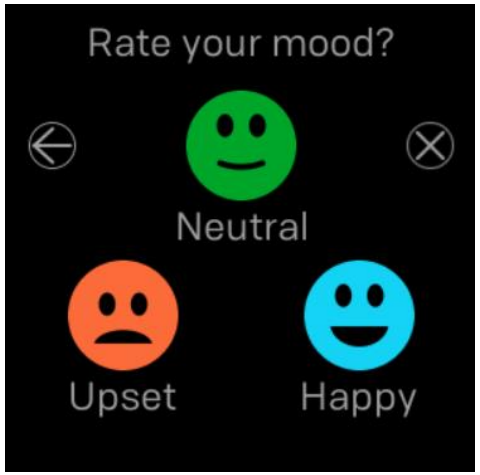


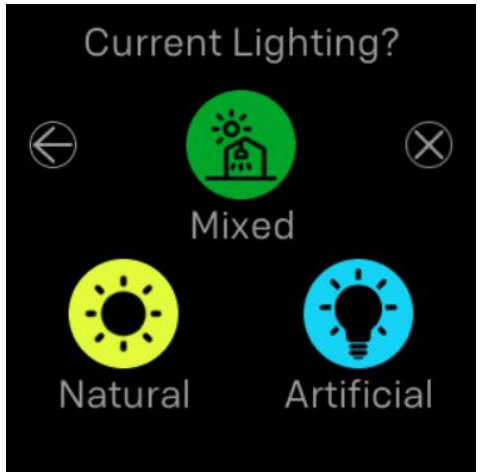
Spectral Irradiances

Melanopic Irradiances

Sample ‘Cozie Light' survey questions

- Track physical activity
- Track sleep patterns
- Track subjective wellbeing through periodic surveys

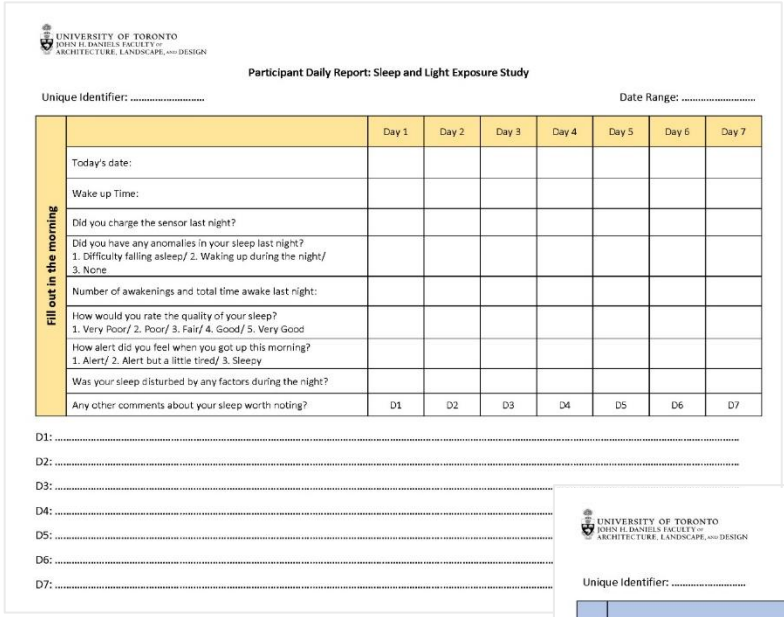




Demographic Information/ Daily Journal

Participants record their:

- Sleep patterns
- Light Exposure Experiences
- Alertness Levels and Mood
- General Locations



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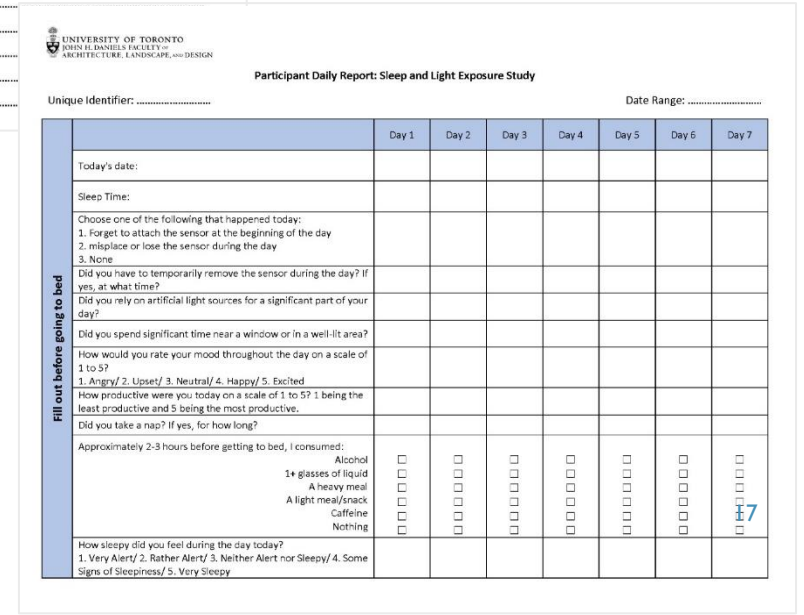
Participant Daily Report: Sleep and Light Exposure Study

Unique Identifier: ..... Date Range: .....

Fill out in the morning	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Today's date:							
Wake up Time:							
Did you charge the sensor last night?							
Did you have any anomalies in your sleep last night? 1. Difficulty falling asleep/ 2. Waking up during the night/ 3. None							
Number of awakenings and total time awake last night:							
How would you rate the quality of your sleep? 1. Very Poor/ 2. Poor/ 3. Fair/ 4. Good/ 5. Very Good							
How alert did you feel when you got up this morning? 1. Alert/ 2. Alert but a little tired/ 3. Sleepy							
Was your sleep disturbed by any factors during the night?							
Any other comments about your sleep worth noting?	D1	D2	D3	D4	D5	D6	D7

D1: .....
D2: .....
D3: .....
D4: .....
D5: .....
D6: .....
D7: .....



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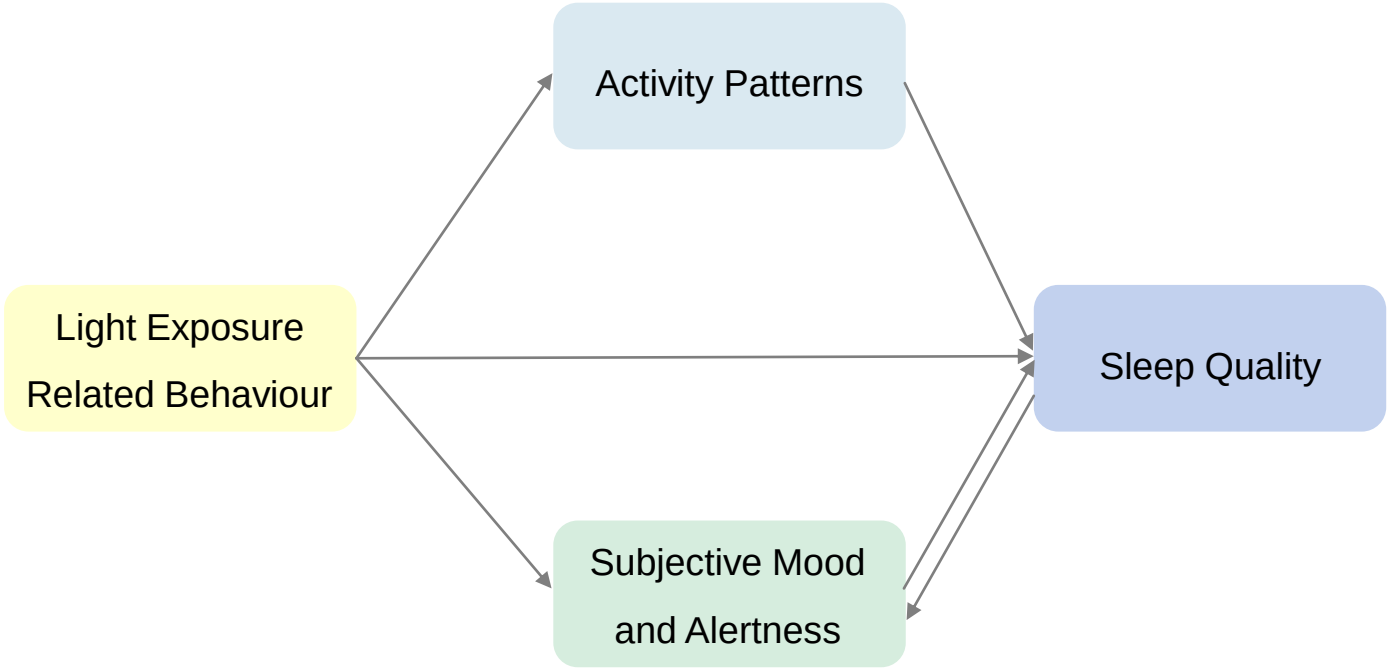
Participant Daily Report: Sleep and Light Exposure Study

Unique Identifier: ..... Date Range: .....

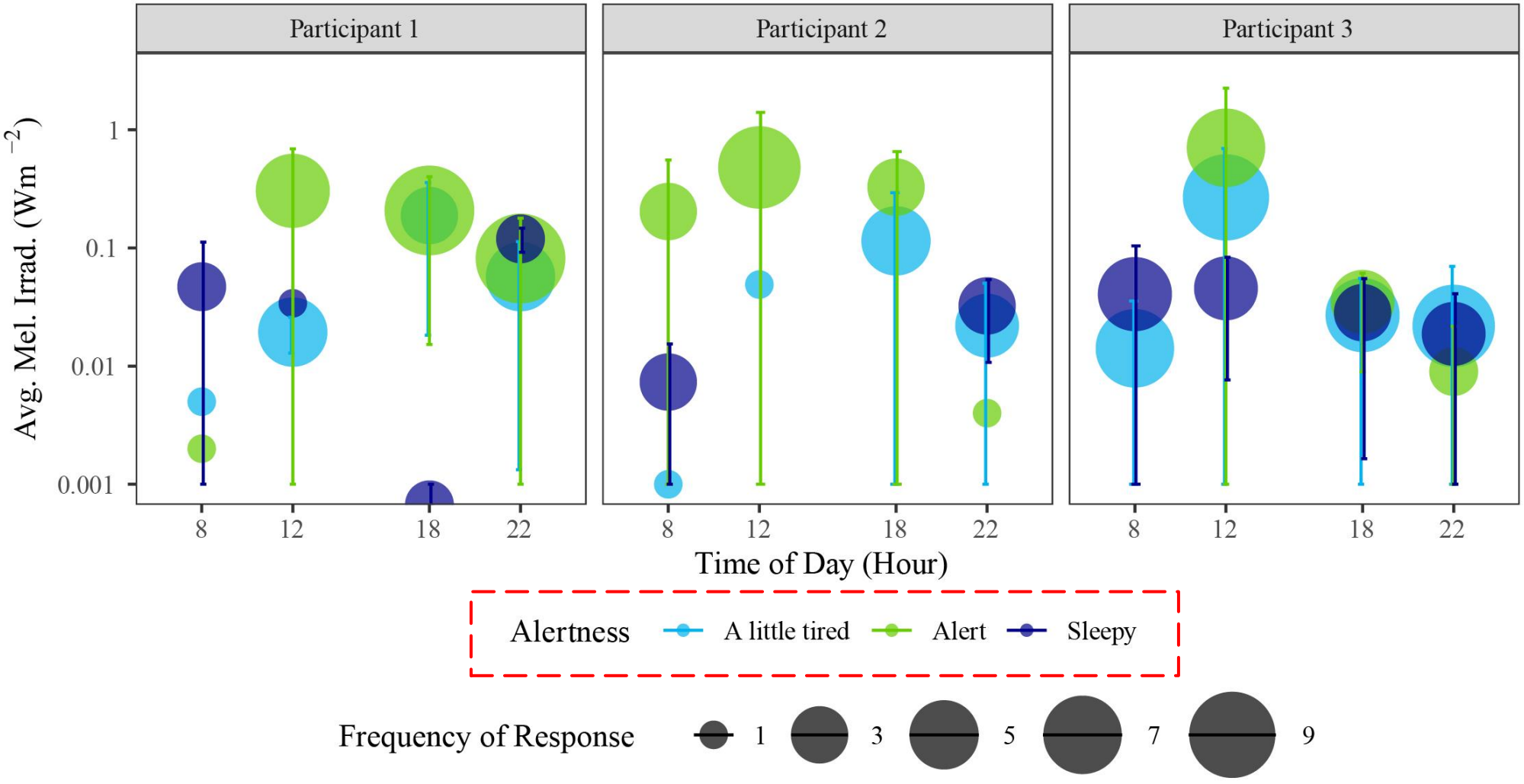
Fill out before going to bed	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Today's date:							
Sleep Time:							
Choose one of the following that happened today: 1. Forget to attach the sensor at the beginning of the day 2. misplace or lose the sensor during the day 3. None							
Did you have to temporarily remove the sensor during the day? If yes, at what time?							
Did you rely on artificial light sources for a significant part of your day?							
Did you spend significant time near a window or in a well-lit area?							
How would you rate your mood throughout the day on a scale of 1 to 5? 1. Angry/ 2. Upset/ 3. Neutral/ 4. Happy/ 5. Excited							
How productive were you today on a scale of 1 to 5? 1 being the least productive and 5 being the most productive.							
Did you take a nap? If yes, for how long?							
Approximately 2-3 hours before getting to bed, I consumed: Alcohol 1+ glasses of liquid A heavy meal A light meal/snack Caffeine Nothing	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐ ☐
How sleepy did you feel during the day today? 1. Very Alert/ 2. Rather Alert/ 3. Neither Alert nor Sleepy/ 4. Some Signs of Sleepiness/ 5. Very Sleepy							

Analysis Plan

- Our goal is to explore:
  - The effects of different **times of day** on melanopic irradiance levels
  - The effects of **locations** on melanopic irradiance levels
  - Individual **sleep schedules** related to **alertness** and **melanopic irradiance**



Participants' alertness levels by considering their light exposure and time of day



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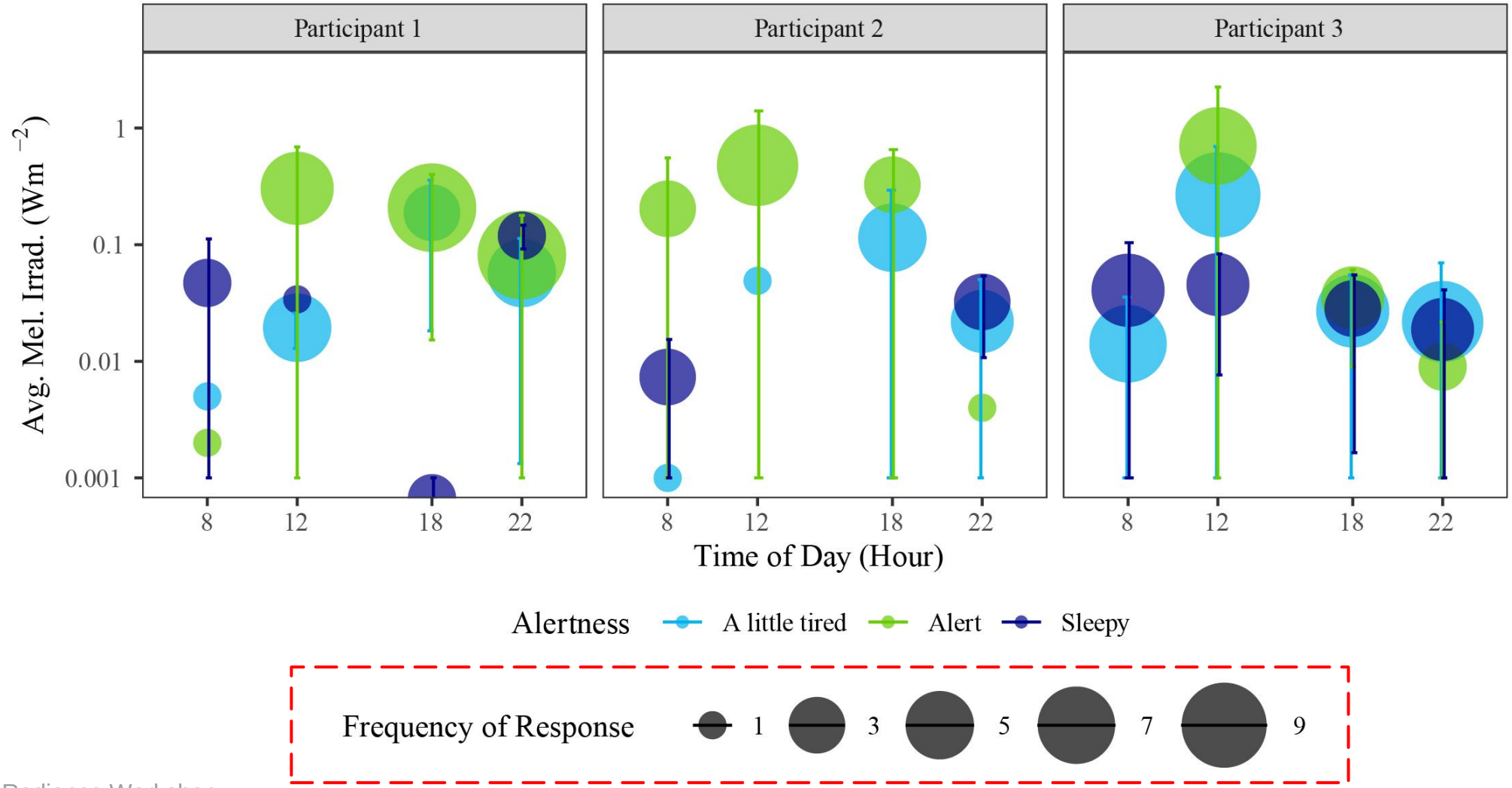
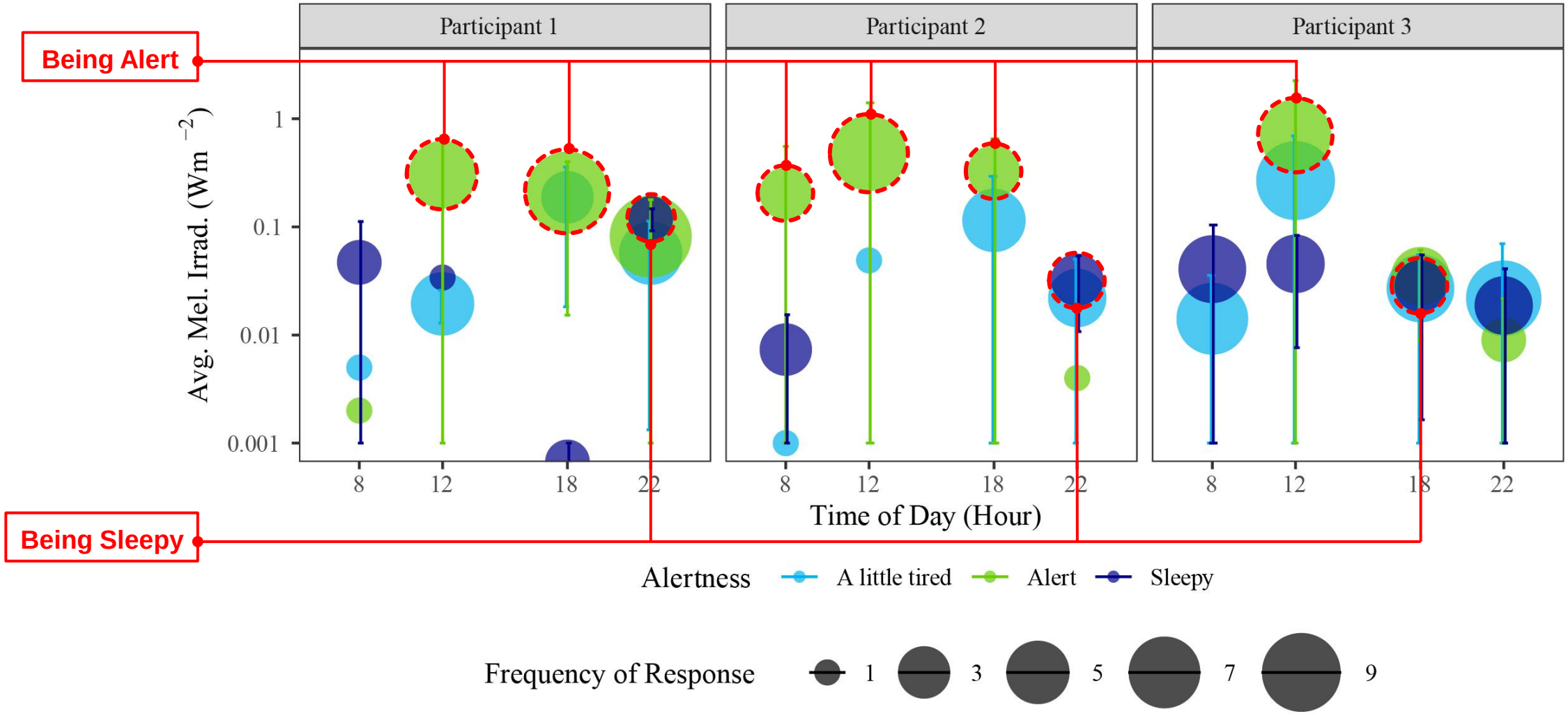
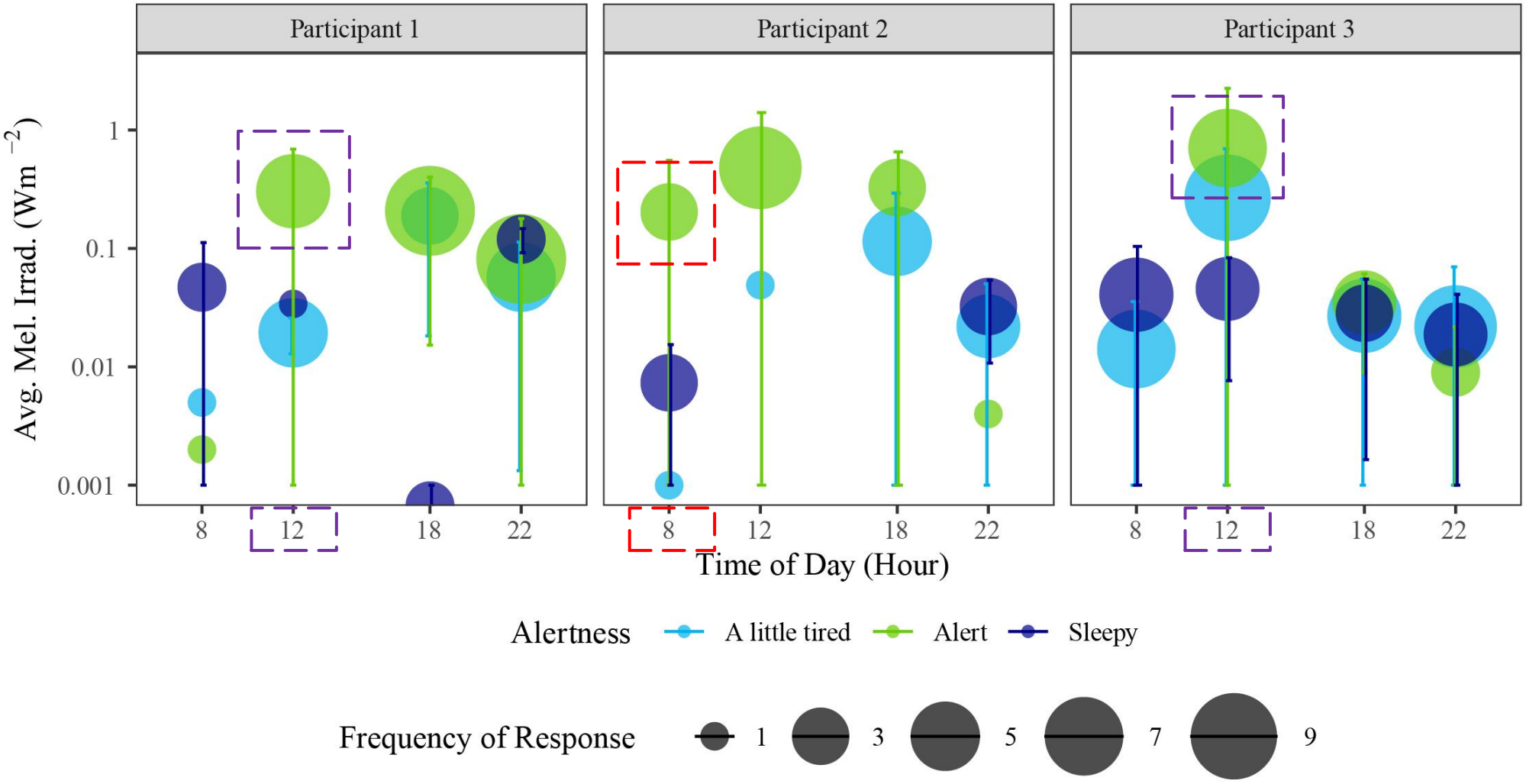


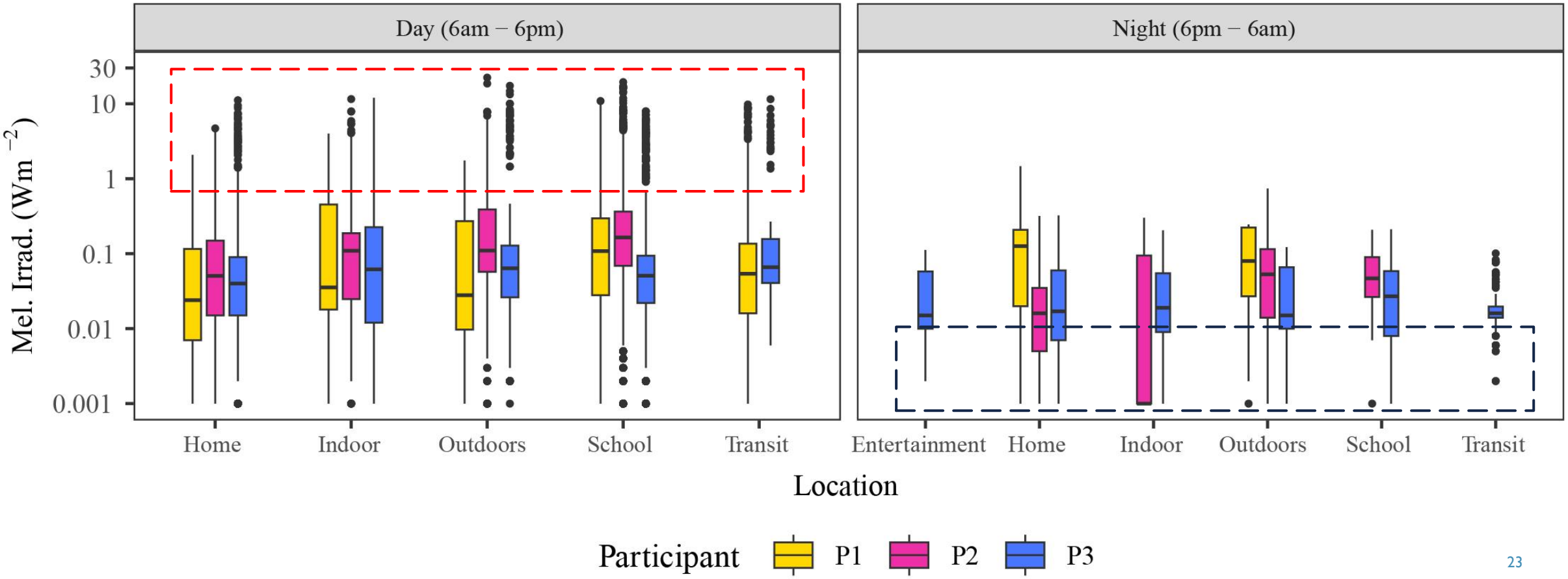
Participants' alertness levels by considering their light exposure and time of day



Participants' alertness levels by considering their light exposure and time of day

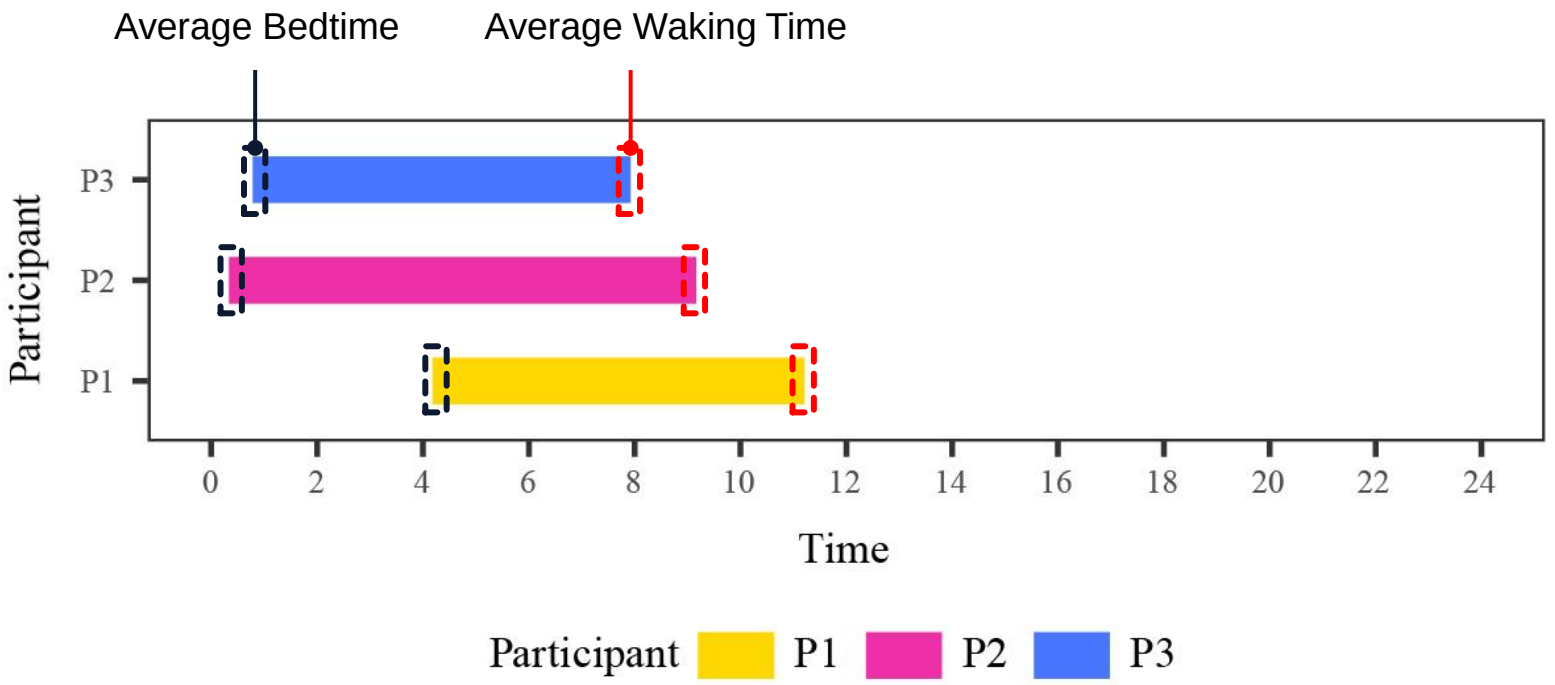


Participants' melanopic irradiance by location and time of day



Participants' average sleep schedule

- Shows:
  - Sleep duration
  - Average bedtime
  - Average waking time
- Explains variations in alertness



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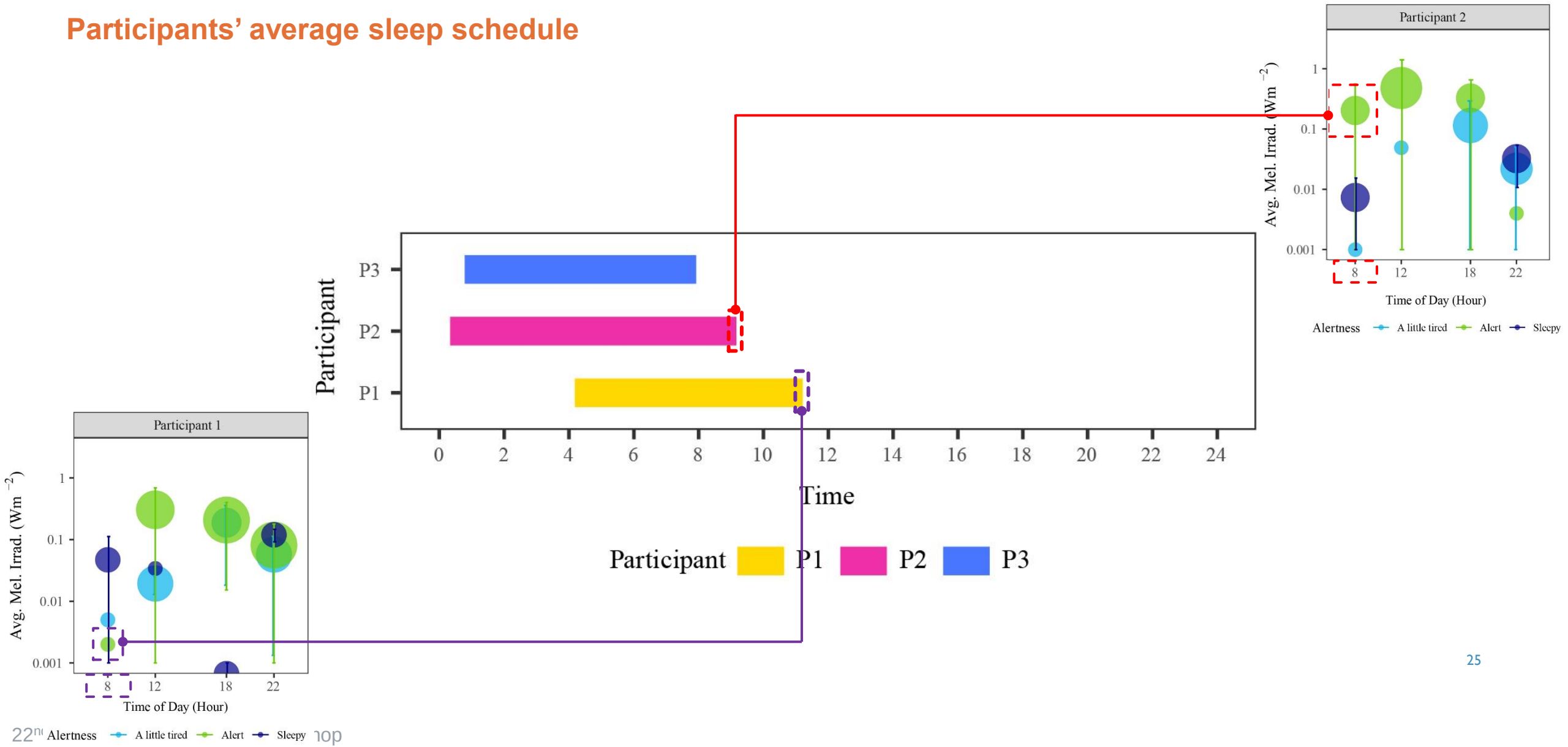
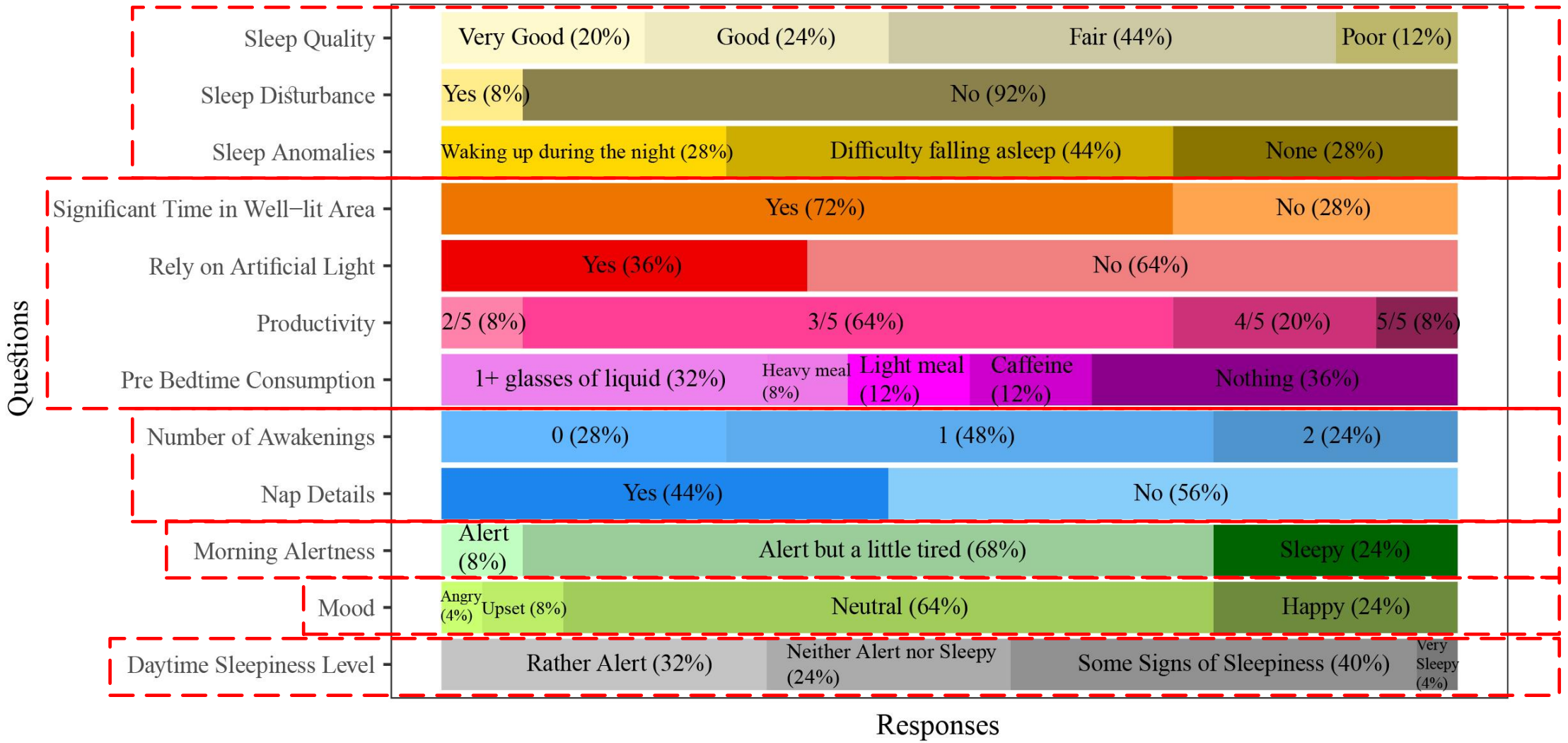
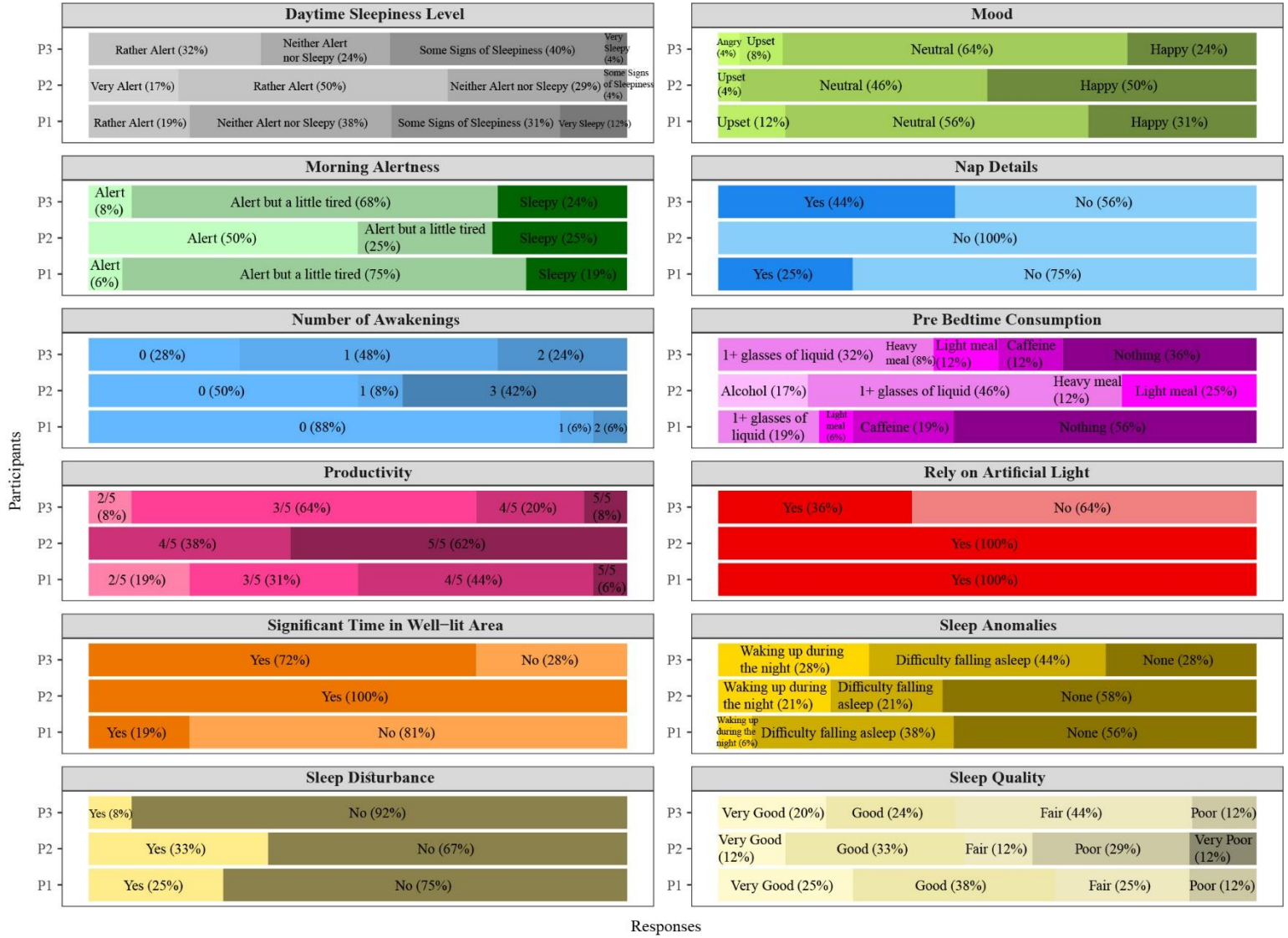
Participants' average sleep schedule



Participant's daily journal responses

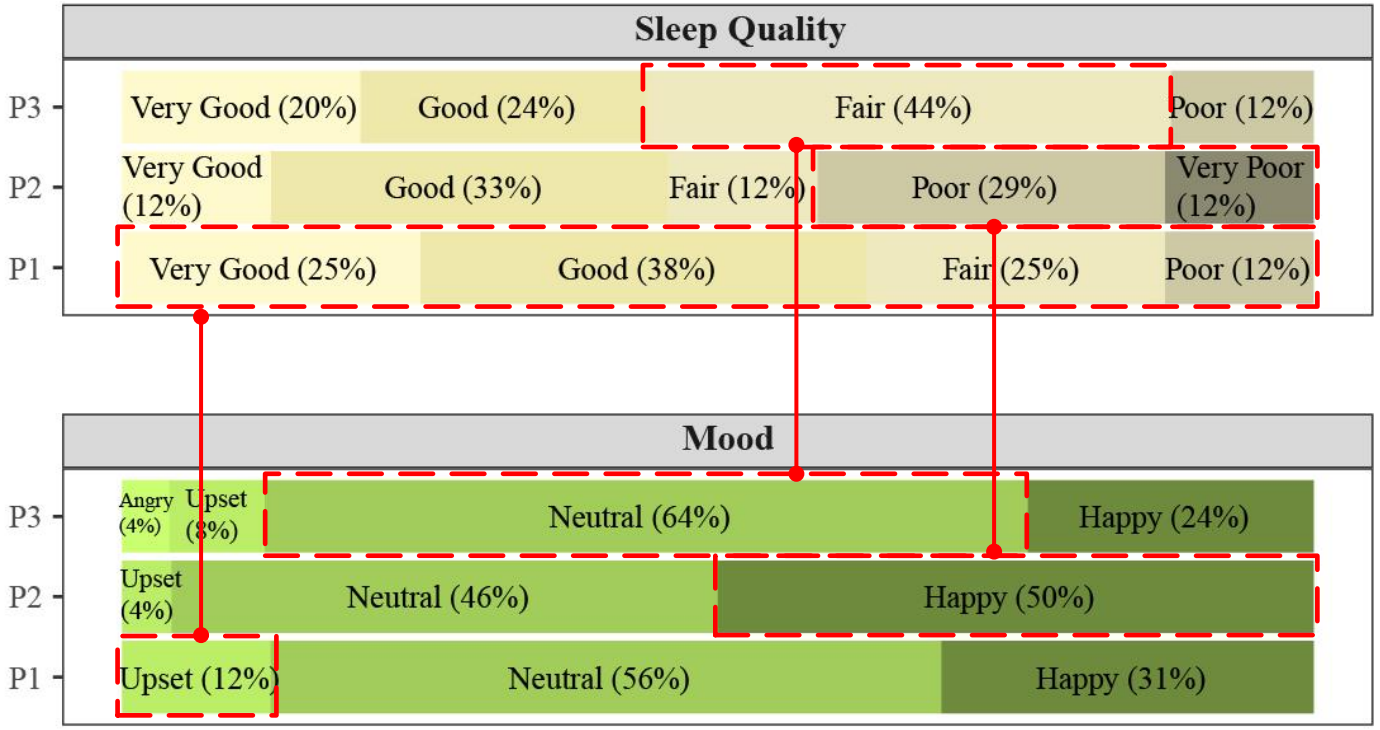


Comparison between participants' daily journal responses



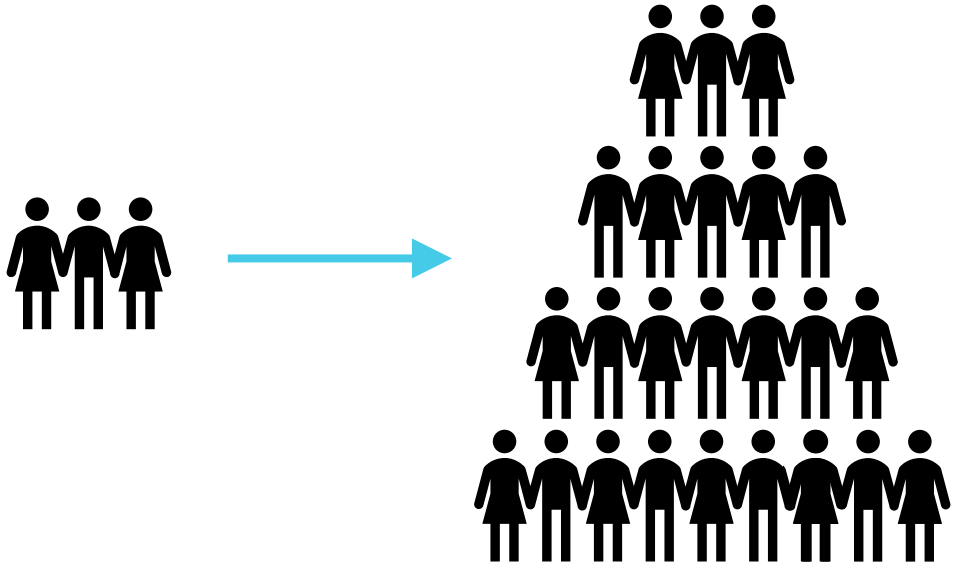
Example of participants' daily journal responses

- Shows a clear relationship between sleep quality and mood
- Individualized relationships between sleep, mood, and daily light exposure
- It can address specific areas of concern like improving sleep hygiene, managing stress, or adjusting light exposure.



Future Research

- Include a more diverse cohort
- Understand light's multifaceted effects
- Develop adaptive and personalized lighting strategies
- Future research is required to investigate effects of longer exposure durations and potential moderations by prior light exposure, personal characteristics, and spectrum.



Thank you for your attention