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# Protocol for Assessing Light Exposure, Sleep, and Cognitive Function in Real-World Settings

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**We use this protocol and it's working**

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## Abstract

Light exposure plays a crucial role in shaping cognitive function; however, its effects outside controlled laboratory settings remain insufficiently explored. This study aimed to investigate the impact of real-world light exposure on cognitive performance, revealing both immediate and cumulative benefits. To achieve this, we employed a wearable melanopic equivalent daylight illuminance monitor (Spectrawear<sup>1</sup>) alongside a mobile application (Brightertime<sup>2</sup>) to assess subjective sleepiness, vigilance, working memory, and visual search performance throughout the day in everyday life. The wrist-worn light dosimeter recorded continuous light exposure at 30-second intervals over a one-week period. The mobile app facilitated data collection, including baseline sociodemographic and health questionnaires, chronotype and sleep quality assessments, daily sleep diaries, and subjective sleepiness reports and cognitive task performance measurements. Participants could engage in cognitive assessments multiple times per day at their convenience. At the end of the one-week study period, participants were invited to a laboratory visit for light sensitivity measurements<sup>3</sup>. These included melanopic brightness discrimination tasks, post-illumination pupil response assessments, and subjective brightness evaluations.

## Materials

### Real-World Measurements

- Spectrawear wearable light dosimeter
- Access to Brightertime mobile app
- Smartphone for participant
- Smartphone with Bluetooth connection for researcher
- Charging cable and adapter

### Laboratory Measurements

- Multi-primary projector system for silent substitution experiments (described in reference 4)
- Chin rest
- Eye patch
- Control keyboard
- Experimenter's computer

## Before start

### Recruitment

**Inclusion and Exclusion Criteria:** Participants were eligible for inclusion if they were at least 18 years old, employed either full-time or part-time, had no history of intercontinental travel in the preceding two weeks, and had not been diagnosed with a sleep disorder.

**Recruitment Strategies:** Participants were recruited through multiple strategies to ensure a diverse and representative sample. Study announcements were disseminated via university newsletters, reaching postgraduate students and staff directly. Additionally, word of mouth played a role, as participants were encouraged to share information about the study within their networks. Posters were displayed in high-traffic areas such as university buildings, libraries, and communal spaces to attract potential participants.

**Initial contact:** The initial recruitment contact was established via email following the participant's expression of interest. In response, available time slots, the participant information sheet, and photos of the wearable device were provided for review. If the participant agreed on a specific date and time, they were offered the option to meet at our recruitment office. However, to accommodate individual preferences, meetings could also take place at a mutually agreed-upon public location of their choice.

### Before the registration meeting

**One day before the registration meeting:** A reminder email was sent to participants, including the mobile app download link and instructions for installation. The wearable device was thoroughly sterilized to ensure hygiene and prepared for use. Additionally, the device's local memory storage was checked and cleared to ensure sufficient capacity for data collection. The device was then left to charge overnight to ensure full battery capacity at the time of distribution. Finally, a functionality test was performed, and any necessary adjustments or fixes were made to ensure optimal performance before the meeting.

**Prior to the registration meeting:** An anonymized participant ID was generated, a designated folder for storing the participant's results was created, and the blank consent form and study instruction was printed.



## Registration meeting

50m 40s

### 1 Initial information

- 1.1 Offer participants the opportunity to read the Participant Information Sheet once again and collect their signature on the consent form. 2m
- 1.2 Have participants fill out the bank account form and provide details regarding compensation payment. 1m
- 1.3 Explain the follow-up laboratory study, including the following key points: 1m
  - Duration: 1 hour
  - Time window: Between 11:00 and 15:00
  - Tasks: Visual light sensitivity tasks in a dark room with light flashes
  - Compensation: Extra payment for participation
- 1.4 Inform the participant that the device should be worn for a minimum of 7 days for data collection. Emphasize that they should continue wearing the devices and playing the games until instructed otherwise during the final meeting. 10s
- 1.5 Inform participants that if they skip wearing or playing the game for one day, they should notify you, and an additional day will be added to their study period. 10s
- 1.6 Explain that at the end of the study period, a meeting will be scheduled to conclude the study and collect the devices. If they are not available, they can continue wearing the device and playing the games until the follow-up meeting. Alternatively, if they prefer, they can stop wearing the device after 7 days but should keep track of the final wear time, with a meeting scheduled later for device collection. 10s
- 1.7 Arrange the date, time, and location for the conclusion meeting. If the participant agrees to the follow-up, clarify that the final meeting will take place between 11:00 and 15:00 in the lab. 10s
- 1.8 Inform participants that all steps will be detailed and explained now, and they are welcome to ask any questions if anything is unclear. 10s

### 2 Wearable light monitor: Spectrawear

- 2.1 Turn the device on if it is in sleep mode. 30s



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|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 2.2  | Inform the participant of the wearable device ID, as the app will request this to match the data.                                                                                                                                                                                                                                                                                                                                                                                            | 10s |
| 2.3  | Specify that the device should be worn on the nondominant hand, and show them the correct direction for wearing it.                                                                                                                                                                                                                                                                                                                                                                          | 2m  |
| 2.4  | Ask participants to wear any other watches or smartwatches on the opposite arm.                                                                                                                                                                                                                                                                                                                                                                                                              | 10s |
| 2.5  | Let the participant wear the device, marking the official start of the project.                                                                                                                                                                                                                                                                                                                                                                                                              | 30s |
| 2.6  | Start the measurement process using the researcher's phone, connecting via Bluetooth to the device. Take note of the start time for light measurement.                                                                                                                                                                                                                                                                                                                                       | 30s |
| 2.7  | Inform the participant not to wear the device while sleeping. Instruct them to place it near their bed, ensuring it is facing up and not covered for overnight charging.                                                                                                                                                                                                                                                                                                                     | 30s |
| 2.8  | Provide the participant with the adapter and USB cable set, and explain that they should charge the device every night using the provided charger and cable.                                                                                                                                                                                                                                                                                                                                 | 30s |
| 2.9  | Mention that the device is water-resistant, capable of withstanding splashes of water, and can be worn in rainy weather (though it should be protected). Advise participants to wash their hands carefully but not swim, shower, or submerge the device in water.                                                                                                                                                                                                                            | 30s |
| 2.10 | Explain that a yellow LED flash indicates an error. Instruct participants to notify you immediately if they see any flash, even a single blink. Also, there should be no blinking while the device is charging and no low battery signals. Request that participants note the date and time when they first observe the yellow LED flash.                                                                                                                                                    | 30s |
| 3    | <b>Mobile app: Brightertime</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                              |     |
| 3.1  | Ask participants to download the app from the App Store and register for an account.                                                                                                                                                                                                                                                                                                                                                                                                         | 5m  |
| 3.2  | Inform participants that they can receive notifications from the app on their phone and can adjust the timing of these notifications. Emphasize the expectation of a minimum of 3 gameplay sessions per day, with 5 being optimal. Recommended times include one session around awakening, one during work, and one after work. Encourage participants to play more than 3 times if possible, as this will help with the study by capturing a variety of light levels and sleepiness states. | 1m  |
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|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 3.3  | Let participants know that they can play offline, but they should connect to the internet with the app open when possible to upload data to the server.                                                                                                                                                                                                                                                                        | 10s |
| 3.4  | Have participants fill out the registration survey, which includes the Sociodemographics and Health Survey, Pittsburgh Sleep Quality Index, and Munich Chronotype Questionnaire.                                                                                                                                                                                                                                               | 10m |
| 3.5  | Ask participants which step they are currently on and remind them that clock answers should be in 24-hour format.                                                                                                                                                                                                                                                                                                              | 10s |
| 3.6  | Introduce the sleep diary, explaining that they need to fill it out for the previous night. Let them know that the sleep diary will automatically appear during their first login of the day. Encourage them to fill out the sleep diary every morning as soon as they wake up.                                                                                                                                                | 3m  |
| 3.7  | Introduce the subjective alertness survey (Karolinska Sleepiness Scale) and inform participants that they will be asked an alertness question automatically each time they log in. This question will ask how sleepy they feel at that moment.                                                                                                                                                                                 | 3m  |
| 3.8  | Let participants know that they will be asked the question, "Have you slept since your last entry?" This refers to any naps lasting more than 15 minutes taken after their last gameplay session.                                                                                                                                                                                                                              | 10s |
| 3.9  | Instruct participants to play the practice games, explaining that they need to be both accurate and quick. If the app crashes, participants should reopen the app and continue playing. Tell them not to interact with their notifications, and if a call occurs. Participants can turn their phone to silent or Do Not Disturb mode if necessary. Additionally, instruct them to hold the phone horizontally during gameplay. | 5m  |
| 3.10 | Explain the Psychomotor Vigilance Task (PVT), instructing participants to fixate on the cross at the center of the screen and stay alert for the zombie image to appear in the center. They should touch the screen as quickly as possible within 1 second.                                                                                                                                                                    | 30s |
| 3.11 | Explain the N-back task, where participants will see letters appear one by one on the screen, each displayed for 2 seconds. If the letter is the same as the letter shown 3 positions before, they should touch the screen.                                                                                                                                                                                                    | 30s |
| 3.12 | Explain the Visual Search task, where participants will see faces in different orientations on the screen. They need to find the "monkey" among the "men," with the only difference being the nose: a "T" for monkey and an "L" for man. They should press the "Absent" or "Present" button as quickly as possible.                                                                                                            | 30s |
| 3.13 | Instruct participants to play the full games for the first time.                                                                                                                                                                                                                                                                                                                                                               | 5m  |
| 3.14 | Ask if participants have any questions about the games or tasks.                                                                                                                                                                                                                                                                                                                                                               | 1m  |



- 3.15 Inform participants that their study week starts now and that they need to play today, including in the evening. Remind them not to forget to charge the device tonight. 1m
- 3.16 Provide a printed to-do list and instructions, and briefly review the study design and what they should do every day during the week. 3m
- 3.17 Remind participants that this study is interested in their regular daily life, and the goal is to collect data as it naturally occurs. They should not change any of their behaviors, sleep patterns, lifestyle, or schedules during the study week. 1m

## During the study week

2h 41m

- 4 Participants will complete the morning sleep diary every day. 21m 
- 5 Participants will complete the subjective alertness report multiple times a day, every day, and play cognitive games. 2h 20m 
- 6 If participants encounter any issues with the Spectrawear device, offer to meet with them the next morning. They can either withdraw from the study and return the devices or have the device replaced with a new one.
- 7 If participants contact you and inform you that they forgot to wear the device or play the games, extend the study end date by one day and arrange a new meeting to conclude the study.
- 8 One day before the end of the week, remind participants about the conclusion meeting.

## Conclusion meeting (no follow-up laboratory study)

19m

- 9 Ask participants if they have encountered any problems or have feedback to share. 3m
- 10 Have participants play the games one final time and fill out the sleep diary if it hasn't been completed already. 7m
- 11 Instruct participants to uninstall the app. 3m



- |    |                                                                                                                            |    |
|----|----------------------------------------------------------------------------------------------------------------------------|----|
| 12 | Stop the Spectrawear measurement and put the device into sleep mode. Once the measurement has stopped, collect the device. | 5m |
| 13 | Inform participants about how they will be compensated.                                                                    | 1m |
| 14 | Transfer all wearable device data and mobile app data to the participant's results folder, and back up the data.           |    |

## Conclusion meeting (with laboratory visit for light sensitivity measurements<sup>3</sup>)

**1h 26m 40s**

- |    |                                                                                                                                                                                                                |          |
|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| 15 | Ask participants if they have encountered any problems or have feedback to share.                                                                                                                              | 3m       |
| 16 | Have participants play the games one final time and fill out the sleep diary if it hasn't been completed already.                                                                                              | 7m       |
| 17 | Instruct participants to uninstall the app.                                                                                                                                                                    | 3m       |
| 18 | Have them sit in front of the multi-primary projector system to the left side of the display.                                                                                                                  | *        |
| 19 | Ask them to complete the participant information survey. Instruct them to note in detail any eye medical conditions they may have, as well as the usage of eyeglasses or lenses, and the reason for their use. | 5m<br>*  |
| 20 | Ensure that the participant does not have a history of migraine, epilepsy, or any other serious light sensitivity conditions.                                                                                  | 30s<br>* |
| 21 | Tell them to put their phone in silent mode and refrain from looking at screens, including smartwatches and other devices.                                                                                     | 30s<br>* |
| 22 | Tell them to cover their right eye with the eye patch. The eye patch should be snug (as tight as possible without causing discomfort) to ensure that nothing can be seen through the right eye.                | 1m<br>*  |



- |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |     |   |
|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---|
| 23 | Show them the keyboard's space bar, arrow keys, and enter key, and explain how to use them in the tasks.                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 30s | * |
| 24 | Inform them that if they feel uncomfortable at any point, they should not hesitate to speak up. They will still receive payment regardless.                                                                                                                                                                                                                                                                                                                                                                                                                    | 10s | * |
| 25 | Participants will perform the tasks in the following order: Flicker photometry calibration, subjective brightness task, and melanopic brightness discrimination task.                                                                                                                                                                                                                                                                                                                                                                                          | 30m | * |
| 26 | Participants will move to another chair in front of the light source for pupil reflex measurements. They should remove the eye patch and use the chin rest. Carefully place the eye tracker on the participant's head, adjusting the cameras as needed to ensure they focus correctly on the pupil. Ask the participant if the position of the eye tracker is comfortable. Emphasize that this is important, as they should not touch the eye tracker throughout the entire experiment. Inform them that there will be 10 minutes of baseline dark adaptation. | 30m | * |
| 27 | Stop the Spectrawear measurement and put the device into sleep mode. Once the measurement has stopped, collect the device.                                                                                                                                                                                                                                                                                                                                                                                                                                     | 5m  |   |
| 28 | Inform participants about how they will be compensated.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 1m  |   |
| 29 | Transfer all wearable device data and mobile app data to the participant's results folder, and back up the data.                                                                                                                                                                                                                                                                                                                                                                                                                                               |     |   |

## Protocol references

- 1** - Mohammadian, N. et al. *A Wrist-Worn Internet of Things Sensor Node for Wearable Equivalent Daylight Illuminance Monitoring*. *IEEE Internet Things J* 11, 16148-16157 (2024). <https://doi.org/10.1109/JIOT.2024.3355330>.
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- 3** - Woelders, T., Didikoglu, A., Bickerstaff, L., Brown, T. M., & Lucas, R. J. *Pupillometric and perceptual approaches provide independent estimates of melanopsin activity in humans*. *Sleep* (2024). <https://doi.org/10.1093/sleep/zsae289>.
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