Jean Heap Bursary – Six-Month Progress Report

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1. Introduction

I would like to express my sincere gratitude to the Society of Light and Lighting and the Jean Heap Bursary panel for their continued support of this research project. The Jean Heap Bursary has provided invaluable assistance in enabling the continuation and development of my doctoral research exploring the relationship between near infrared (NIR) exposure, sleep physiology, and behavioural outcomes.

This report provides an overview of the progress undertaken during the first six months of the project, including the development of the original human pilot study, the subsequent transition to a *Drosophila melanogaster* (fruit fly) experimental model, the construction and calibration of the behavioural monitoring infrastructure, and the progression of the current pilot investigation.

As previously communicated to the SLL panel in February 2026, the methodological direction of the study required revision from a human participant investigation to an experimental *Drosophila* model. This decision was not taken lightly and resulted primarily from the extended timelines associated with institutional ethical approval procedures for the original human sleep study. Although substantial progress had already been made in relation to the human protocol, the anticipated timeframe for ethical clearance extended beyond the period required for my doctoral upgrade submission and pilot data collection.

Rather than delaying the research entirely, the project was redesigned around a highly controlled behavioural sleep model using *Drosophila melanogaster*. This revised approach enabled the continuation of the central research question whilst maintaining scientific relevance, methodological rigour, and translational applicability to future human studies.

Importantly, the fundamental research hypothesis remains unchanged. The study continues to investigate whether exposure to NIR light influences sleep pressure accumulation and subsequent rebound sleep following sleep deprivation. This work remains directly relevant to the built environment and contemporary lighting design, particularly in the context of the increasing replacement of broad-spectrum incandescent and halogen lighting with narrow-spectrum LED technologies that emit negligible amounts of near infrared radiation.

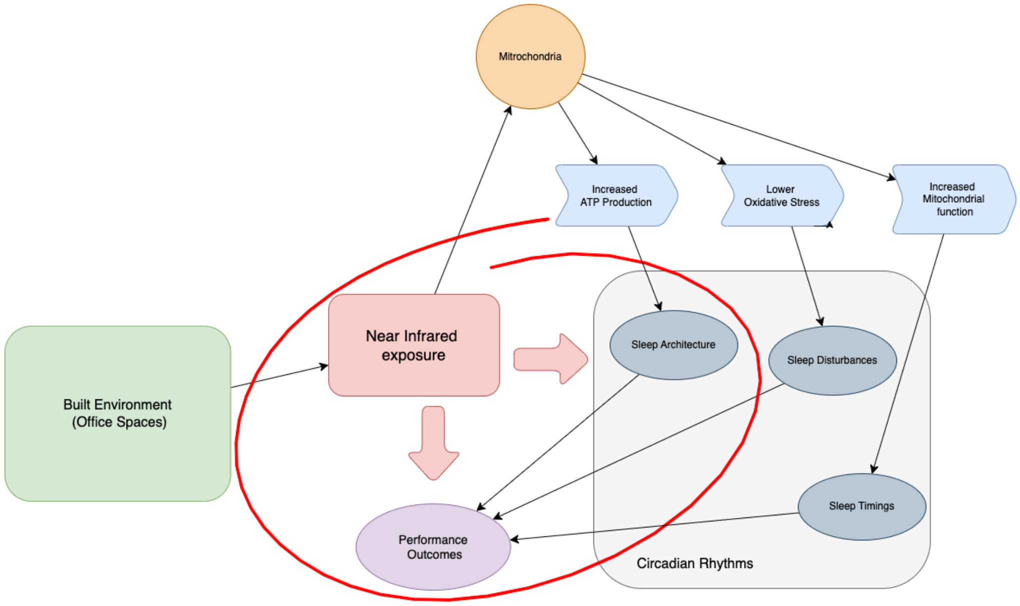

Figure 1. An illustration of the overarching research areas, with the red circle highlighting the areas of analysis.

Modern indoor environments differ substantially from natural daylight conditions. Whilst electric lighting systems have become increasingly energy efficient, many contemporary LED systems produce highly restricted spectral outputs compared with historical lighting technologies and solar radiation. Near infrared wavelengths, which constitute a substantial proportion of natural daylight, are largely absent from most indoor lighting environments. Consequently, there remains limited understanding regarding the physiological implications of prolonged exposure to light environments deficient in NIR wavelengths.

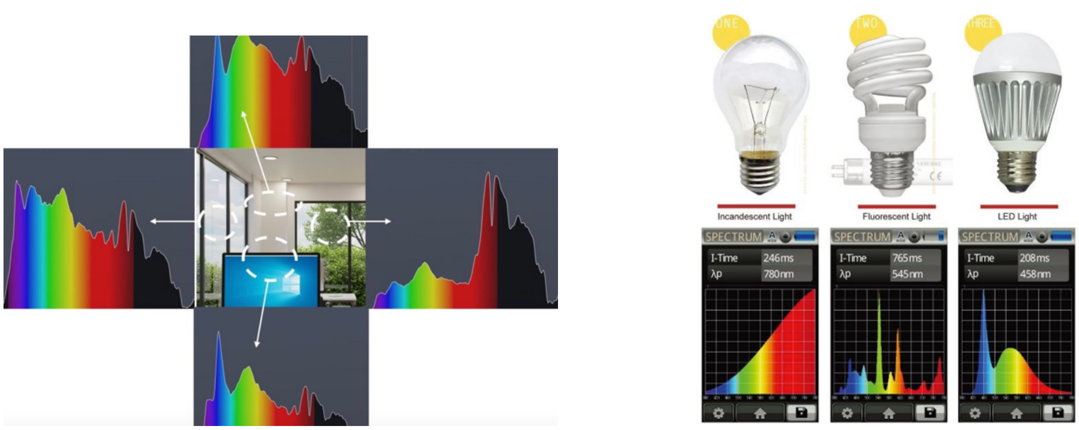

Figure 2. a) Overview of NIR across a standard office room, indicating the lack of NIR in the desk setting. b) Typical lamp sources with corresponding spectral distribution highlighting the areas devoid of NIR.

This doctoral research therefore seeks to contribute to a broader understanding of how spectral composition may influence physiological and behavioural outcomes beyond conventional visual and circadian pathways. In particular, the project investigates whether

NIR exposure may influence mitochondrial processes associated with energy metabolism, sleep pressure accumulation, and recovery following sustained wakefulness.

2. Overview of previous work undertaken for the original Human Study

Prior to the methodological revision, extensive work had already been undertaken in preparation for the original human pilot study investigating the effects of near infrared exposure on afternoon napping and cognitive performance.

The original human study was designed as a controlled laboratory investigation examining whether exposure to NIR-enriched lighting environments could influence sleep architecture, subjective sleepiness, and cognitive performance within a setting representative of indoor office environments. The broader aim of the study was to investigate whether spectral deficiencies in modern indoor lighting may influence human physiological functioning.

The proposed methodology employed a repeated-measures, within-subjects experimental design in which participants would undergo multiple laboratory visits under differing lighting conditions. The protocol incorporated environmental monitoring, electroencephalography (EEG) sleep measurements, cognitive testing, subjective sleep questionnaires, and longitudinal home-based sleep and light exposure assessments.

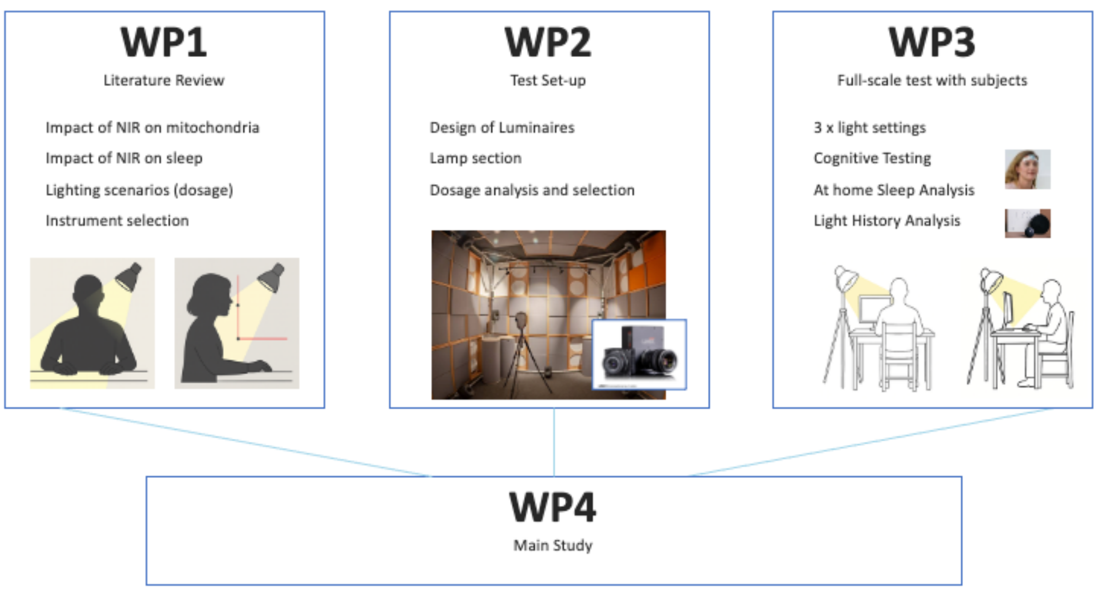

Figure 3. An overview of the wider stages for the original pilot study, which will become the main study to be undertaken later in 2026.

A considerable amount of preparatory work was completed in advance of the planned pilot investigation. This included the development of a detailed pilot study protocol outlining the experimental methodology, participant procedures, measurement instruments, data collection methods, and environmental controls. Preparatory work also included the production of participant documentation, recruitment materials, sleep questionnaires, and laboratory procedural guidance.

In addition, substantial effort was dedicated towards identifying and sourcing appropriate lighting equipment capable of delivering both NIR-enriched and standard LED lighting conditions. Consideration was given not only to spectral characteristics, but also to luminaire geometry, illuminance distribution, colour temperature, and environmental consistency within the laboratory setting.

The planned human study incorporated several forms of physiological and behavioural monitoring equipment, including home sleep testing systems, actigraphy devices, environmental air quality monitoring tools, and cognitive assessment platforms. Preparatory calibration procedures were also developed to ensure consistency in spectral irradiance measurements and environmental monitoring across all testing conditions.

The original study was designed specifically to address the important issue within the built environment of the increased reduction in full-spectrum light exposure resulting from the widespread adoption of contemporary LED lighting systems. Whilst LEDs offer significant energy-saving benefits, they emit comparatively little near infrared radiation relative to both natural daylight and traditional incandescent light sources.

The pilot study in humans was therefore aimed to explore whether this reduction in NIR exposure may have implications for sleep physiology, recovery processes, and cognitive functioning. Although the study could not proceed within the required timeframe due to ethical approval delays, the preparatory work remains highly valuable and will directly form the future translational human investigations following completion of the current pilot study.

The experience gained during the development of the human protocol has also strengthened the theoretical and methodological framework underpinning the doctoral research more broadly. The work undertaken has provided a clearer foundation for my main study in the future, where I shall examine the relationship between light spectra, sleep physiology, and environmental lighting design.

3. Rationale for the new *Drosophila* Study

The revised pilot study employs *Drosophila melanogaster* (fruit flies) as a model organism to investigate the effects of near infrared exposure on rebound sleep following overnight sleep deprivation.

Drosophila has become one of the most widely used behavioural and sleep models within neuroscience and circadian biology research. Over the past two decades, substantial evidence has demonstrated that sleep in *Drosophila* shares many conserved characteristics with mammalian sleep, including circadian regulation, homeostatic rebound sleep following deprivation, prolonged periods of behavioural immobility, and modulation through metabolic and mitochondrial pathways.

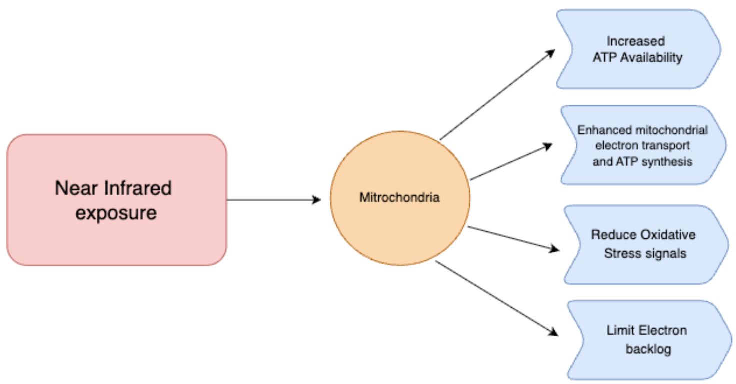

Figure 4. Overview of the revised pilot study rationale, illustrating the hypothesised pathway through which NIR exposure modulates mitochondrial processes during sustained wakefulness to attenuate rebound sleep

The model is particularly appropriate for the present research because the primary hypothesis relates to sleep pressure accumulation and mitochondrial function. Current literature suggests that NIR may interact with cytochrome-c oxidase within the mitochondrial electron transport chain, potentially altering ATP production, oxidative metabolism, and cellular energy balance. These mechanisms are believed to be evolutionarily conserved across species.

The use of *Drosophila* provides several methodological advantages at this stage of the research project. Firstly, the model allows highly controlled behavioural experiments to be conducted under tightly regulated environmental conditions. Light exposure, temperature, humidity, circadian timing, and sleep deprivation parameters can all be standardised with a high degree of precision.

Secondly, the model enables high-throughput behavioural monitoring across multiple independent cohorts, allowing repeated experimental assays to be conducted efficiently whilst maintaining consistency in experimental conditions.

Thirdly, *Drosophila* sleep assays are well established within behavioural neuroscience research, with validated methodologies for measuring sleep, locomotor activity, sleep rebound, and behavioural recovery following deprivation.

Importantly, the revised pilot study acts as a translational bridge between environmental lighting research and future human investigations. Whilst the present work does not directly measure human sleep architecture, it provides a behavioural framework for examining whether NIR exposure influences sleep pressure accumulation through mechanisms linked to mitochondrial function and sustained wakefulness.

The project therefore remains closely aligned with the broader objectives to add to the contemporary research within the built environment. As humans increasingly occupy indoor spaces illuminated by narrow-spectrum electric lighting systems, there is growing importance in understanding whether changes in spectral exposure may influence physiological and behavioural outcomes beyond conventional circadian entrainment.

The current pilot study aims to establish an initial behavioural foundation upon which future translational human research may be developed.

4. Equipment Build, Purchases, Design Development and Measurement Tools

A substantial proportion of the reporting period has involved the design, construction, calibration, and testing of a custom-built Ethoscope behavioural monitoring system for *Drosophila* sleep analysis.

The Ethoscope is an open-source behavioural monitoring platform developed for high-resolution automated analysis of *Drosophila* locomotor activity and sleep behaviour. The system consists of a 3D printed housing structure containing a Raspberry Pi single-board computer, infrared-sensitive camera, integrated illumination system, and sleep arena designed to house individual flies within isolated monitoring tubes.

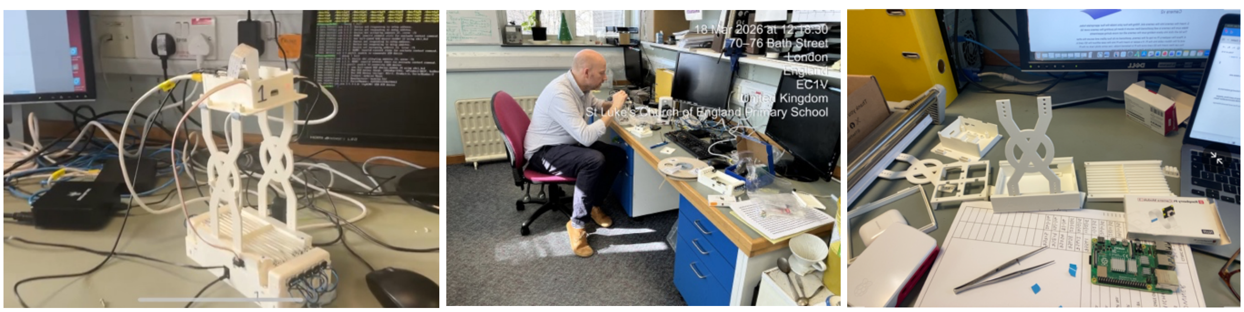

Figure 5. The building process of the Ethoscope behavioral monitors, designed to monitor the movement and sleep of the flies over several days.

The transition to the *Drosophila* model required extensive technical development and system integration. Multiple Ethoscope devices were constructed and calibrated to ensure stable behavioural tracking under tightly controlled environmental conditions. This process included the assembly of 3D printed housing units, installation of Raspberry Pi computer operating systems, integration of infrared camera modules, configuration of behavioural tracking software, and testing of automated recording systems.

Additional work was undertaken to establish environmental control systems suitable for long-duration behavioural monitoring. Each Ethoscope unit was housed within a controlled incubator environment to maintain stable thermal conditions and regulated light-dark cycles throughout experimental recording periods.

The behavioural monitoring system incorporates a custom-built illumination system to enable continuous video tracking during dark phases without introducing invisible light contamination into the experimental environment.

The study also required the development and testing of a sleep deprivation apparatus capable of maintaining prolonged wakefulness during overnight deprivation periods. Mechanical shaker systems were integrated into the monitoring setup and calibrated to ensure consistent sleep disruption across experimental cohorts.

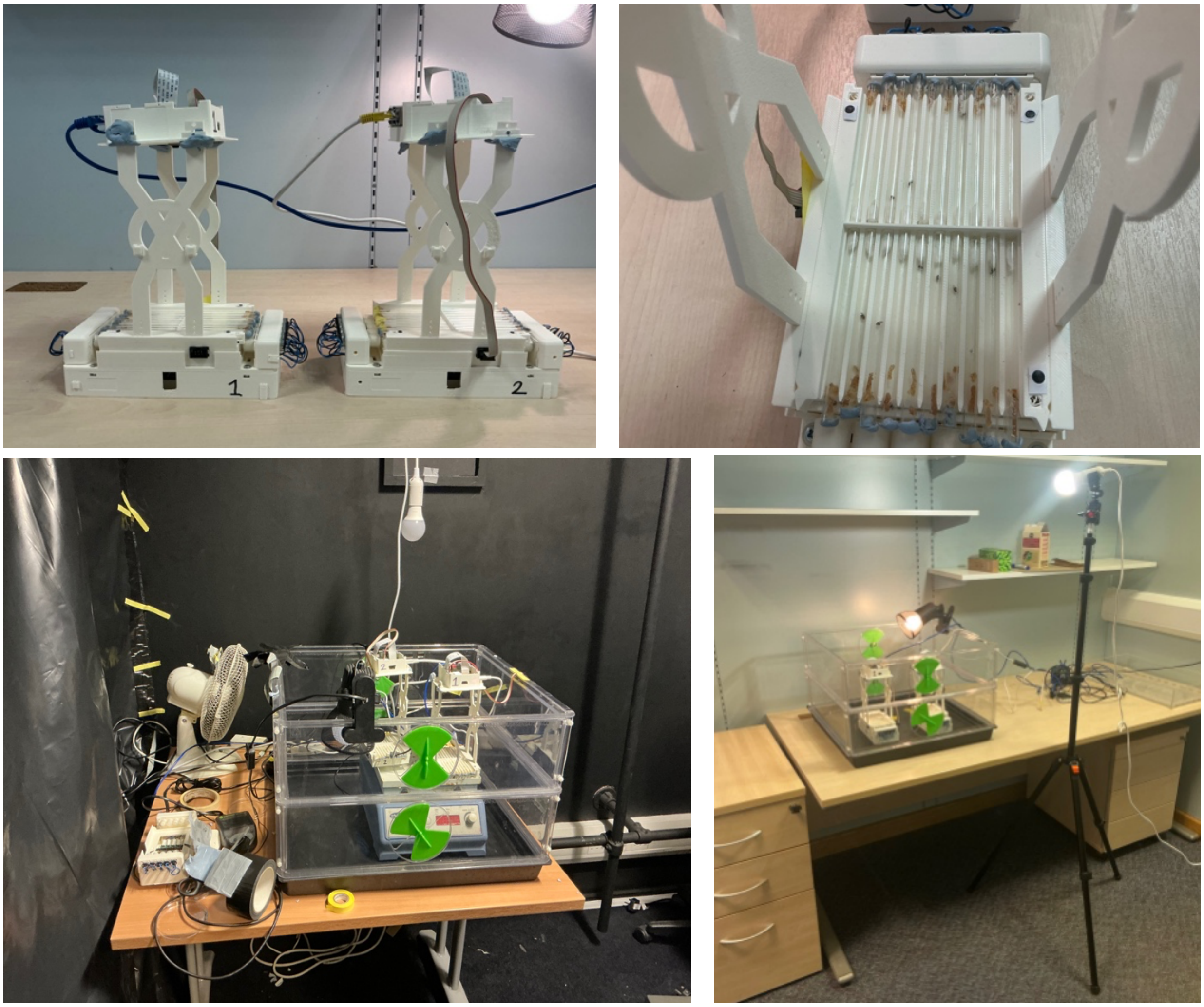

Figure 6. The final Ethoscope designs, with lighting set up and sleep monitoring arena.

Significant time was additionally devoted towards software installation, behavioural tracking validation, and data processing workflows. Ethoscopy and Jupyter-based behavioural analysis via Python pipelines were implemented to enable automated processing of the experimental datasets.

Project expenditure during this period has primarily related to:

- Raspberry Pi computers and associated hardware.
- Infrared-sensitive cameras and optical components.
- 3D printed structural components and assembly materials.
- Lighting equipment and experimental lamps.

- Environmental incubator systems.
- Behavioural monitoring accessories.
- Data storage and computational analysis infrastructure.

Expenses breakdown for the period January – April 2026

Item	**No.**	**Price per Item (£)**	**Total Cost (£)**
1. Ethoscope Behavioural Monitoring System			
NIR cameras	2	45	90
Raspberry Pi – computer, adapters	2	85	170
3D printed Ethoscope housings & sleep arenas	2	65	130
Ethoscope light boxes & NIR tracking illumination	2	40	80
Glass sleep tubes / fly tubes	1	50	50
Temperature / environmental monitoring equipment	1	35	35
Ethernet cables, USB cables, connectors & miscellaneous electronics	1	60	60
TP-Link network switch / networking hardware	1	65	65
Linux computer	1	145	145
Subtotal – Ethoscope System			**825**
2. Experimental Lighting & Environmental Rig			
Vitopod environmental housing/incubator	1	40	40
NIR LED lamps (850 nm)	6	10	60
Incandescent broad-spectrum lamps	12	6	72
Control LED lamps	12	5	60
Lamp holders, fixtures & wiring	-	-	50
Lighting stands / tripods / mounting hardware	-	-	75
Timers, plugs & extension leads	-	-	40
Circuit protection / fused adaptors	-	-	25
Environmental housing materials & blackout modifications	-	-	50
Subtotal – Lighting Rig			**472**
3. Modular Sleep Deprivation Device			
Modular SD device PCB & electronics	2	60	120
N20 Motors	30	3	90
Arduino & control electronics	35	2	70
3D printed module housing & mounts	30	2	60
External Power Supply	20	1	20
Wiring, connectors & assembly components	-	-	35
Subtotal – Sleep Deprivation Module			**395**
4. Consumables & Experimental Materials			
Laboratory consumables & cleaning materials	-	-	30
Adhesives, mounting tape & assembly materials	-	-	35
Subtotal – Materials			**65**
TOTAL			**£1,757**

The technical development phase represented a major component of the first three months of the project. However, the resulting infrastructure now provides a highly reproducible and tightly controlled platform capable of investigating behavioural responses to NIR exposure under experimentally controlled conditions.

5. Protocol of the Current Study

The current pilot investigation examines whether exposure to near infrared light prior to overnight sleep deprivation alters subsequent rebound sleep behaviour in *Drosophila melanogaster*.

The study employs a between-subjects experimental design using independent cohorts of male flies monitored continuously using automated video-based behavioural tracking.

Three experimental lighting conditions are currently being investigated:

1. Broad-spectrum incandescent light exposure.
2. Narrow-band 850 nm NIR exposure.
3. Standard non-NIR LED control exposure.

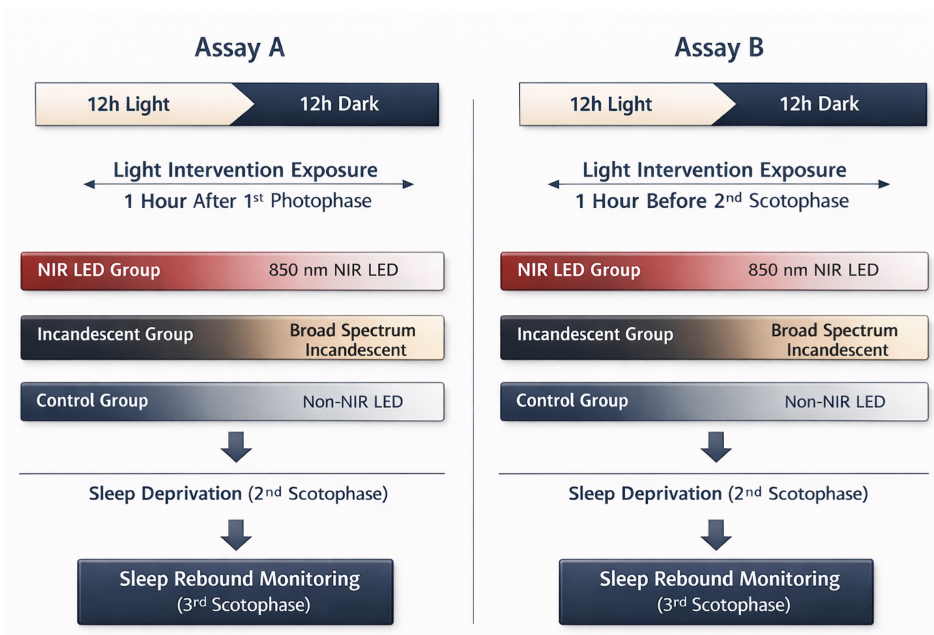

Figure 7. An overview of the experiment protocol.

The experimental protocol consists of several distinct phases. Initially, flies undergo entrainment under controlled 12-hour light and 12-hour dark cycles to establish stable baseline behavioural rhythms. Following baseline recording, experimental light interventions are administered at specific time points during the photophase.

Subsequently, flies undergo overnight sleep deprivation during the second scotophase using a controlled mechanical disturbance protocol. Behavioural recovery and rebound sleep are then monitored continuously during the subsequent recovery phase.

The primary outcome measure of the study is rebound sleep following deprivation, quantified through automated behavioural analysis. Secondary measures include sleep latency, locomotor activity patterns, and temporal characteristics of sleep recovery.

Particular emphasis has been placed upon maintaining tightly controlled environmental conditions throughout all stages of the experimental protocol. Environmental temperature, humidity, circadian timing, and monitoring conditions have been standardised across all cohorts in order to minimise confounding variables.

At present, behavioural data processing and preliminary analyses are ongoing. The current phase of work involves quality control procedures, verification of behavioural tracking outputs, and preparation of datasets for statistical analysis.

6. Potential Outcomes and Relevance to the Built Environment

The broader significance of this research lies in its potential contribution to understanding how spectral characteristics of light may influence physiological processes beyond conventional visual and circadian pathways.

Modern indoor environments are increasingly illuminated by narrow-spectrum LED lighting systems that differ substantially from both natural daylight and historical incandescent light sources. Whilst these technologies provide considerable energy efficiency advantages, they also remove substantial portions of the near infrared spectrum that humans would historically have experienced during daylight exposure.

Near infrared wavelengths constitute a major proportion of natural solar radiation and are increasingly recognised within photobiomodulation research for their potential interactions with mitochondrial processes, oxidative metabolism, and cellular energy production.

The present pilot study investigates whether NIR exposure may influence sleep pressure accumulation and behavioural recovery following sleep deprivation. If supported, these findings may have important implications for future environmental lighting design, particularly in settings involving prolonged indoor occupancy, shift-working schedules, circadian disruption, fatigue management, and recovery from sustained wakefulness.

The research also contributes to a growing interdisciplinary dialogue between neuroscience, sleep physiology, environmental design, and lighting engineering. As understanding of non-visual effects of light continues to develop, there may be increasing importance in considering broader spectral composition within future lighting standards and building design strategies.

Although the current work is exploratory and utilises a *Drosophila* model, the conserved nature of mitochondrial function and sleep regulation provides important translational relevance for future human investigations.

The project therefore remains closely aligned with the objectives of the Society of Light and Lighting in advancing understanding of how lighting conditions may influence health, wellbeing, and human performance within the built environment.

7. Plan for the Next Three Months

The next phase of the project will focus primarily upon behavioural data processing, statistical analysis, interpretation of findings, and preparation of academic outputs.

Current experimental datasets are undergoing quality control procedures and behavioural validation prior to formal statistical analysis. Particular attention is being given to ensuring consistency in behavioural tracking outputs and verification of sleep scoring procedures.

Over the next three months, planned activities include completion of behavioural sleep analyses across all experimental cohorts, statistical comparison between lighting intervention conditions, and generation of publication-quality data visualisations.

In parallel, the findings from the pilot study will be integrated into the broader doctoral framework examining near infrared exposure, sleep physiology, and environmental lighting design.

The forthcoming phase of work will also involve preparation of doctoral upgrade documentation, drafting of dissertation chapters, and development of a manuscript for submission to a peer-reviewed academic journal.

In addition, the current pilot study will inform the development of future translational human research proposals examining the influence of NIR exposure within indoor lighting environments.

The present project is therefore intended to provide a foundational behavioural framework supporting future investigations into the relationship between NIR spectral light exposure, sleep physiology, and the built environment.

I would again like to thank the Society of Light and Lighting and the Jean Heap Bursary panel for their continued support of this research.