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IT3920 - Master in Informatics

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Abstract

This thesis explores the design and evaluation of a novel mobile application aimed at improving sleep quality by modifying light exposure behavior, a primary regulator of the human circadian rhythm. Sleep quality issues, prevalent worldwide, are especially pronounced in northern regions due to large seasonal variations in daylight hours, resulting in significant circadian rhythm shifts. The application, in conjunction with a wearable light sensor, provides personalized feedback designed to increase user awareness of light exposure patterns and motivate behavioral adjustments to optimize circadian rhythm regulation. The application's design is grounded in theoretical models of behavior change.

The thesis is organized around two key research questions:

Can feedback derived from light exposure tracking improve knowledge and attitudes towards healthy light exposure and induce change in behaviors? Does the manner of presenting and interacting with the data increase the likelihood of behavioral change? These questions are addressed through multiple evaluation iterations involving potential users, comparing attitudes and behaviors before and after the use of the application. Concept and prototype evaluations, user testing, and in-depth interviews provide valuable qualitative and quantitative data.

The findings from this research underline the significance of personalized feedback and the impact of a self-determination based model of behavior change in motivating users to modify light exposure behaviors. The study further highlights areas for future work, including testing with larger and more diverse population samples, enhancing measurement accuracy, and exploring additional behavior change models. The research implications extend to the development of applications and sensors for improved sleep and overall well-being.

Contents

Chapter 1

Introduction

1.1 Motivations

The importance of light exposure for human health and well-being is well-documented. Light exposure influences our circadian rhythms, sleep patterns, mood, and overall health. However, in today's digital age, many people spend the majority of their time indoors, often in front of screens, which can lead to suboptimal light exposure patterns. This, in turn, can disrupt our circadian rhythms and negatively impact our health and well-being.

The potential of Information and Communication Technology (ICT) in promoting healthy light exposure habits is a promising area of research. ICT can provide personalized feedback and interactive data presentation, which can potentially motivate individuals to change their light exposure habits. However, the effectiveness of such interventions and the best ways to implement them are still open questions.

1.2 Project and Context

This master's thesis is conducted within the field of Health and Well-being in Built Environments. The research is part of a research project called SWELL, which aims to nurture health and well-being in urban environments by addressing the complex interaction between individual human well-being and the built environment. The project employs interdisciplinary, cross-professional, and multi-sector collaboration and Urban Living Labs to achieve greater social and economic goals.

The specific focus of this thesis is on the use of Information and Communication Technology (ICT) to promote healthy light exposure habits. The research is centered around a mobile application designed to increase users' awareness about their light exposure by providing feedback based on their light exposure and location data. The application is part of a broader effort to raise awareness and empower behavior changes towards healthier light environments in urban settings.

The research conducted in this thesis is part of the course IT3920 - Master in Informatics, Master's Thesis at the Norwegian University of Science and Technology (NTNU) in Trondheim. The purpose of this report is to demonstrate the student's ability to work independently at an advanced level and to acquire and create new knowledge within the student's field of specialization, in this case, software engineering.

1.3 Contribution

This thesis contributes to the field by exploring the potential of ICT in promoting healthy light exposure habits. It investigates the effectiveness of personalized feedback and interactive data presentation in motivating behavior change. The research also explores the potential of using location data in conjunction with light exposure data to promote healthier light environments. Furthermore, it delves into the potential benefits of personalizing light exposure feedback based on individual attributes such as chronotype, age, or thresholds for melatonin suppression and circadian phase shifting.

1.4 Research Goal

The goal of this research is to explore the potential of ICT in promoting healthy light exposure habits and to investigate the effectiveness of different strategies to motivate behavior change in this context.

1.5 Research Questions

The research questions for this study are:

1. Can feedback derived from light exposure tracking improve knowledge and attitudes toward healthy light exposure?
2. Does the presentation of, and manner of interaction with the data increase the chance of behavior change for the participant?

A more thorough explanation of the research goals and their motivations is given in Section 4.1.

Chapter 2

Background

2.1 Sleep Problems and their Implications

Insufficient sleep is recognized as a pervasive issue with substantial public health implications [7]. Necessary for optimal physical and mental health as well as overall quality of life, good sleep has become increasingly elusive in the 24-hour society of today. Insufficient sleep not only leads to adverse medical and mental dysfunctions but is also under-reported, often unrecognized, and carries high economic costs.

Globally, the problem of insufficient sleep spans across different age groups, contributing to the growing burden of diseases. The consequences of sleep deficiency can be quite severe, disrupting body systems, and leading to a rise in cardiovascular morbidity, diabetes mellitus, and obesity. Moreover, insufficient sleep can result in impaired cognitive functions, increasing the likelihood of vehicular accidents and workplace incidents [7].

The increasing usage of smartphones and electronic devices has further exacerbated the epidemic of insufficient sleep. There is a noted correlation between insufficient sleep and overweight adolescents, who may also experience depressive symptoms. As such, the assessment of sleep quality should be considered a significant early risk indicator, offering a proactive approach to reducing the incidence of a wide spectrum of health complications [7].

2.2 Light Exposure and Circadian Rhythm

The human circadian rhythm is a near 24-hour internal clock that regulates our sleep-wake cycle and influences various physiological processes [**plosbiology2020**]. The circadian rhythm is significantly influenced by environmental cues, with light being the most powerful zeitgeber (a term from German meaning "time giver") [**springer2021**].

Exposure to bright light during wakefulness has been shown to improve sleep quality in healthy men, demonstrating the direct influence of light on sleep patterns [**sagepub2021**]. Furthermore, bright light therapy has proven beneficial in managing sleep disturbances and functional outcomes in delirious older hospitalized adults, emphasizing the therapeutic potential of light [**ncbi2013**]. This therapy has also been successfully used to prevent circadian rhythm desynchronization during chemotherapy for breast cancer, illustrating its broader health implications [**tandfonline2011**].

Light's impact on the circadian rhythm is not uniform across the day. For instance, morning light exposure has shown positive effects in treating winter depression, indicating the timing of light exposure may play a critical role [**jamanetwork1998**]. The influence of light is also modulated by its intensity, duration, and spectral quality. For example, the degree of melatonin suppression at night is related to the intensity of daytime light exposure [**ncbi2015**]. Also, intermittent light exposure is more effective in resetting the circadian rhythm than continuous exposure [**jci2016**].

Blue light in particular has been noted for its substantial impact on the circadian rhythm, primarily driven by melanopsin, a photopigment found in the retinal ganglion cells of the eye [**jpinealres2019**, **ncbi2018**]. As such, exposure to blue light during the evening can lead to phase shifts in the circadian rhythm and delay sleep onset.

In summary, light exposure significantly influences the human circadian rhythm. The timing, intensity, duration, and spectral quality of light exposure can have considerable impacts on sleep quality, mood, and overall health. Future research should focus on optimizing light exposure for therapeutic purposes and understanding its long-term effects on circadian rhythm disorders.

2.2.1 Light exposure recommendations

The light exposure recommendation values used in the application are based on the following sources:

- The calculations for circadian phase shift are based primarily on Hilaire et al.[17]
- The calculations for melatonin suppression are based primarily on Nowokin et al.[13]
- The calculations for melatonin suppression are based primarily on Zeitser et al.[5]

Chapter 3

Literature Review

3.1 Goal of behavior change models in ICT scoping review

The first goal of the scoping review was to explore whether there was research on the specific use of behavior models and ICT to improve light viewing behavior.

As this is a very narrow search, a second goal was also created, which was to explore what has been written on behavior change models for ICT in general, and compile a

3.2 Goal of literature review on optimal light exposure

A literature review on optimal light exposure was performed in order to find the best supported model for optimal lux values relative to the phase of the circadian rhythm. A secondary goal was to find out if there is any consensus on the optimal way to phase shift circadian rhythm in a beneficial way using light.

3.3 Scoping review of behavior change models

Sources used

- **IEEEXplore and ACM Library:** IEEEXplore and the ACM Digital Library were used as the primary sources for papers as they are considered among the best academic databases for computer science. These are preferred over Google Scholar or other more general academic databases in order to reduce the number of irrelevant results.
- **Google scholar:** If IEEE and ACM did not yield adequate results, Google Scholar was used for its larger data set.
- **PubMed:** For search terms specific to light in relation to health (meaning not relating to IT) PubMed was used as it is the leading database of academic papers within medicine.

3.4 ICT for Changing light viewing behavior

The first set of search terms was used to check if there was any specific research on the use of ICT to change light viewing behavior. Search terms used where *"(ICT or IT) and (Circadian or Sleep) and (Lux) and (Behavior or Behavior or Habit)*. Lux was used instead of light to avoid results with terms such as "light weight" or similar. This search yielded limited results in IEEEXplore and ACM. The search was therefore repeated in Google Scholar due to its larger dataset, but still did not yield many results. In total, 23 papers were found. The articles were evaluated on the basis of the following inclusion and exclusion criteria.

Inclusion Criteria

- A systematic process for altering behavior has been used.
- The process relied primarily on ICT.
- The behavior to change involved the participants light viewing behavior.

Exclusion criteria

- Written earlier than the year 2010.

This produced only two papers that were convincingly relevant (Appendix 11.1.3) and two that were somewhat relevant.

3.5 General behavior change models used in ICT

As the search for ICT for behavior change had limited results when related to lux specifically, a more general search for behavior change and ICT was performed, in order to get an overview of what behavior change models in ICT looks most effective and needs more research. The search terms used were *(ICT or IT) and (Behavior change)*. The papers where evaluated based on the following inclusion and exclusion criteria.

Inclusion Criteria

- A systematic process for altering behavior has been used.
- The process relied primarily on ICT.
- One or more specific and well-defined behavior change models were used.

Exclusion criteria

- Written earlier than the year 2010.

This produced 172 results11.1.3 out of which 38 were convincingly relevant and 14 were potentially relevant but to a limited extent. 28 had restricted access, so only abstract could be read. A set of behavior change models that fit the requirements were identified and are further described in Chapter **??**. Figure 3.1 shows the number of papers in which a set of models and keywords have been referenced.

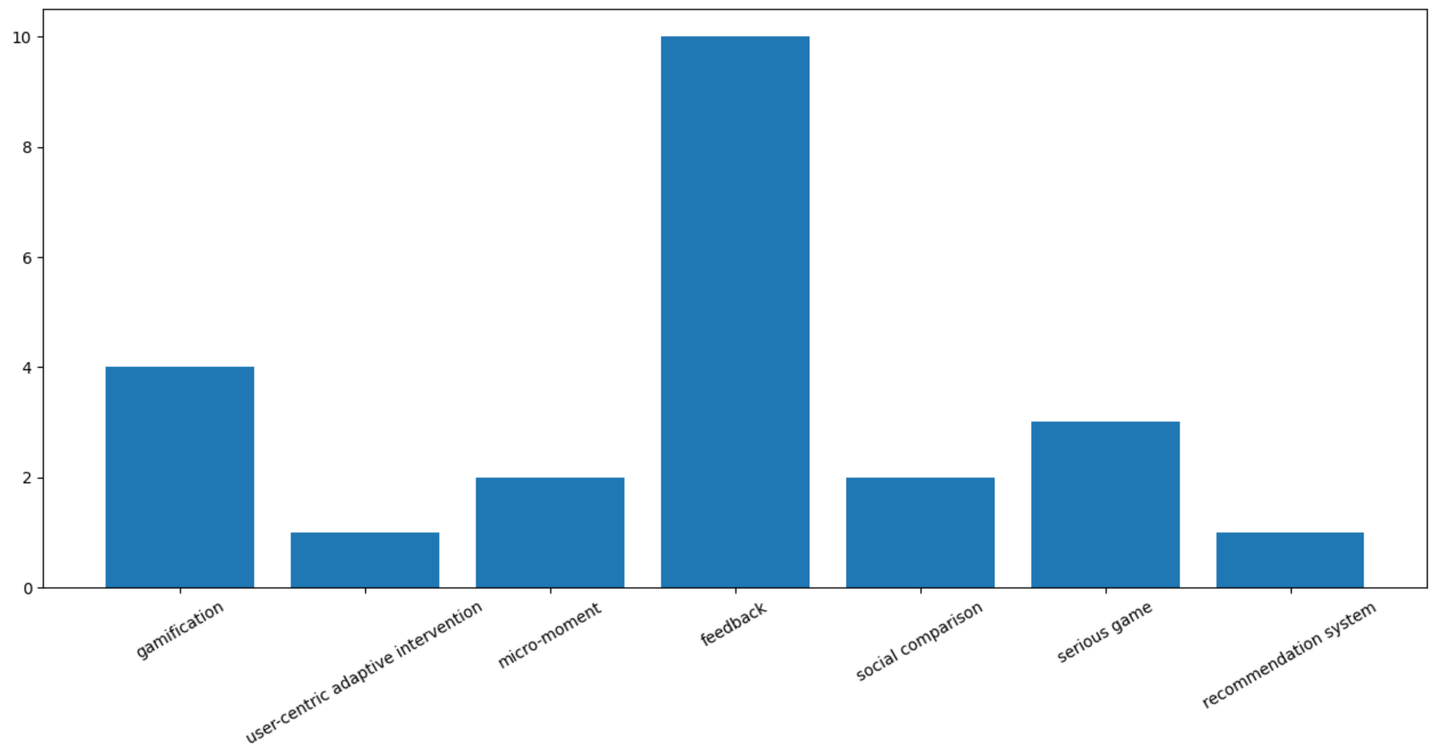


Figure 3.1: Models used in relevant papers

3.6 Technology review

A small technology review was performed in order to find systems and applications similar to the one described in Section **??**. Apple App Store and Google Play Store were searched for *("lux" OR "light exposure")*, but did not produce results beyond light measurement apps. In terms of equivalents to the Arduino Nano, it is very common for smart watches to have both ambient light sensors and Bluetooth; however, few of them give the user access to the ambient light data, and it is unclear how accurate the sensor is (mostly it is used to adjust screen brightness).

3.7 Literature review on light viewing for circadian rhythm

A search was performed in PubMed using the search term *(light exposure OR lux) AND (circadian) AND (optimal)*. The search yielded 47 results 11.1.3. The following inclusion and exclusion criteria were used to judge whether the papers were relevant.

Inclusion Criteria

- Specific numbers are given optimal light values at specific times or phases in the circadian cycle.
- Based on empirical data.

Exclusion criteria

- Written earlier than the year 2000.

12 were considered convincingly relevant, 5 were somewhat relevant and 30 were not considered relevant. In conclusion, there is no completely clear consensus on what specific values or thresholds are optimal to entrain the circadian clock. However, Brown et al.[4] released a paper in March 2022, which, based on the results of this literature review, appears to be the most up-to-date and extensive paper on optimal light exposure in each part of the day.

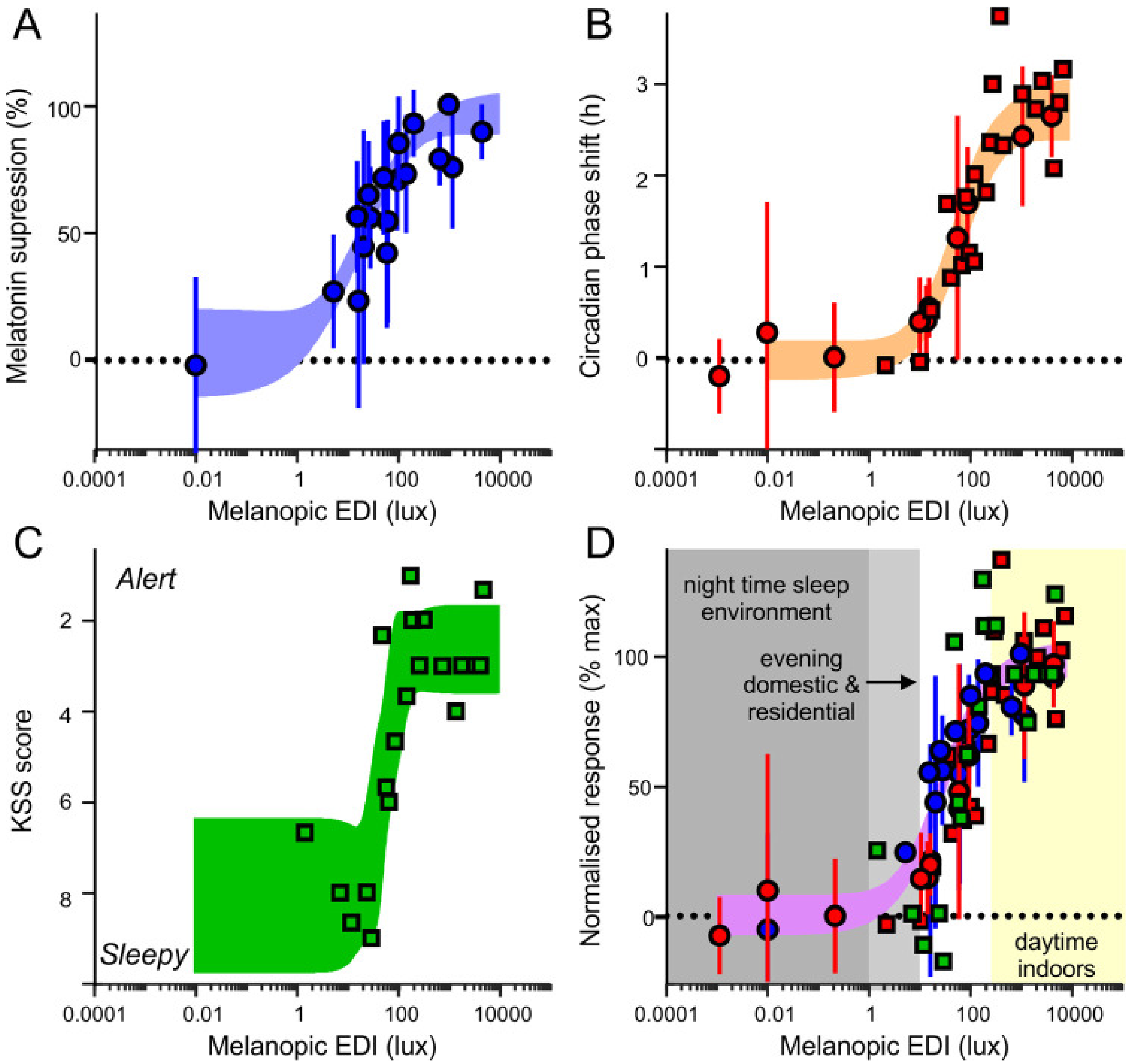


Figure 3.2: Recommendation for light exposure graphs (by Brown et al.[4]

Figure 3.2 shows specific lux value recommendations (graph D) by Brown et al. based on three different metrics (graphs A-C).

- A: KSS score (Karolinska Sleepiness Scale score)
- B: Melatonin suppression. Melatonin is the primary hormone that causes sleepiness
- C: circadian phase shift. Describes the adjustment of circadian rhythm

- D: Normalized response. Specific light recommendations for each part of the day, based on graphs A-C

3.8 Further topics to explore

These are some areas that would be valuable to explore further that were either revealed during the scoping review, or were not prioritized in this thesis in order to limit the scope:

- Currently, the application tracks location, but the literature on how this location data could be used in conjunction with light exposure data was not explored in depth in this thesis. The correlations between geographical location and light exposure can be explored from a city planning and architecture perspective, by correlating architectural features and design of public spaces with the effect it has in terms of healthy light exposure. If one could clearly correlate problematic light exposure to certain city features, based on location, the data could be used in city planning to inform decisions that promote healthier light environments.

- A deeper exploration into personalization of light exposure feedback, particularly in relation to individual attributes such as chronotype, age, or thresholds for melatonin suppression and circadian phase shifting, presents a promising direction for future research. Chronotype, or an individual's natural inclination towards specific sleep and wake times, can significantly influence the effectiveness of different light exposure interventions. Personalized light exposure recommendations that take into account an individual's chronotype could potentially lead to more effective circadian rhythm recommendations and improved sleep quality. However, the viability of accurately determining these personal attributes in a non-intrusive and simple manner remains a challenge. Age and chronotype can be determined with simple questions, but finding the specific individual thresholds for melatonin suppression, circadian phase shift and alerting effects of light is a lot more challenging. Additionally, the extent to which such personalized adjustments provide significant added value over general recommendations is yet to be fully understood. A more thorough exploration of personalization of light exposure feedback could make it easier to determine which personalized considerations are most useful and viable to include.

Chapter 4

Methodology

This chapter will describe the general research framework and the methodology decisions for the paper. The specific methodology for the concept evaluation and prototype evaluation are described in Chapter 5 and Chapter 6, respectively. Based on the literary review in 3, as well as discussion with supervisor and others with relevant expertise, the following research questions where created:

4.1 Research Questions

This research aims to explore the potential of Information and Communication Technology (ICT) in promoting healthy light exposure habits. The research questions have been formulated based on the findings from the literature review presented in Chapter 3.

4.1.1 Research Question 1

Can feedback derived from light exposure tracking improve knowledge and attitudes toward healthy light exposure? This question is motivated by the lack of research found on the specific use of behavior models and ICT to improve light viewing behavior.

- Can personalised feedback help participants change their attitudes toward timing of light exposure?
- Does personalized feedback increase motivation for habit and behavior change?

4.1.2 Research Question 2

Does the presentation of, and manner of interaction with the data increase the chance of behavior change for the participant? This question arises from the general behavior change models used in ICT found in the literature review.

- Does a self-determination based model of behavior change make participants more motivated to change compared to just getting data and recommendations?
- Does personalized feedback bring significant added value compared to general feedback?
- Is personalized and interactive feedback useful for increasing knowledge about healthy light exposure?

4.2 Research Framework

The methodology for this research is inspired by the interdisciplinary and systems-oriented approach presented in "A New Framework for Computer Science and Engineering"[16]. This approach combines elements of computer science and engineering, focusing on the integration of academic and systems-oriented perspectives.

4.2.1 System Design and Implementation

The first step in our methodology involves the design and implementation of a system that integrates various aspects of computer science and engineering. This system will be designed based on principles from both academic and systems-oriented perspectives, as suggested by the framework. The design and requirements for the system will be created based on concept evaluations, as described in Chapter 5. The final design and requirements can be found in Chapter 8 and Chapter 7, respectively.

4.2.2 Data Collection and Analysis

Data collection will be primarily through user testing and interviews. Both quantitative and qualitative data will be collected in the interviews, as described in Chapter 5. Additionally, the time-stamped light exposure and location data from the user tests, described in Chapter 6, will be stored on a cloud server.

The collected data will be analyzed using appropriate statistical and qualitative analysis methods. System performance data will be analyzed to assess the efficiency and effectiveness of the system. The interview transcripts will be analyzed using thematic analysis to identify common themes related to system use and effectiveness. User feedback will be analyzed to assess user satisfaction and identify areas for improvement.

4.2.3 Ethical Considerations

In conducting this research, several steps were taken to ensure compliance with the ethical and legal standards set forth by NTNU. The Sikt Notification Form was utilized to ensure compliance with university guidelines.

The data collected during the user testing is anonymized but can still be used to identify participants due to the location tracking. Therefore, the data will be aggregated before it can be used for further research after this study to ensure the anonymity of the participants.

Consent will be documented manually for each participant by having the participants sign the information letter shown in Appendix 11.1.3. Participants may withdraw their consent at any time by contacting the master student or supervisor. Participants may also request access to their personal data or have their personal data corrected or deleted by contacting the master student or supervisor.

No personal data will be transferred or made available to a third country or international organization outside the EU/EEA. Directly identifiable data will not be stored separately from the rest of the collected data, as location data are only useful if they can be directly correlated with light intensity and time.

Technical and practical measures that will be used to secure personal data include sending/transferring personal data in encrypted form, storing personal data in encrypted form, maintaining a record of changes, restricting access, and maintaining an access log.

4.2.4 Limitations

This framework has multiple limitations that should be acknowledged. In particular, the framework for this study has problems in the following areas:

- **Data Collection:** The data collection is primarily through user testing and interviews. These methods may introduce biases, such as social desirability bias in interviews or performance bias in user testing. The reliance on self-reported subjective data could also be a limitation, as it may not accurately reflect actual behaviors or experiences.
- **Data Analysis:** The data analysis for this study is largely based on qualitative data. While qualitative data can provide rich and detailed insights, it also has weaknesses. Interpretation of qualitative data

can be subjective and may vary between researchers. It also does not lend itself to statistical analysis, which can make it difficult to quantify effects or draw definitive conclusions.

- **Generalizability:** The findings of this study may not be generalizable to all contexts or populations. The user testing and interviews involved exclusively students from the researcher's and supervisor's networks, all students at the Norwegian University of Science and Technology. Their experiences and responses may not represent those of all potential users. Furthermore, the project had a very small sample size, which further limits the generalizability of the findings.

Chapter 5

Concept Evaluation

This chapter describes the methodology used in the concept evaluation. The concept evaluation consisted of two primary parts.

- **UI/Concept interviews:** The primary method of gathering feedback on the UI and concept was through two rounds of interviews. They is further described in Section 5.1. The results of the evaluation can be found in **??**. The specific interview answers can be found in Appendix 11.1.3
- **SWELL presentation feedback:** A concept presentation was held for the SWELL project at NTNU. After the presentation, the listeners were given a small questionnaire where they could give feedback on the concept. It is described in further detail in Section 9.1.1.

Following the interviews, a concept presentation was given to members of the SWELL project at NTNU. This project aims to contribute to healthy and sustainable urban environments through increased knowledge and understanding among citizens about the impacts of their actions on their health, environment, and community. Feedback was collected through a post-presentation form, which allowed the members to rate the usefulness and potential benefits of the concept, and to provide additional comments and suggestions.

To ensure the quality and reliability of the feedback collected, all interviews were conducted following a pre-established interview guide (Appendix 11.1.3). Data from interviews and feedback forms were analyzed using content analysis

5.1 Concept and UI Interviews

The evaluation of the proposed concept comprises two rounds of interviews. The aim is to elicit qualitative feedback on the Figma design and the overall concept based on a structured questionnaire. This questionnaire probes the participants' impressions, expectations, and suggestions for improvement. To assess the UI, participants were tasked to interact with a semi-functional Figma design while verbalizing their thought process, known as the think-aloud method.

The design of this evaluation adheres to a human-centered approach, emphasizing the importance of understanding users' needs and experiences [12, 15]. It includes interviews and a concept presentation for feedback.

The primary objectives are to assess user experiences with the Figma design, collect feedback on the overall concept, and understand user perceptions toward the proposed application. This evaluation will help identify key design elements that could enhance usability and appeal for target users and provide insight into the viability of further exploration of the concept.

Ethically, participants were briefed about the study's purpose, their voluntary participation, and measures ensuring confidentiality and anonymity before each interview. Informed consent was acquired from all participants. The study adhered to ethical guidelines for research involving medical information about human subjects [2].

5.1.1 Participant Selection

The first round of interviews had two participants which were students in the supervisor's network. The second round interview had only one participant. The participant chosen for the second round was a student from the author's extended network (extended in this case means someone the author does not know personally, but a friend of a friend). The participant was chosen because of their extensive IT design experience and education.

5.1.2 Content Analysis

The methodological approach to analyze the data obtained from these interviews was primarily qualitative content analysis, as it allows for in-depth exploration of the participants' responses, allowing us to gain rich, detailed insights [9]. This method is particularly appropriate when dealing with a limited number of interviews, as it focuses more on the depth and complexity of the data rather than the breadth or generalizability of the findings. In the context of our study, content analysis allowed us to identify recurring patterns or themes in the participants' responses, which were then coded and classified based on their relevance to our research questions.

5.2 SWELL Presentation

The SWELL presentation served as an opportunity to present the concept to a wider audience and collect expert feedback. A post-presentation form was used to gather the audience's ratings and comments on the concept. The details of the form and the feedback collected are provided in Appendix 11.1.3. As the SWELL questionnaire mostly had numerical answers, no advanced content analysis was needed.

5.3 Summary

This chapter presented the methodology and outcomes of the concept evaluation, encompassing two primary components: UI/concept interviews and SWELL presentation feedback. The interviews, grounded in a human-centered design approach, served to gather qualitative user feedback on the Figma design and the overall concept. Through the application of the think-aloud method, valuable insights into user interactions and perceptions were gleaned.

The chosen participants, primarily from the student network, provided perspectives shaped by their IT design experiences and education. The data analysis relied on qualitative content analysis, focusing on the depth and complexity of participant responses. This in-depth exploration enabled the identification of recurring patterns, themes, and key design elements to enhance usability and user appeal, and to gauge the overall viability of the concept.

The SWELL presentation allowed for a wider dissemination of the concept and the collection of expert feedback. A post-presentation form was used to compile audience responses, providing additional perspectives on the concept's potential benefits and areas for improvement. The feedback thus gathered reinforces the comprehensive approach taken in this evaluation, promoting an understanding of user needs, experiences, and expectations that are fundamental in the iterative process of concept development.

Chapter 6

Prototype Evaluation

This chapter outlines the methodology employed in the light exposure evaluation. The evaluation comprised two main components.

- **Light Exposure Interviews:** The primary method of gathering feedback on the light exposure concept was through two rounds of interviews. These are further described in Section **??**. The results of the evaluation can be found in **??**. The specific interview answers can be found in Appendix **??**
- **SWELL presentation feedback:** A concept presentation was held for the SWELL project at NTNU. After the presentation, the listeners were given a small questionnaire where they could give feedback on the concept. It is described in further detail in Section 9.1.1.

Following the interviews, a concept presentation was given to members of the SWELL project at NTNU. This project aims to contribute to healthy and sustainable urban environments through increased knowledge and understanding among citizens about the impacts of their actions on their health, environment, and community. Feedback was collected through a post-presentation form, which allowed the members to rate the usefulness and potential benefits of the concept, and to provide additional comments and suggestions.

To ensure the quality and reliability of the feedback collected, all interviews were conducted following a pre-established interview guide (Appendix 11.1.3). Data from interviews and feedback forms were analyzed using content analysis.

6.1 User Test Interviews

The evaluation of the proposed light exposure concept comprises two rounds of interviews. The aim is to elicit qualitative feedback on the light exposure sensor and app based on a structured questionnaire. This questionnaire probes the participants' impressions, expectations, and suggestions for improvement.

The design of this evaluation adheres to a human-centered approach, emphasizing the importance of understanding users' needs and experiences [12, 15]. It includes interviews and a concept presentation for feedback.

The primary objectives are to assess user experiences with the light exposure sensor and app, collect feedback on the overall concept, and understand user perceptions toward the proposed application. This evaluation will help identify key design elements that could enhance usability and appeal for target users and provide insight into the viability of further exploration of the concept.

Ethically, participants were briefed about the study's purpose, their voluntary participation, and measures ensuring confidentiality and anonymity before each interview. Informed consent was acquired from all participants. The study adhered to ethical guidelines for research involving medical information about human subjects [2].

6.1.1 Participant Selection

The first round of interviews had two participants which were students in the supervisor's network. The second round interview had only one participant. The participant chosen for the second round was a student from the author's extended network (extended in this case means someone the author does not know personally, but a friend of a friend). The participant was chosen because of their extensive IT design experience and education.

6.1.2 Content Analysis

The methodological approach to analyze the data obtained from these interviews was primarily qualitative content analysis, as it allows for in-depth exploration of the participants' responses, allowing us to gain rich, detailed insights [9]. This method is particularly appropriate when dealing with a limited number of interviews, as it focuses more on the depth and complexity of the data rather than the breadth or generalizability of the findings. In the context of our study, content analysis allowed us to identify recurring patterns or themes in the participants' responses, which were then coded and classified based on their relevance to our research questions.

6.1.3 Comparative Analysis Methodology

The comparative analysis was conducted to evaluate the changes in participants' understanding, attitudes, and behaviors regarding light exposure and its impact on sleep, before and after using the app and sensor. The methodology for this comparative analysis is outlined below.

Procedure

Each participant was interviewed twice, once before and once after the user test. The interviews consisted of a series of questions designed to assess the participants' understanding of light exposure, their attitudes towards managing their light exposure, their comfort with using technology for health tracking, and their knowledge of light intensity.

In addition to the interviews, the participants were also asked to complete a quiz before and after the user test. The quiz was designed to assess the participants' knowledge of light intensity. The participants were asked to place various light sources on a scale of light intensity, ranging from 0 to 100,000 lux.

Data Analysis

The responses from the interviews and quizzes were analyzed to identify changes in the participants' understanding, attitudes, and behaviors. The analysis focused on comparing the participants' responses before and after the user test.

For each question in the interviews, the participants' responses were compared to identify any changes in their understanding, attitudes, or behaviors. For the quiz, the participants' placements of the light sources on the scale were compared to identify any changes in their knowledge of light intensity.

Evaluation Criteria

The comparative analysis was guided by the following evaluation criteria:

- Understanding of Light Exposure: Did the participants' understanding of the importance of light exposure for sleep improve after the user test?
- Attitudes towards Light Exposure: Did the participants' attitudes towards managing their light exposure change after the user test?
- Use of Technology for Health Tracking: Did the participants' comfort with using technology for health tracking increase after the user test?

- Knowledge of Light Intensity: Did the participants' knowledge of light intensity improve after the user test?

The results of the comparative analysis were then used to evaluate the effectiveness of the app and sensor in enhancing the participants' understanding, attitudes, and behaviors regarding light exposure and its impact on sleep.

6.2 Summary

This chapter detailed the comprehensive evaluation of the light exposure sensor and app prototype, which was conducted through two primary methods: user test interviews and feedback from a concept presentation to the SWELL project at NTNU. The user test interviews, conducted before and after the user test, provided valuable insights into the participants' understanding, attitudes, and behaviors regarding light exposure and its impact on sleep. The interviews were guided by a structured questionnaire, and the responses were analyzed using qualitative content analysis to identify recurring patterns or themes.

In addition to the interviews, the participants completed a quiz before and after the user test to assess their knowledge of light intensity. The comparative analysis of the quiz results and interview responses revealed changes in the participants' understanding, attitudes, and behaviors, which were evaluated based on specific criteria.

The feedback from the SWELL project presentation further supplemented the evaluation by providing an external perspective on the concept's usefulness and potential benefits. The combination of these evaluation methods allowed for a thorough assessment of the prototype's effectiveness in enhancing the participants' understanding, attitudes, and behaviors regarding light exposure and its impact on sleep. The findings from this evaluation will inform future iterations of the prototype, contributing to the development of a more user-centered and effective solution.

Chapter 7

Development Process

The development process followed in this research has been iterative and feedback-oriented, involving frequent check-ins with the project supervisor and concept evaluations. As there was only one researcher working on the application, a complex development framework was not considered useful and instead a simple prioritized backlog was used.

7.1 Initial Requirements Gathering

The first step in the process was to establish the initial requirements of the project. These were created in collaboration with my supervisor, ensuring the project's goals align with academic standards and its relevance to the field of computer science and circadian rhythm study. A literature review was performed as described in Chapter 3 to determine whether there was a research gap in this area and what particular directions were the most in need of exploration. A list of functional requirements was created based on this.

General

ID	Functional Requirement	Priority	Complete
FR1	The user should be able to view current light exposure at any time.	High	Yes
FR2	The sensor should take quicker light measurements when the homepage is open.	Medium	No
FR3	The system should efficiently manage the power usage of the wearable sensor.	Low	Partial
FR5	The system should maintain consistent connectivity between the wearable sensor and the mobile application.	High	Yes
FR6	The mobile application should stay active in the background and communicate with the sensor even when the app is not open.	Medium	Yes
FR7	The user should be able to adjust their light exposure goals at any time.	Medium	No
FR8	The system should convert standard lux measurements to Melanopic lux for accurate light exposure data.	Medium	No
FR9	The user should be directed to an explanation page when necessary permissions are denied.	Medium	No
FR10	The system should work on both Android and Iphone.	Medium	No
FR11	The system should store the user's light exposure data in persistent storage.	High	Yes
FR12	The user should be able to log in to their account and maintain their session state, including goals and sensor connection id.	High	Yes
FR13	The user should be able to connect to a wearable sensor from within the application.	High	Yes
FR14	The user should be able to disconnect from the wearable sensor from within the application.	High	Yes
FR15	The user should be able to download the mobile application as an APK.	High	Yes
FR16	The user should be able to download the mobile application from Google Play or App store.	Low	No
FR17	The system should auto-connect to the wearable sensor if the device is saved in local storage.	Medium	Yes
FR18	The administrator should be able to access the light exposure data with correct timestamp and coordinates.	High	Yes
FR19	The system should automatically synchronize data between the wearable sensor, the mobile application and the back-end.	Medium	Yes
FR20	The sensor should buffer the light exposure data until it is confirmed that the application has received the data.	High	Yes
FR21	The application should change background color based on what is beneficial for that part of the day (bright at day, dark at night).	Low	No
FR22	The application homepage should have a graph with long-term adherence to goals.	Medium	No
FR23	The application homepage graph should have adjustable timespan.	Low	No

Table 7.1: General Functional Requirements

Morning Review

ID	Functional Requirement	Priority	Status
FR21	The user should receive personalized, daily feedback based on their light exposure.	High	Yes
FR22	The user should send a morning notification to the user, reminding them to check their daily light exposure review.	Medium	No
FR23	The user should see the effect light had on their circadian phase shift.	High	Yes
FR24	The user should see the effect light had on their suppression of melatonin.	High	Yes
FR25	The user should see the effect light had on their alertness level during the day.	Medium	Yes

Table 7.2: Morning Review Functional Requirements

Onboarding

ID	Functional Requirement	Priority	Status
FR26	The user should be able to take an onboarding quiz to test their understanding of light exposure.	Low	No
FR27	The user should get an explanation of healthy light exposure as an onboarding feature when opening the app the first time.	Low	No
FR28	The user should be able to access the onboarding explanation of healthy light exposure at any time.	Low	No
FR29	The user should be able to set their light exposure goals when opening the app for the first time.	High	Yes

Table 7.3: Onboarding Functional Requirements

7.2 Quality Attributes

Quality attribute requirements for a system are satisfied through the structures and behaviors of its architecture. These attributes are often poorly captured in many architectural designs. Therefore, quality attribute scenarios, consisting of six key parts, are recommended to express requirements according to Bass et. al.[3]. Usability, securty, privacy and modifiability where chosen as the primary focus in this system for the reasons outlined below in Sections 7.2.1-7.2.4.

7.2.1 Usability

Usability refers to the effectiveness, efficiency, and satisfaction with which a user can perform tasks in a particular environment. In the context of the application, it concerns how easily users can set their light exposure goals and review their progress using the mobile application. As the primary goal of the system is to improve users' understanding of a somewhat complex topic, as well as motivate them to make changes regarding it, usability is critical. Among the tactics used to ensure a high degree of usability, are the following:

- Don Norman's design principles[11, 12] where actively used during UI design and design evaluation.
- The design was evaluated based on feedback and reworked as described in Chapter 5

A Figma design (Figure 7.1) was also created and iterated on between the concept evaluations.

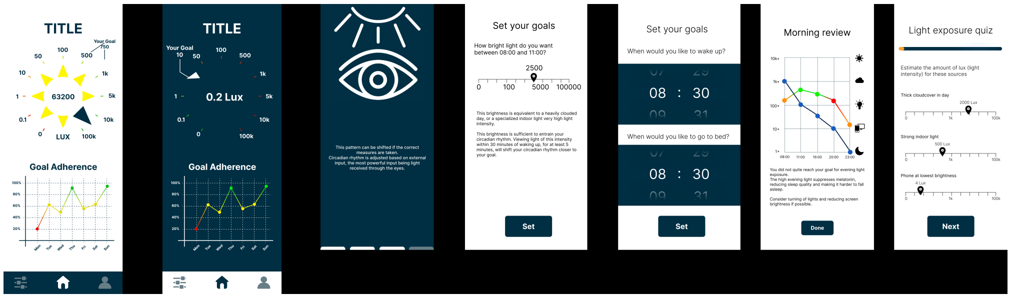


Figure 7.1: Final Figma images. The application itself iterated once more on this design as shown in Chapter 8

Quality Attribute Scenario

Source of stimulus	User
Stimulus	Using the application to set goals and review progress
Environment	Normal operation
Artifact	Mobile application
Response	System provides the ability to set goals and review feedback in a simple and understandable way
Response measure	Time to perform tasks, user satisfaction

Table 7.4: Usability Quality Attribute Scenario

7.2.2 Security

Security is the measure of the system's ability to resist unauthorized attempts at usage and potential harm. It includes the system's ability to protect sensitive user data. Security is extremely important in a system such as this where location- and health-related data is stored and was therefore a high priority. Security was ensured primarily by using an off-the-shelf backend provider with robust security (Google Firebase Firestore). This allows for reliable authentication and encryption.

Quality Attribute Scenario

Source of stimulus	Client
Stimulus	Only the correct user and admin should be access location and light exposure data
Environment	Normal operation
Artifact	Firebase Firestore Backend
Response	System resists unauthorized access, data is encrypted
Response measure	Degree of unauthorized access resisted

Table 7.5: Security Quality Attribute Scenario

7.2.3 Privacy

Privacy involves the protection of sensitive information from unauthorized access and dissemination, as well as control over personal information. This is important in this application for the same reason as described in Section 7.2.2. It is also particularly important since the users' data might be used for future research, and sufficient strategies for anonymizing data and protecting privacy must be employed. Some of the strategies employed to ensure this include:

- Data will be aggregated and generalized at the end of the project, in a way that future researcher can not infer the identity of the participants based on their location.
- When signing agreement to participate in user test, participants received contact information and instructions on how to request removal or changes to their personal data.

Quality Attribute Scenario

Source of stimulus	Client
Stimulus	Desire to change or remove personal data
Environment	Normal operation
Artifact	Firebase Firestore
Response	Admin removes or changes data
Response measure	Admin response time, degree of control over data

Table 7.6: Privacy Quality Attribute Scenario

7.2.4 Modifiability

Modifiability refers to the ease with which a system can accommodate changes to requirements. The system might be inherited and further built upon by another researcher in the future, with different goals and requirements for the system. The system must therefore be easily modifiable and easy to adopt for someone that is not familiar with it. Some examples of tactics and patterns that have been used to support this include:

- Loose coupling: The major parts of the system (sensor, application, backend) can easily be swapped out without requiring major changes to the code in the other parts.
- Application is developed in React Native, a flexible framework that can compile to Android, Ios and Web if desired.

Quality Attribute Scenario

Source of stimulus	Developers or system stakeholders
Stimulus	Requirement for a new feature or change in existing feature
Environment	During the development or maintenance phase
Artifact	System architecture
Response	System is modified to accommodate the change
Response measure	Time and resources required for modification

Table 7.7: Modifiability Quality Attribute Scenario

7.3 Concept Evaluation

Following the establishment of initial requirements, the project transitioned into the concept evaluation phase. This phase . The significance of this evaluation in shaping the project's direction cannot be understated, as it was instrumental in the subsequent refinement of project requirements.

7.4 Refining Requirements and Prioritization

After the concept evaluation, the requirements were further refined based on the insights gained. These refined requirements then formed the basis for the project backlog. Each task in the backlog was prioritized based on its relevance and impact on the project's overall goals.

7.5 Task Tracking

Task tracking was conducted using Trello, a project management tool that offers a visual way to organize tasks and track their progress. Tasks were organized into categories such as 'To Do', 'In Progress', and 'Completed'. Each task was labelled based on its priority, and moved across these categories as it went through different stages of development.

7.6 Development

The actual development process involved implementing the tasks in the prioritized backlog, starting with the highest priority tasks. This process was dynamic, allowing for the reevaluation and adjustment of tasks and priorities as necessary. Frequent interactions with the project supervisor helped keep the development process aligned with the research goals.

7.7 Feedback and Iteration

The development process was iterative, with each cycle involving development, testing, and refinement based on feedback. This approach allowed for continual improvement of the project and ensured that the final application was robust and fulfilled its intended purpose.

7.8 Conclusion

In conclusion, the development process was an iterative, dynamic process that involved continuous refinement of tasks and requirements based on feedback and concept evaluations. The tools and processes used were chosen for their simplicity and effectiveness, allowing me to focus on the primary goals of the research.

Chapter 8

System Design

8.1 Architecture

The architecture of the system is structured in a three-tier model, with the Arduino Nano 33 BLE Sense sensor acting as the data collection tier, Google Firebase Firestore for data storage and authentication, and the React Native application acting as the data presentation and user interaction tier. An administrative "interface" is also implemented using a Python script for data processing and visualization purposes.

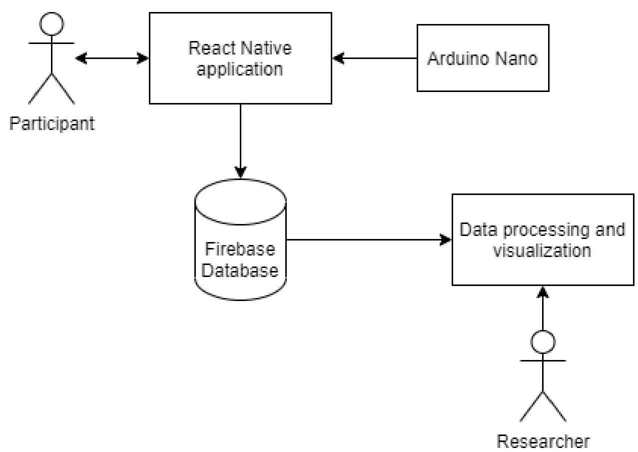


Figure 8.1: Main Architecture Diagram

8.1.1 Architecturally Significant Requirements (ASRs)

Architecturally significant requirements (ASRs) are those requirements that have a measurable effect on a system's architecture. The list below contains functional requirements and quality attributes (also known as non-functional requirements) that affected the system architecture in significant manner.

- **FR1 - Viewing current light exposure:** This requirement impacts the system architecture as it necessitates a real-time, accurate data retrieval and display mechanism.
- **FR3 & FR5 - Efficient power usage and consistent connectivity:** These requirements influence the choice of communication protocol between the wearable sensor and the mobile application. They imply the need for an architecture that promotes efficient power usage and can maintain consistent connections even in less than ideal conditions.

- **FR11 & FR18 - Data storage and administrative access:** These requirements necessitate a robust and secure database system. This impacts the choice of database technology and the design of the data schema and access mechanisms.
- **FR10 - Cross-platform compatibility:** This requirement necessitates a cross-platform development approach. This impacts the choice of development tools and frameworks, leading to the adoption of solutions like React Native that can target multiple platforms from a single codebase.
- **FR12 & FR13 - User session management and device connectivity:** These requirements influence the design of the user authentication and session management system, as well as the system's ability to manage device connections. This implies an architecture that can securely manage user sessions and handle device connectivity.
- **FR19 & FR20 - Data synchronization and buffering:** The need to synchronize data across devices and buffer data until receipt confirmation significantly impacts the design of the system's data management and error handling mechanisms. To minimize the data loss each main component of the system (sensor, application and backend) needs some degree of persistence.
- **FR21 - Personalized daily feedback:** This requirement requires two-way communication between backend and frontend. As the application only temporarily stores the data locally, a way to access the data in the backend is required. This also means that the backend requires a way too separate the data from each user and only make them available to the correct user.
- **Usability** Usability concerns how easily users can set their light exposure goals and review their progress using the mobile application. This requirement influences the design of the user interface and the interaction mechanisms within the app.
- **Security** Security measures the system's ability to resist unauthorized attempts at usage and potential harm. It is critical in a system such as this where location- and health-related data is stored. This requirement impacts the choice of backend provider, leading to the adoption of Google Firebase Firestore, known for its robust security features.
- **Privacy** Privacy involves the protection of sensitive information from unauthorized access and dissemination. This requirement influences the design of the data storage and access mechanisms, necessitating solutions that provide sufficient control over personal information.
- **Modifiability** Modifiability refers to the ease with which a system can accommodate changes to requirements. This requirement impacts the system's overall design, leading to the adoption of modular and loosely coupled architectures that can be easily modified.

8.1.2 Frontend - React Native with TypeScript

React Native, a popular open-source framework for building mobile applications, was chosen for the development of the user-facing frontend due to its ability to deliver native-like performance and its compatibility with TypeScript. TypeScript, a statically typed superset of JavaScript, was chosen to improve developer productivity and code quality, by enabling features such as static checking, code refactoring, and IntelliSense. This also increases the modifiability of the code, as it is much easier to make changes without breaking the application if it is written with strict typing. The frontend application facilitates user interactions, providing interfaces for viewing data, receiving feedback, and modifying user settings.

The architecture of the frontend utilizes the advantages of writing in React Native and is described below.

```
/
├── App.tsx
├── assets
├── index.js
├── package-lock.json
├── package.json
├── src
│   ├── components
│   │   ├── buttons
│   │   ├── charts
│   │   │   └── util
│   │   ├── Dial
│   │   │   └── util
│   │   ├── loading
│   │   ├── overlays
│   │   └── pickers
│   ├── contexts
│   ├── data
│   ├── screens
│   │   ├── homeScreen
│   │   ├── loginScreen
│   │   ├── morningReviewScreen
│   │   ├── setGoalScreen
│   │   └── settingsScreen
│   ├── styles
│   └── util
├── tsconfig.json
└── types
```

Figure 8.2: Folder structure of the React Native app (bottom level files and some generic folders are not included for the sake of keeping it compact)

8.1.3 Component-Based Architecture

React Native's fundamental principle of a component-based architecture is utilized, in which reusable and self-contained parts of the user interface encapsulate their own styles and behaviors. The directory `src/components` contains these components, which are further subdivided based on their functionality into directories such as `buttons`, `charts`, `loading`, `overlays`, and `pickers`. This degree of encapsulation and decoupling makes the components extremely easy to reuse and modify.

8.1.4 Screen-Based Architecture

The application adopts a screen-based architectural approach, embodied in the `src/screens` directory. Each subdirectory within this location encapsulates the logic and components specific to a particular screen in the application. This encapsulation aligns with the Single Responsibility Principle, as each screen component manages its own functionality and rendering.

8.1.5 Utility Functions

A clear separation of utility functions from the main application codebase is established within the `src/util` directory. These helper functions, including the likes of `adherenceCalculator.ts`, `deviceScan.ts`, and `formatting.ts`, are abstracted into this directory to avoid repetition and promote reusability throughout the application, adhering to the DRY (Don't Repeat Yourself) principle.

8.1.6 Context Management

Global state management is handled by the React Context API, as evidenced by the `src/contexts` directory. Contexts provide a means to pass data through the component tree without the need for manual prop drilling, enabling state management at a higher, more global level.

In conclusion, the application exhibits a well-structured and thoughtfully designed frontend architecture that greatly enhances both modifiability and readability. This architecture ensures that future developers can more easily understand the structure and functionality of the application and can smoothly conduct updates and modifications.

8.1.7 Backend - Google Firebase Firestore

Google Firebase Firestore is used as the back-end of the system. Firestore is a flexible and scalable NoSQL cloud database that is used for synchronization and storage of persistent data for the application, as well as an access point to the data that can be used by the researcher. It also offers a robust and reliable authentication system.

8.1.8 Sensor - Arduino Nano 33 BLE Sense

The Arduino Nano 33 BLE Sense is utilized as the wearable light sensor. This choice was motivated by its compact size, ease of use, and the fact that it contained all necessary components without requiring external components. The device collects ambient light data, which is then transferred to the application. The sensor design is further described in Section 8.2

8.1.9 Administrative Interface - Python Script

An administrative interface is created using a Python script, which is used to authenticate as an admin user and access the data stored in the Firebase Firestore. This interface is utilized for data processing and visualization purposes, allowing for a more detailed and comprehensive analysis of the collected light exposure and location data.

8.2 Sensor - Arduino Nano 33 BLE Sense

The system employs the Arduino Nano 33 BLE Sense as the wearable light sensor. This device was selected based on several key features:

- **Built-in Bluetooth Low Energy (BLE):** The Arduino Nano 33 BLE Sense includes built-in Bluetooth Low Energy (BLE) technology, which is fundamental for the sensor's power efficiency. This technology enables the sensor to run continuously throughout the day without significant energy consumption. As a wearable device, low power usage is essential for user convenience and continuous data acquisition. Moreover, having BLE built into the device contributes to the robustness of the sensor by eliminating the risk of connections coming loose during wear.

- **Integrated Light Sensor (APDS9960):** The Arduino Nano 33 BLE Sense comes equipped with an integrated APDS9960 light sensor, which eliminates the need for external components. This feature significantly reduces the potential for bugs and issues that could occur due to the integration of external hardware, and removes the risk of connections coming loose when worn. The built-in light sensor simplifies the overall design of the system and ensures more reliable data collection.

- **Versatility and Future Use:** The Arduino Nano 33 BLE Sense offers considerable versatility, making it suitable for potential future project expansions or modifications. Its range of built-in features and compatibility with various environments provide a robust and flexible platform for continuous development and innovation.

These features make the Arduino Nano 33 BLE Sense a powerful, compact, and energy efficient solution for ambient light data collection, effectively meeting the specific needs of this project.

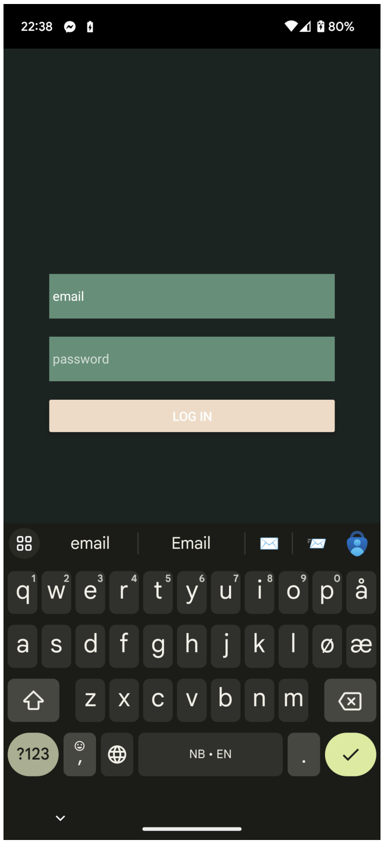
8.2.1 Power Source

A Sandberg powerbank was selected, mainly due to its Always-On mode. The Arduino Nano 33 BLE Sense, and all other powerbanks that were tested (without Always-On Mode) turned off due to the device not drawing enough current. Batteries connected directly to VIN could also solve this problem, but the risk of frying the board is significantly higher, particularly when the board needs to be on for extended periods of time.

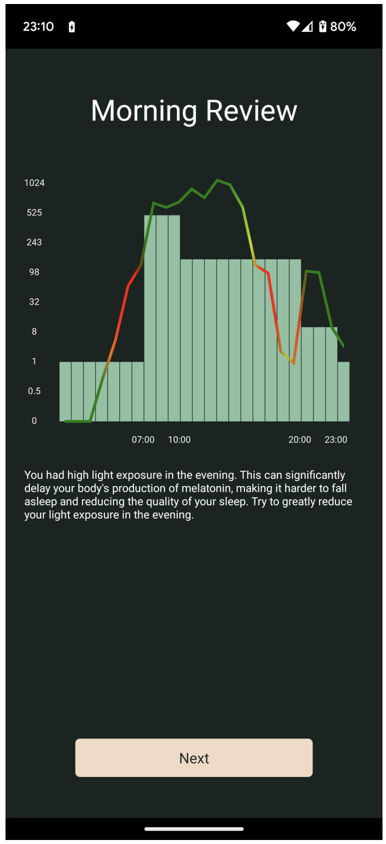
8.3 Frontend

8.3.1 Design

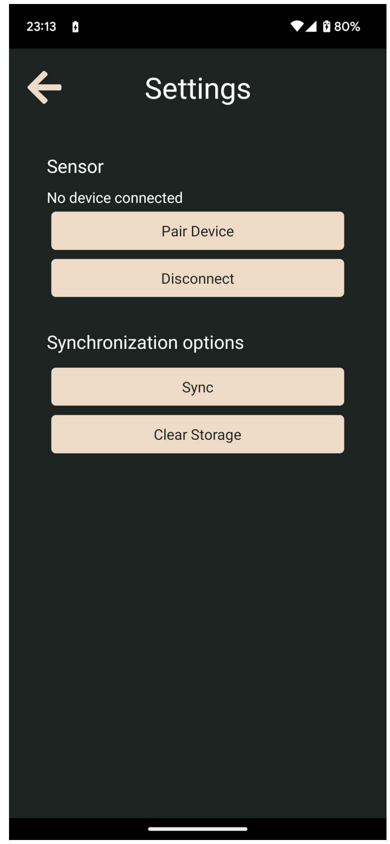
The final design was simplified due to time restraints. The included features were selected from the functional requirements on the basis of priority and expected development time. Figure 8.3 shows the different screens in the application. Section **??**, shows the process of creating, evaluating, and iterating the design.



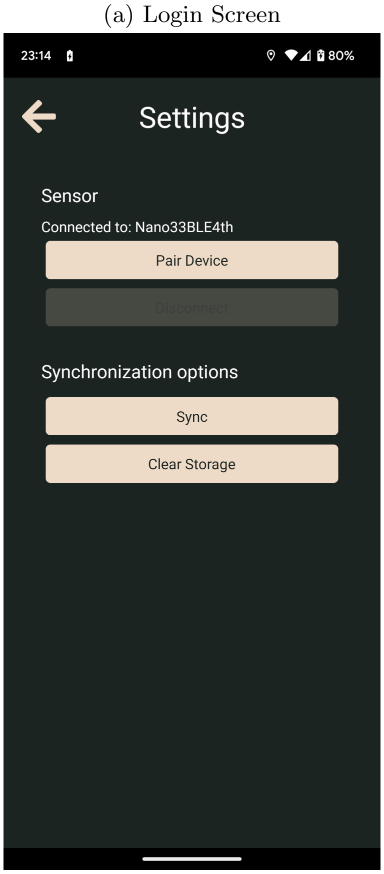
(a) Login Screen



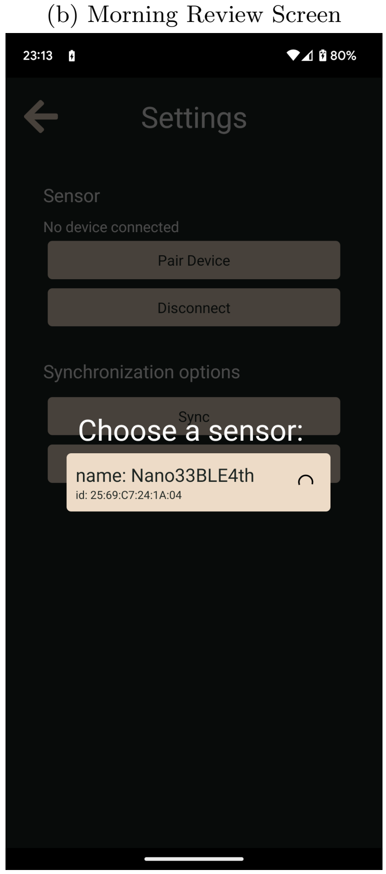
(b) Morning Review Screen



(c) Settings Screen



(d) Button Feedback Screen



(e) Button Loading Screen

(f) Homepage Screen

Figure 8.3: Final Screenshots of the Mobile Application

The final design was changed from the final Figma design based on the last round of UI feedback. Buttons were made more responsive and the homepage less confusing by adding the number in the middle instead of a graphic. The navbar was changed to a simple cog in the corner, this was also due to the fact that a navbar is highly unnecessary until more of the functional requirements are added.

8.4 Firebase Firestore

The decision to adopt Firebase Firestore as the backend of the system was influenced by a number of significant factors. These predominantly revolved around the requirements for quick development, a minimal need for business logic in the backend, and robust management of authentication and security.

8.4.1 Quick Development Time

Firebase Firestore's rich set of APIs and SDKs provided out-of-the-box solutions to many common development tasks. It offered real-time updates and complex queries, without the need to set up additional servers or write server-side code. This considerably reduced the setup and development time, thereby providing a significant advantage in the project delivery speed.

8.4.2 Minimal Backend Business Logic

The nature of the project required a majority of the business logic to reside within the wearable device, the mobile application and the admin script. Firebase Firestore, being a simple, off-the-shelf, NoSQL database provided more than enough modifiability without requiring significant development time. With its easy-to-use client-side SDKs, much of the processing could be handled directly on the device, reducing the reliance on the server for processing.

8.4.3 Robust Authentication and Security

Firebase Firestore, being a product of Google, inherently offered robust and reliable solutions for user authentication. Firestore's Security Rules provided fine-grained, attribute-based access control to the database, offering an extra layer of security to protect sensitive user information.

Chapter 9

Results

This chapter will outline the results collected in the concept evaluation and prototype evaluation.

9.1 Concept Evaluation

This sections describes the results after analyzing the data from the concept interviews.

9.1.1 Content Analysis of Interview Data

We conducted interviews with three participants with varied backgrounds - a Bachelor in Computer Science pursuing a master's degree in Industrial Design, a first-year student of Business Administration, and a third-year Architecture student. The interviews aimed at understanding user perspectives on a mobile application's design and usability. The feedback and responses were analyzed under several themes as follows:

App Design

The participants provided valuable feedback regarding the overall design of the application. They provided comments on the use of bold text, the bottom bar, margins, and the contrast of the progress bar. Issues were raised about the design elements such as font size, color scheme, and contrast. Some participants found certain design elements overwhelming, indicating the need for a cleaner and more streamlined design.

Usability

There were mixed reactions regarding the usability of the application. Some participants struggled with navigation, expressing confusion with the swipe function. There were also comments on the location and size of certain buttons, indicating that certain elements were not intuitive. However, all participants stated that they would be able to use the application without guidance or onboarding, suggesting that despite the initial confusion, the application is user-friendly.

App Features

The participants showed a positive response towards the features of the application. Comments were made about the application's responsiveness and feedback when interacting with it. However, participants also expressed confusion over certain features such as the progress bar and time picker. This suggests the need for a more detailed explanation or guidance when first using these features.

*Suggestions for Improvement

The participants offered suggestions for improvement in different aspects of the application. These suggestions ranged from visual aspects such as font size and color scheme to more complex changes such as the inclusion of new features. Some participants suggested connecting light viewing behavior to current habits and the addition of notifications, gamification, and social features.

Understanding of the Concept

All participants agreed that an app of this kind could be beneficial, showing an understanding of the concept behind the application. However, they also highlighted areas that were difficult to understand or find, indicating a need for improved clarity and visibility of features and information.

In conclusion, the feedback obtained from these interviews provides valuable insight into the usability and design of the application, highlighting areas of strength and potential improvements.

SWELL presentation The participants at the SWELL seminar were generally positive to the concept as shown in Appendix 11.1.3. The usefulness of the concept was rated, on average, at 6.8/10. It was also considered positive for health and well-being, however the answers to whether they would use the system themselves was more mixed. The participants had valuable feedback in the open question as well, but mostly in terms of widening the scope and exploring new directions for the concept.

9.2 Prototype Evaluation

Content Analysis of Interview Data

Interviews were with three participants. The interviews aimed at understanding user perspectives on the light exposure sensor and app. The feedback and responses were analyzed under several themes as follows:

Sensor and App Design

The participants provided valuable feedback regarding the overall design of the sensor and the app. They provided comments on the comfort of the sensor, the app's user interface, and the clarity of the data presented. Issues were raised about the design elements such as font size, color scheme, and contrast. Some participants found certain design elements overwhelming, indicating the need for a cleaner and more streamlined design.

Usability

There were mixed reactions with respect to the usability of the sensor and the app. Some participants struggled with wearing the sensor, expressing discomfort or inconvenience. There were also comments on the location and size of certain buttons in the app, indicating that certain elements were not intuitive. However, all participants stated that they would be able to use the app without guidance or onboarding. This implies that the physical sensor is not currently practically usable, as was expected, but the application was better.

Sensor and App Features

The participants showed a positive response towards the features of the sensor and app. Comments were made about the sensor's practicality and the app's responsiveness and feedback when interacting with it. However, participants also expressed confusion over certain features such as the light intensity scale and the goal-setting process. This suggests the need for a more detailed explanation or guidance when first using these features.

Suggestions for Improvement

The participants offered suggestions for improvement in different aspects of the sensor and app. These suggestions ranged from practical aspects such as alternative ways to wear the sensor to more complex changes such as the inclusion of new features in the app. Some participants suggested connecting light exposure behavior to current habits and the addition of notifications, gamification, and social features.

Understanding of the Concept

Participants 1 and 2 had limited understanding of the concepts before the study and showed some improvement after, as will be shown in the comparative analysis. Participant 3 was familiar with the concepts before, but stated in question 2.7 that they gained more specific knowledge than they previously had.

Comparative Analysis of Before and After Answers

The interviews conducted before and after the user test provided valuable insights into the participants' understanding and attitudes towards light exposure and its impact on sleep.

Understanding of Light Exposure

Before the user test, all participants had a basic understanding of the importance of light exposure for sleep. For instance, in question 1.7, Participant 1 stated they were unsure about the importance of light exposure, Participant 2 thought it was somewhat important, and Participant 3 believed it was very important. After the user test, all participants showed a more nuanced understanding of light exposure. In question 2.18, all participants agreed that light exposure is quite important for overall health and well-being. This suggests that the user test was effective in enhancing the participants' knowledge about light exposure.

Attitudes towards Light Exposure

Before the user test, participants' attitudes towards light exposure varied. Some were motivated to change their light exposure habits, while others did not see it as a priority. For example, in question 1.3, Participant 1 did not feel particularly motivated to change their light exposure habits, while Participant 3 was already aware of the importance of light exposure for sleep. After the user test, all participants expressed a greater interest in managing their light exposure. In question 2.6, all participants indicated that they would be more aware of their light exposure, especially in the evening. This indicates that the user test was successful in raising awareness about the importance of light exposure and motivating behavior change.

Use of Technology for Health Tracking

Before the user test, participants' comfort with using technology for health tracking ranged from moderate to high. For instance, in question 1.4, Participant 1 rated their comfort level as 5, while Participant 3 rated it as 8. After the user test, all participants expressed a greater comfort and interest in using technology for this purpose. In question 2.5, all participants agreed that they would use a sensor and app like this if it was integrated into technology they already have. This suggests that the user test was effective in demonstrating the potential of technology for health tracking.

Knowledge of Light Intensity

Before the user test, participants' knowledge of light intensity varied. For example, in the quiz before the user test, Participant 1 placed sunlight in the 5,000-10,000 lux range, while Participants 2 and 3 correctly placed it in the 10,000-50,000 lux range. After the user test, all participants correctly placed sunlight in the 50,000-100,000 lux range. This indicates that the user test was effective in improving participants' understanding of light intensity.

In conclusion, the user test appears to have had a positive impact on the participants' understanding of light exposure, their attitudes towards managing their light exposure, and their comfort with using technology for health tracking. These findings support the potential benefits of the app and provide valuable insights for its further development.

Chapter 10

Discussion

This chapter discusses the findings from the evaluation of the light exposure sensor and app prototype in relation to the research questions (RQs) outlined in the introduction. The discussion is structured around each RQ, providing a detailed analysis of how the findings from the evaluation address these questions. The chapter also discusses the limitations of the study and shares experiences and lessons learned from the process.

10.1 RQ1

The first research question (RQ1) asked: "How does the use of a light exposure sensor and app affect users' understanding of light exposure and its impact on sleep?"

The findings from the user test interviews and quizzes suggest that the use of the light exposure sensor and app significantly improved the participants' understanding of light exposure and its impact on sleep. Prior to the user test, participants had a general understanding of the importance of light exposure for sleep but lacked specific knowledge about light intensity and its effects on the circadian rhythm. After using the app and sensor, participants demonstrated a more nuanced understanding of these concepts, as evidenced by their improved quiz scores and more detailed responses in the post-test interviews.

Moreover, the app's personalized feedback and goal-setting features seemed to enhance participants' understanding by providing them with concrete, actionable information about their own light exposure habits. This suggests that personalized, real-time feedback can be an effective strategy for improving users' understanding of abstract health concepts.

10.2 RQ2

The second research question (RQ2) asked: "How does the use of a light exposure sensor and app influence users' attitudes and behaviors towards managing their light exposure?"

The findings suggest that the use of the light exposure sensor and app positively influenced participants' attitudes and behaviors towards managing their light exposure. After the user test, participants expressed a greater awareness of their light exposure habits and a stronger motivation to manage their light exposure to improve their sleep. Some participants also reported specific changes in their behaviors, such as seeking more bright light during the day and reducing their screen brightness in the evening.

These changes in attitudes and behaviors can be attributed to several factors. Firstly, the improved understanding of light exposure and its impact on sleep likely contributed to a shift in attitudes, as participants recognized the importance of managing their light exposure. Secondly, the app's personalized feedback and goal-setting features likely played a role in motivating behavior change, by providing users with a clear direction and measurable targets for improvement.

10.3 Limitations

While the findings from the evaluation are promising, the study has some strong limitations. The sample size was extremely small, with only three participants for concept evaluations and three (other) participants for user tests, and the user test period was relatively short. This limits the generalizability of the findings and the ability to assess long-term changes in understanding, attitudes, and behaviors.

Furthermore, the participants in this study were all students with a certain level of comfort with using technology for health tracking. The findings may not be representative of other populations, such as older adults or individuals with low technological literacy.

This study also only looked at willingness to change behavior, and not whether the participants actually did. Having a follow up questionnaire at a later time or a very long user test could solve this.

It would also be useful to see if the feedback actually affected sleep quality. Optimally, this would be done in a sleep lab but could also be done with a Karolinska Sleepiness Scale (KSS)[1] questionnaire.

10.4 Lessons Learned

The process of developing and evaluating the light exposure sensor and app prototype provided several valuable insights and lessons learned. These lessons not only inform future iterations of the prototype but also contribute to the broader understanding of designing and implementing health tracking technology.

10.4.1 Power Bank

One of the key lessons learned relates to the power supply for the Arduino Nano used in the prototype. The Arduino Nano has a low current draw, which can cause issues when powered by a power bank. Many power banks have an automatic shutdown feature designed to save power when the connected device is not drawing enough current. Because the Arduino Nano's current draw is so low, it can trigger this automatic shutdown, causing the power bank to turn off even while the Arduino is still in use.

To address this issue, it's necessary to use a power bank with an 'always on' mode. This mode prevents the power bank from automatically shutting down, ensuring a consistent power supply for the Arduino Nano. Future iterations of the prototype should consider this requirement when selecting a power supply.

10.4.2 Bluetooth Low Energy (BLE)

Another important lesson learned pertains to the use of Bluetooth Low Energy (BLE) for data transfer. While BLE is a power-efficient method for wireless communication, it requires acknowledgements to reliably transfer data without loss.

During the evaluation, there were instances where data sent from the sensor to the app was lost. This was likely due to the lack of acknowledgements in the BLE communication protocol used in the prototype. Without acknowledgements, the sender has no way of knowing whether the data was successfully received, leading to potential data loss if the data packet is dropped or if the receiver is not ready to receive the data.

To improve the reliability of data transfer, future iterations of the prototype should implement a BLE communication protocol with acknowledgements. This will ensure that the sender receives confirmation when data is successfully received, allowing it to resend the data if necessary.

Chapter 11

Conclusion

The aim of this thesis was to design, develop, and evaluate a light exposure sensor and app prototype that could provide users with feedback on the quality of their light exposure, with a particular focus on its impact on sleep. This objective was driven by the growing recognition of the role of light exposure in sleep health and the absence of existing applications that offer feedback on the quality of light exposure.

To achieve this aim, an extensive literature review was first conducted to gain a comprehensive understanding of existing solutions and approaches in the field. This review encompassed academic research, commercial products, and health guidelines, providing a broad perspective on the current state of knowledge and technology related to light exposure and sleep health. Following this, a concept for the light exposure sensor and app was developed in collaboration with the supervisor. This concept was designed to address the identified gaps in existing solutions, particularly the lack of feedback on the quality of light exposure.

To answer the research questions, a two-pronged evaluation approach was employed, encompassing concept evaluations and prototype evaluations. The concept evaluations involved presenting the proposed solution to a wider audience and gathering their feedback. This feedback provided valuable insights into the perceived usefulness and potential benefits of the concept, as well as suggestions for improvement.

The prototype evaluations were more hands-on, involving user testing of the light exposure sensor and app. Participants were interviewed before and after the user test, and their responses were analyzed to assess changes in their understanding, attitudes, and behaviors regarding light exposure and its impact on sleep. Additionally, participants completed a quiz before and after the user test to assess their knowledge of light intensity. The comparative analysis of the quiz results and interview responses provided a comprehensive understanding of the prototype's effectiveness in enhancing the participants' understanding, attitudes, and behaviors regarding light exposure and its impact on sleep.

11.1 Future Work

The evaluation of the light exposure sensor and app prototype has provided insights and identified several areas for future work. These areas can be broadly categorized as addressing limitations of the current study, exploring new ideas to expand the scope of the project, and adding new features to the application or sensor.

11.1.1 Addressing Limitations

Larger Sample Size and More Diverse Participants

Future studies should aim to include a larger and more diverse sample size. This would not only increase the statistical power of the study but also allow for a more comprehensive understanding of the user experience across different demographics. In particular, it would be beneficial to include participants from more varied age groups and lifestyles, not just students or those with a "normal" 9-5 schedule.

Longer Term Data and More Quantitative Data

The current study was limited in its duration and the type of data collected. Future work should aim to collect longer-term data, which could provide more useful sleep metrics and a more comprehensive understanding of the impact of light exposure on sleep over time. In addition to subjective reports, more quantitative data should be collected, such as objective sleep measurements from sleep labs.

Improving Accuracy

The accuracy of the sensor could be improved in several ways. One approach is to consider the positioning of the sensor, as its current placement may not accurately represent the light exposure experienced by the user's eyes. Another approach is to incorporate measurements of melanopic equivalent light (MEL), which could provide a more accurate representation of the light's impact on the circadian system. Finally, more advanced calculations could be used to process the sensor data, beyond the current method of calculating hourly averages with consideration for strong spikes of light.

11.1.2 Ideas to Expand

Impact on Blind People with Eyes

An interesting area for future exploration is the impact of light exposure on blind individuals who still have melanopsin-containing retinal ganglion cells. These individuals do not have functional rods and cones for photopic vision but may still experience effects on their circadian rhythm due to light exposure. An application such as this would be particularly useful for them because it is harder for them to judge whether they are getting sufficient light exposure throughout the day, without assistance.

Other Behavior Models

Future work could also explore other behavior models to understand and influence light exposure habits. This could provide additional insights into the factors that influence these habits and identify new strategies to promote healthy light exposure.

11.1.3 Application/Sensor Features

Correlate Healthy Light Exposure with Screen Time

A potential feature for the application could be to correlate healthy light exposure with screen time. This could provide users with a more comprehensive understanding of their light exposure habits and how they relate to their use of digital devices.

Improved Personalization

The application could also benefit from improved personalization features. This could include personalized recommendations based on the user's specific light exposure patterns and sleep habits, as well as personalized goals and feedback. Sensitivity to light is also highly individual[8] and could be improved by adjusting to the specific individual.

Simple Objective Sleep Metrics

Finally, the application could incorporate simple objective sleep metrics, such as sleep duration and quality. This would provide users with a more comprehensive overview of their sleep health and how it relates to their light exposure.

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Appendix

Behavior change and ICT in relation to light exposure scoping review papers

title	relevant	year	link	authors	publication type
Sleep Posture Detection Using an Accelerometer Placed on the Neck	no	2022	https://ieeexplore.ieee.org//document/9871300/	Rawan S. Abdulsadig,	Conference Paper
Improved Sleep Detection Through the Fusion of Phone Agent and Wearable Data Streams	maybe	2020	https://ieeexplore.ieee.org//document/9156211/	Gonzalo J. Martinez, Stephen M. Mattingly,	Conference Paper
Proof of Concept of a Novel Neck-Situated Wearable PPG System for	no	2021	https://ieeexplore.ieee.org//document/9441342/	Sukhpreet Singh, MichaÅ,	Journal Article
Biomechanical procedure to assess sleep restriction on motor control	no	2017	https://ieeexplore.ieee.org//document/8037094/	G.S. Umemura, C.L. Noriega, D.F.	Conference Paper
A 75 μ W Real-Time Scalable Body Area Network Controller and a	no	2012	https://ieeexplore.ieee.org//document/6069821/	Seulki Lee, Long Yan, Taehwan Roh,	Journal Article
Experimental sleep phases monitoring	no	2016	https://ieeexplore.ieee.org//document/7455976/	Oana Ramona Velicu, Natividad	Conference Paper
The Smart Patches and Wearable Band (W-Band) for comfortable sleep	no	2011	https://ieeexplore.ieee.org//document/6091741/	Seulki Lee, Long Yan, Taehwan Roh,	Conference Paper
Comparison of sleep parameters assessed by actigraphy of healthy young adults from a small town and a	yes	2017	https://ieeexplore.ieee.org//document/8227619/	G.S. Umemura, J.P. Pinho, F. Furtado, B.S.B. GonÃ§alves,	Conference Paper
Wearable Sensor-Based Human Exhalation Rhythm Recognition using	no	2022	https://ieeexplore.ieee.org//document/9914288/	S. Jaanaa Rubavathy, G R	Conference Paper
Sustained logging and discrimination of sleep postures with low-level,	maybe	2008	https://ieeexplore.ieee.org//document/4911588/	Kristof Van Laerhoven, Marko	Conference Paper
An N-of-1 Investigation into Stress-Related Hemodynamics in the	no	2021	https://ieeexplore.ieee.org//document/9659157/	Zilu Liang	Conference Paper
Wearable ECG recorder with acceleration sensors for monitoring	no	2013	https://ieeexplore.ieee.org//document/6610601/	Y. Okada, T. Y. Yoto, T. Suzuki, S.	Conference Paper
A multimodal drowsiness monitoring ear-module system with closed-loop	no	2016	https://ieeexplore.ieee.org//document/7833850/	Unsoo Ha, Hoi-Jun Yoo	Conference Paper
Verification methodology for Smart Awakening Systems	no	2021	https://ieeexplore.ieee.org//document/9629977/	Denys Sverdlov, Valerii Dziubliuk,	Conference Paper
A low power wearable respiration monitoring sensor using pyroelectric	no	2017	https://ieeexplore.ieee.org//document/7878302/	I. Mahbub, S. Islam, S. Shamsir, S. A.	Conference Paper
Wearable sensor and algorithm for automated measurement of screen time	yes	2016	https://ieeexplore.ieee.org//document/7764564/	R. R. Fletcher, D. Chamberlain, D. Richman, N.	Conference Paper
Wearable Wireless Sensor System With RF Remote Activation for Gas	no	2018	https://ieeexplore.ieee.org//document/8270614/	Denis Spirjakin, Alexander Baranov,	Journal Article
26.1 A 4.5mm2 Multimodal Biosensing SoC for PPG, ECG, BIOZ	no	2020	https://ieeexplore.ieee.org//document/9063112/	Yun-Shiang Shu, Zhi-Xin Chen, Yu-Hong	Conference Paper

Design and development of wireless sensor network for biomedical	no	2016	https://ieeexplore.ieee.org//document/7748981/	Resham Raj Shivwanshi,	Conference Paper

Behavior change and ICT in relation to light exposure scoping review papers

title	relevant	year	link	authors	publication type
Internet Health Promotion and Behavior Change Theory: An Integrated Model	maybe	2015	https://ieeexplore.ieee.org//document/7070174/	Gordana Culjak, Nick Kowalenko, Mark	Conference Paper
Developing a Social Marketing Behavior Change: The Case of "Show Racism the Red	no	2015	https://ieeexplore.ieee.org//document/7399158/	Guochao Lin, Lujie Hao	Conference Paper
Platform for Promoting Behavior Change of Residents towards Resident-Centered Local	yes	2018	https://ieeexplore.ieee.org//document/8853787/	Koya Kimura, Yurika Shiozu, Ryo Shioya, Ivan	Conference Paper
Poster Abstract: Empirical Research on Behavior Change Promoted by Information	yes	2017	https://ieeexplore.ieee.org//document/7944827/	Yutaka Arakawa	Conference Paper
Interaction Platforms, Energy Conservation, Behavior Change Research, and More	no	2013	https://ieeexplore.ieee.org//document/6562730/	Jason Hong, Mary Baker	Magazine Article
Preliminary Experiment on the Effect of a Magic Circle on Behavior Change	no	2019	https://ieeexplore.ieee.org//document/8959864/	Seiya Tsubaki, Naohiro Matsumura	Conference Paper
Possibility of Gamified ICT Applications for Young Elderly	no	2017	https://ieeexplore.ieee.org//document/8010663/	Hyeongju Ryu, Ahjung Byun, Hyeoiyun Lee,	Conference Paper
Design and deployment of eHealth interventions using behavior change	no	2015	https://ieeexplore.ieee.org//document/7347983/	Mate BeÅ¡tek, Kristina Curtis, Andrej Brodnik	Conference Paper
ShishuPoshan application: ICT to solve issues of high social importance by scaled behavior	yes	2019	https://ieeexplore.ieee.org//document/8711149/	Kamaxi Bhate, Prashant Gangal, Sunita Shanbhag,	Conference Paper
Investigating User Reactions to Interactive-signage-based Stimulation Toward Behavior	maybe	2018	https://ieeexplore.ieee.org//document/8653587/	Zhihua Zhang, Yuta Takahashi, Manato	Conference Paper
Behavior change tactics of the social marketing	no	2005	https://ieeexplore.ieee.org//document/1499446/	Xiaohui Chen, Shukai Liang, Xiaowei Zhang,	Conference Paper
Design of Typing Skills Feedback System for Behavior Change	no	2020	https://ieeexplore.ieee.org//document/9368335/	Tokio Takahashi, Masaru Honjo, Akio Yoneyama,	Conference Paper
The design and implementation of a web mobile-based behavior change application	no	2008	https://ieeexplore.ieee.org//document/4570573/	Yaojin Yang	Conference Paper
Exploring the Impacts of Elaborateness and Indirectness in a Behavior Change Support	yes	2021	https://ieeexplore.ieee.org//document/9429258/	Zhihua Zhang, Juliana Miehle, Yuki Matsuda,	Journal Article
Recommendation System for Energy Consumption Behavior Change on	yes	2021	https://ieeexplore.ieee.org//document/9589458/	Yuki Takayama, Yuiko Sakuma, Hiroaki Nishi	Conference Paper
Combining Persuasive Computing and User Centered Design into an Energy Awareness	yes	2016	https://ieeexplore.ieee.org//document/7723467/	Thomas Vilarinho, Babak Farshchian, Leendert	Conference Paper
Rethinking Health: ICT-Enabled Services to Empower People to Manage Their Health	maybe	2011	https://ieeexplore.ieee.org//document/6065740/	Anita Honka, Kirsikka Kaipainen, Henri Hietala,	Journal Article
Detecting Semantic Conflicts via Automated Behavior Change Detection	no	2020	https://ieeexplore.ieee.org//document/9240661/	Leuson Da Silva, Paulo Borba, Wardah	Conference Paper
The energy piggy bank â€” A serious game for energy conservation	yes	2017	https://ieeexplore.ieee.org//document/8379794/	BjÃ¶rn Hedin, Anton LundstrÃ¶m, Magnus	Conference Paper
Assessing the Impact of Engagement and Real-Time Feedback in a Mobile Behavior	no	2021	https://ieeexplore.ieee.org//document/9513591/	Yousef A. Asiri, David E. Millard, Mark J. Weal	Journal Article
Developing a Smartphone Application to Support Smoking Behavior Change through	yes	2019	https://ieeexplore.ieee.org//document/8856672/	Christos Maramis, Vasiliki Mylonopoulou, Agnis	Conference Paper
A behavioral medicine microcrocomputer program of health behavior change	no	1983	https://ieeexplore.ieee.org//document/764637/	M.P. Naditch	Conference Paper

Introduction to Health Behavior Change Support Systems (HBCSS) Minitrack	yes	2016	https://ieeexplore.ieee.org//document/7427569/	Harri Oinas-Kukkonen, Khin Than Win, Samir	Conference Paper
Visualizing carbon footprint from school meals	no	2017	https://ieeexplore.ieee.org//document/8379805/	BjÃ¶rn Hedin, Philip Claesson, Patrik Odqvist	Conference Paper
Ontological Analysis of the Research on the Use of Social Media for Health Behavior	no	2015	https://ieeexplore.ieee.org//document/7069752/	Mohanraj Thirumalai, Arkalgud Ramaprasad	Conference Paper
It was a bit of a race: Gamification of version control	no	2012	https://ieeexplore.ieee.org//document/6225927/	Leif Singer, Kurt Schneider	Conference Paper
myPace: An Integrative Health Platform for Supporting Weight Loss and Maintenance	no	2015	https://ieeexplore.ieee.org//document/6966721/	Julie Barnett, Michelle Harricharan, Dave	Journal Article
Need for a context-aware personalized health intervention system to ensure long-	yes	2013	https://ieeexplore.ieee.org//document/6602481/	Adil Mehmood Khan, Seok-Won Lee	Conference Paper
The Role of Micro-Moments: A Survey of Habitual Behavior Change and	yes	2019	https://ieeexplore.ieee.org//document/8673323/	Abdullah Alsalemi, Christos Sardianos, Faycal	Journal Article
Towards Understanding Emotional Intelligence for Behavior Change Chatbots	no	2019	https://ieeexplore.ieee.org//document/8925433/	Asma Ghandeharioun, Daniel McDuff, Mary	Conference Paper
A Density-Based Clustering Approach for Behavior Change Detection in Data Streams	no	2012	https://ieeexplore.ieee.org//document/6374821/	Rosane M.M. Vallim, JosÃ© A. Andrade Filho,	Conference Paper
A Transformer-based Model for Older Adult Behavior Change Detection	no	2022	https://ieeexplore.ieee.org//document/9874707/	Fateme Akbari, Kamran Sartipi	Conference Paper
â€˜Itâ€™s just like you talk to a friendâ€™ relational agents for older adults	no	2005	https://ieeexplore.ieee.org//document/8160505/	Timothy W. Bickmore, Lisa Caruso, Kerri Clough-	Journal Article
The Pedagogical Use of the Internet of Things in Virtual Worlds to Encourage a	no	2017	https://ieeexplore.ieee.org//document/8276824/	Fabiana Santiago Sgobbi, Liane Margarida	Conference Paper
SocialCycle what can a mobile app do to encourage cycling?	yes	2013	https://ieeexplore.ieee.org//document/6758494/	Karla Felix Navarro, Valerie Gay, Loic Golliard,	Conference Paper
An Analysis of Adaptive Digital Predistortion Algorithms in RF Power Amplifier	no	2018	https://ieeexplore.ieee.org//document/8464925/	Han Le Duc, Bruno Feuvrie, Matthieu	Conference Paper
Towards User-Centric Intervention Adaptiveness: Influencing Behavior-Context	yes	2020	https://ieeexplore.ieee.org//document/9205803/	Hafiz Syed Muhammad Bilal, Muhammad Bilal	Journal Article
Spoonful: Mobile Application for Reducing Household Food Waste using Fogg Behavior	yes	2021	https://ieeexplore.ieee.org//document/9648506/	Muhammad Akmal, Ginar Santika Niwanputri	Conference Paper
Behavioral Informatics and Computational Modeling in Support of Proactive Health	yes	2015	https://ieeexplore.ieee.org//document/7283558/	Misha Pavel, Holly B. Jimison, Ilkka Korhonen,	Journal Article
Personalized behavior change support for disease prevention	no	2011	https://ieeexplore.ieee.org//document/6090196/	Kirsikka Kaipainen, Anita Honka, Niilo Saranummi	Conference Paper
Methods to influence change in home safety	no	2012	https://ieeexplore.ieee.org//document/6165534/	P. E. Thomas A. Domitrovich, Anna H. L.	Conference Paper
Application of wearable devices in sports: behavior change and result effect	no	2021	https://ieeexplore.ieee.org//document/9681115/	Qun Yang, Jian Sun, Zhi Yong Zhang, Shi Cong	Conference Paper
Identifying and Evaluating User Requirements for Smartphone Group Fitness	yes	2018	https://ieeexplore.ieee.org//document/8259286/	Edith Talina Luhanga, Akpa Akpro Elder	Journal Article
The Effectiveness of Upward and Downward Social Comparison of Physical Activity in an	yes	2016	https://ieeexplore.ieee.org//document/7828590/	Julia S. Mollee, Michel C.A. Klein	Conference Paper
How can you save the world? Empowering sustainable diet change with a serious game	yes	2021	https://ieeexplore.ieee.org//document/9618895/	Dennis BÃ¶hm, Bob Dorland, Rico Herzog,	Conference Paper

Personalization in Real-Time Physical Activity Coaching Using Mobile Applications: A	yes	2020	https://ieeexplore.ieee.org//document/8906021/	Francisco Monteiro-Guerra, Octavio Rivera-	Journal Article
A Dyad of Lenses for the Motivational Design of mHealth: Bridging the Gap between	yes	2019	https://ieeexplore.ieee.org//document/8904839/	Jonas Geuens, Luc Geurts, Kathrin Gerling, Robin De	Conference Paper
Usage of Facebook-and Anonymous Forum --Based Peer Support Groups Online and Their	maybe	2016	https://ieeexplore.ieee.org//document/7427572/	Heini Taiminen, Kimmo Taiminen	Conference Paper
A Context-Aware, Interactive M-Health System for Diabetics	maybe	2016	https://ieeexplore.ieee.org//document/7478497/	Shih-Hao Chang, Rui-Dong Chiang, Shih-Jung	Magazine Article
Energy Use in the Media Cloud: Behaviour Change, or Technofix?	no	2010	https://ieeexplore.ieee.org//document/5708503/	Chris Preist, Paul Shabajee	Conference Paper
Persuading students for behavior change by determining their personality type	maybe	2012	https://ieeexplore.ieee.org//document/6511472/	Muhammad Adnan, Hamid Mukhtar,	Conference Paper
A Tailoring Algorithm to Optimize Behavior Change	yes	2014	https://ieeexplore.ieee.org//document/6758934/	Janet Brigham, Harold S. Javitz, Ruth E. Krasnow,	Conference Paper
Behavior Change in Response to Subreddit Bans and External Events	no	2021	https://ieeexplore.ieee.org//document/9+B54377565	Pamela Bilo Thomas, Daniel Riehm, Maria	Journal Article
Integration of spoken dialogue system and ubiquitous computing	no	2019	https://ieeexplore.ieee.org//document/8730712/	Yutaka Arakawa	Conference Paper
Information technology and the smart grid - A pathway to conserve energy in buildings	no	2013	https://ieeexplore.ieee.org//document/6544394/	Mahmoud Alahmad, Yuye Peng, Evans Sordiashie,	Conference Paper
Maintaining reality: Relational agents for antipsychotic medication adherence	no	2010	https://ieeexplore.ieee.org//document/8147288/	Timothy W. Bickmore, Kathryn Puskar, Elizabeth	Journal Article
An architecture for emotional smartphones in Internet of Things	no	2016	https://ieeexplore.ieee.org//document/7750812/	R. Barbosa, D. Nunes, A. Figueira, H. Aguiar, J. SÃ¡	Conference Paper
Discovering consumer's behavior changes based on purchase sequences	no	2012	https://ieeexplore.ieee.org//document/6233731/	Chong Wang, Yanqing Wang	Conference Paper
A Personalized Pacing System for Real-Time Physical Activity Advising	maybe	2017	https://ieeexplore.ieee.org//document/8010650/	Hung-Yang Chang, Zhiguo Li, Subhro Das, Tian Hao,	Conference Paper
Prediction of E-shopper's Behavior Changes Based on Purchase Sequences	no	2010	https://ieeexplore.ieee.org//document/5655292/	Liu Jian, Wang Chong	Conference Paper
Behavior Analysis of Pandemic Source Media Communications	no	2021	https://ieeexplore.ieee.org//document/9373229/	Yohn Jairo Parra Bautista, Jinwei Liu, Richard AlÃ³	Conference Paper
Rich context information for just-in-time adaptive intervention promoting physical	yes	2017	https://ieeexplore.ieee.org//document/8036957/	F. Cruciani, C. Nugent, I. Cleland, P. McCullagh	Conference Paper
Is the ultrasonic velocity of biological tissue reversible when applying continuous heating-	no	2019	https://ieeexplore.ieee.org//document/8717326/	G. A. Cortela, W. A. C. Pereira, C. Negreira	Conference Paper
Assessing app quality through expert peer review: A case study from the gray matters	yes	2016	https://ieeexplore.ieee.org//document/7591697/	Phillip J Hartin, Ian Cleland, Chris D Nugent,	Conference Paper
Personalized technology for supporting health behaviors	maybe	2013	https://ieeexplore.ieee.org//document/6719267/	Silje C. Wangberg, Cand Psychol	Conference Paper
What Kind of Interventions Can Help Users from Falling for Phishing Attempts: A	no	2013	https://ieeexplore.ieee.org//document/6480330/	Mary B. Burns, Alexandra Durcikova, Jeffrey L.	Conference Paper
Design and Evaluation of a Peripheral Robotic Conversation Companion	no	2015	https://ieeexplore.ieee.org//document/8520619/	Guy Hoffman, Oren Zuckerman, Gilad	Conference Paper
A Pleasurable Persuasive Model for E-Fitness System	yes	2016	https://ieeexplore.ieee.org//document/7756131/	Lizhen Han, Zhigeng Pan, Mingmin Zhang, Feng	Conference Paper

Transient Structural health monitoring of The Test Bridges Using Finite Element	no	2018	https://ieeexplore.ieee.org//document/8467223/	Ali Akbar Shah, B.S. Chowdhry, Jawaid	Conference Paper
Micro-generation evaluation of the zero emissions technologies in the Portuguese	no	2008	https://ieeexplore.ieee.org//document/4579113/	Cristina Camus, Eduardo Eusebio	Conference Paper
Smart-phone application design for lasting behavioral changes	maybe	2013	https://ieeexplore.ieee.org//document/6627804/	Eleni Stroulia, Shayna Fairbairn, Blerina Bazelli,	Conference Paper
What did Really Change with the New Release of the App?	no	2018	https://ieeexplore.ieee.org//document/8595197/	Paolo Calciati, Konstantin Kuznetsov, Xue Bai,	Conference Paper
InfoPlant: Multimodal augmentation of plants for enhanced human-computer	no	2015	https://ieeexplore.ieee.org//document/7390646/	Jan Hammerschmidt, Thomas Hermann, Alex	Conference Paper
Bayesian Statistical Inference in Machine Learning Anomaly Detection	no	2010	https://ieeexplore.ieee.org//document/5629203/	Ying Zhao, Zhigao Zheng, Hong Wen	Conference Paper
Bayesian Quickest Detection of Changes in Statistically Periodic Processes	no	2019	https://ieeexplore.ieee.org//document/8849824/	Taposh Banerjee, Prudhvi Gurram, Gene Whipps	Conference Paper
Variability in the wave climate of the North Pacific: links to interannual and interdecadal	no	2003	https://ieeexplore.ieee.org//document/1283419/	N.E. Graham	Conference Paper
Strategies for the implementation of a simple, implantable sensor across different	no	2015	https://ieeexplore.ieee.org//document/7117088/	John F. Drazan, Omar T. Abdoun, Michael T.	Conference Paper
An Outcome Based approach to delivery and assessment of a course in Control System	no	2009	https://ieeexplore.ieee.org//document/5490592/	Y. K. Lee, A. A. A. Rahim, N. M. Thamrin, A. J.	Conference Paper
Lost in persuasion A multidisciplinary approach for developing usable, effective,	yes	2015	https://ieeexplore.ieee.org//document/7349377/	Olivier A. Blanson Henkemans, Pepijn van	Conference Paper
Pervasive Persuasion for Stress Self-Regulation	no	2019	https://ieeexplore.ieee.org//document/8730850/	Yingding Wang, Nikolai Fischer, FranÃ§ois Bry	Conference Paper
recoverApp - A mobile health solution to support people in stationary rehabilitation	no	2020	https://ieeexplore.ieee.org//document/9201839/	Christoph Aigner, Matthias Eder, RenÃ©	Conference Paper
Backend Concept of the eSano eHealth Platform for Internet- and Mobile-based	no	2022	https://ieeexplore.ieee.org//document/9941520/	Abdul Rahman Idrees, Robin Kraft, RÃ¼diger	Conference Paper
Cooperative pursue in pursuit-evasion games with unmanned aerial vehicles	no	2015	https://ieeexplore.ieee.org//document/7354022/	Alexander Alexopoulos, Tobias Schmidt,	Conference Paper
Guiding the Viewer's Imagination: How Visual Rhetorical Figures Create Meaning in	no	2009	https://ieeexplore.ieee.org//document/5190830/	Ralph Lengler, Andrew Vande Moere	Conference Paper
A conceptual model of Al-Furqan courseware using persuasive system design	no	2014	https://ieeexplore.ieee.org//document/6986040/	Aryati Bakri, Nor Hawaniah Zakaria, Siti	Conference Paper
Incorporating persuasion into a decision support system: The case of the water user	yes	2016	https://ieeexplore.ieee.org//document/7604957/	Kim Perren, Lili Yang, Jinjin He, Shuang-Hua	Conference Paper
Energy awareness, an important goal for empowering the end customer	no	2017	https://ieeexplore.ieee.org//document/7975034/	Mihai Sanduleac, Dorel Stanescu, Carmen	Conference Paper
Dynamic Multi-level Privilege Control in Behavior-based Implicit Authentication	no	2020	https://ieeexplore.ieee.org//document/9356028/	Yingyuan Yang, Xueli Huang, Yanhui Guo,	Conference Paper
Change detection of electric customer behavior based on AMR measurements	no	2015	https://ieeexplore.ieee.org//document/7232269/	Tao Chen, Antti Mutanen, Pertti JÃ¤rventausta,	Conference Paper
Design and development of remote vehicle health monitoring system using context	no	2013	https://ieeexplore.ieee.org//document/6558196/	R. Ganesan, S. Mydhile	Conference Paper
Persuasiveness web 2.0 in behavioral intention: A conceptual model	yes	2017	https://ieeexplore.ieee.org//document/8304120/	Yohana Dewi Lulu Widyasari, Lukito Edi	Conference Paper

Lean Deployment Boundary Model: From Knowledge Elicitation to System Design	no	2018	https://ieeexplore.ieee.org//document/8588252/	Ronald Leandro Elizondo, Raymond Houe Ngouna,	Conference Paper
Web Based Application for Healthy Habit Development Through Gamification with ML	yes	2022	https://ieeexplore.ieee.org//document/9716318/	R Gowthamani, K Sasi Kala Rani, M Indira	Conference Paper
Security and Privacy Implications of Pervasive Memory Augmentation	no	2015	https://ieeexplore.ieee.org//document/7030265/	Nigel Davies, Adrian Friday, Sarah Clinch,	Magazine Article
iDetective: A Location Based Game to Persuade Users Unconsciously	no	2011	https://ieeexplore.ieee.org//document/6029818/	Akihito Yoshii, Yoshio Funabashi, Hiroaki	Conference Paper
Demand Response in Greece: An Introductory Mobile Application	no	2018	https://ieeexplore.ieee.org//document/8494424/	I.M. Chatzigeorgiou, D. Manolas, T. Gkaragkouni,	Conference Paper
Towards Estimating UV Exposure Using GPS Signal Strength from a Carrying Smartphone	maybe	2021	https://ieeexplore.ieee.org//document/9556257/	Soichiro Higuma, Kosuke Hatai, Yuuki Nishiyama,	Conference Paper
Achieving Domestic Energy Efficiency Using Micro-Moments and Intelligent	yes	2020	https://ieeexplore.ieee.org//document/8959214/	Abdullah Alsalemi, Yassine Himeur, Fayal	Journal Article
Exploring Longitudinal Use of Activity Trackers	no	2016	https://ieeexplore.ieee.org//document/7776345/	Jochen Meyer, Jochen Schnauber, Wilko	Conference Paper
HyperSight: Towards Scalable, High-Coverage, and Dynamic Network Monitoring	no	2020	https://ieeexplore.ieee.org//document/9060873/	Yu Zhou, Jun Bi, Tong Yang, Kai Gao, Jiamin Cao,	Journal Article
OH-BUDDY: Mobile Phone Texting Based Intervention for Diabetes and Oral Health	yes	2015	https://ieeexplore.ieee.org/	Anaga Ojo, Samir Chatterje	Conference Paper
Happyinu: exploring how to use games and extrinsic rewards for consistent food	yes	2016	https://ieeexplore.ieee.org/	Edith Talina Luhanga, Akpa	Conference Paper
Application of Systems Thinking to energy demand reduction	no	2011	https://ieeexplore.ieee.org/	Rachel Freeman, Theo Tryf	Conference Paper
Just in time Intervention for Personalized Healthcare: Behavior-Context based	yes	2020	https://ieeexplore.ieee.org/	Hafiz Syed Muhammad Bil	Conference Paper
Causal Analysis for Understanding Vehicle Behavior Affected by Multiple Factors	no	2021	https://ieeexplore.ieee.org/	Ranulfo Bezerra, Kazunori	Conference Paper
Does Learning Method Matter in Cyber Security Behaviour? Spaced Vs. Massed e-	yes	2021	https://ieeexplore.ieee.org/	Tiffany Skinner, Jacqui Tay	Conference Paper
Mobile-Computing Based Rationalization for Energy Consumption	maybe	2017	https://ieeexplore.ieee.org/	Salaheddin Odeh, Daniel V	Conference Paper
A study on the customer behavior tracking model based on temporal description logic	no	2012	https://ieeexplore.ieee.org/	Feng Yang, JiuWei Wang, H	Conference Paper
Improving the lifestyle behavior of type 2 diabetes mellitus patients using a mobile	yes	2022	https://ieeexplore.ieee.org/	Andreia Pinto, JoÃ£o Viana	Conference Paper
PredGaze: A Incongruity Prediction Model for Userâ€™s Gaze Movement	no	2020	https://ieeexplore.ieee.org/	Yohei Otsuka, Shohei Akita	Conference Paper
Towards the Evaluation of the Usability and Portability of Serious Games	yes	2021	https://ieeexplore.ieee.org/	Moises Arevalo, Vanessa R	Conference Paper
Extended Engel-Kollat-Blackwell Consumption Behavior Model for Residential	no	2020	https://ieeexplore.ieee.org/	Jianmin Zhang, Yusheng Xu	Conference Paper
The self-management of chronic illnesses: Theories and technologies	no	2010	https://ieeexplore.ieee.org/	Silvia Torsi, Peter Wright, C	Conference Paper
Automatic Deceit Indication through Reliable Facial Expressions	no	2007	https://ieeexplore.ieee.org/	Thomas E. Slowe, Venu Go	Conference Paper

Online estimation of time-varying torque characteristics of automotive clutches using	no	2013	https://ieeexplore.ieee.org/	A. Tarasow, G. Wachsmuth	Conference Paper
Importance of stable velocity in agile maintenance	no	2013	https://ieeexplore.ieee.org/	Samir Omanovic, Emir Buz	Conference Paper
Output distributional influence function	no	2001	https://ieeexplore.ieee.org/	S. Peltonen, P. Kuosmanen	Journal Article
AChE biosensor based on aniline-MWNTs modified electrode for the detection of	no	2011	https://ieeexplore.ieee.org/	Xia Sun, Qingqing Li, Xiang	Conference Paper
Analyzing Voting Behavior in Italian Parliament: Group Cohesion and Evolution	no	2012	https://ieeexplore.ieee.org/	Alessia Amelio, Clara Pizzu	Conference Paper
Machine Speed Condition Monitoring using Statistical Time-Domain Features Modeled	no	2020	https://ieeexplore.ieee.org/	Xinlai Ye, Xin Wen, Zhenjie	Conference Paper
An efficient approach for network traffic classification	no	2013	https://ieeexplore.ieee.org/	Shankar Lal, Parag Kulkarn	Conference Paper
The Change Matters! Measuring the Effect of Changing the Leader in Joint Music	no	2022	https://ieeexplore.ieee.org/	Giovanna Varni, Maurizio I	Journal Article
Changing human behavior through the options and feedback design of service	maybe	2013	https://ieeexplore.ieee.org/	Zhenwei You, Haruo Hibin	Conference Paper
Organizational change in a public housing foundation: The crucial importance of	no	2012	https://ieeexplore.ieee.org/	J. H. Pieterse, J. M. Ulijn, A	Conference Paper
Designing for Healthy Lifestyles: Design Considerations for Mobile Technologies to	yes	2014	https://ieeexplore.ieee.org/	Sunny Consolvo, Predrag K	Book
Platform for monitoring obesity and overweight	maybe	2020	https://ieeexplore.ieee.org/	Juan Montenegro, Lilia Mu	Conference Paper
An effect of noise on mental health indicator using voice	no	2017	https://ieeexplore.ieee.org/	Masakazu Higuchi, Shuji Sh	Conference Paper
Dynamics of liquid in pulsed power driven electrospray	no	2013	https://ieeexplore.ieee.org/	D. Obata, H. Tasaka, Shr. H	Conference Paper
Power Adaptive Digital Predistortion for Wideband RF Power Amplifiers With	no	2015	https://ieeexplore.ieee.org/	Yan Guo, Chao Yu, Anding	Journal Article
Trust evaluation method adapted to node behavior for secure routing in mobile ad hoc	no	2015	https://ieeexplore.ieee.org/	Sayaka Umeda, Sonoko Ta	Conference Paper
Looking Into a Future Which Hopefully Will Not Become Reality: How Computer	maybe	2020	https://ieeexplore.ieee.org/	Giulia Wally Scurati, Franc	Magazine Article
Occupancy Forecasting using LSTM Neural Network and Transfer Learning	no	2020	https://ieeexplore.ieee.org/	Piyapat Leeraksakiat, Wan	Conference Paper
Risk distribution method from worker behavior measurement using Behavior-	no	2021	https://ieeexplore.ieee.org/	Rieko Hojo, Tetsuo Sujino,	Conference Paper
The Modeling of Farmer Behavior Analysis in Small Water Project Participatory	no	2008	https://ieeexplore.ieee.org/	Zhang Ning, Dong Hongji	Conference Paper
Effective methods for implementating calendar of events for VANET models	no	2017	https://ieeexplore.ieee.org/	Kirill Tkachev	Conference Paper
Response to a relational agent by hospital patients with depressive symptoms	no	2010	https://ieeexplore.ieee.org/	Timothy W. Bickmore, Suz	Journal Article
Towards know-when technology in the mobile information space: long-term user	no	2003	https://ieeexplore.ieee.org/	T. Yamakami	Conference Paper

The Single Training Sample Extraction of VEP Based on Wavelet Transform	no	2008	https://ieeexplore.ieee.org/	Fang Liu, Zhi-gang Fan	Conference Paper
Use of sensor-based feedback technology in reducing home energy consumption	yes	2011	https://ieeexplore.ieee.org/	Annika Matta, AurÃ©lia H	Conference Paper
Towards Developing a Voice-activated Self-monitoring Application (VoiS) for Adults with	no	2022	https://ieeexplore.ieee.org/	Masud Rabbani, Shiyu Tiar	Conference Paper
Nuadu Concept for personal management of lifestyle related health risks	no	2008	https://ieeexplore.ieee.org/	E. Mattila, I. Korhonen, R.	Conference Paper
B2C Marketing Communication in Social Media: Fashion Industry Specifics	no	2019	https://ieeexplore.ieee.org/	Vida Davidaviciene, Sigitas	Conference Paper
Healthy Apps: Mobile Devices for Continuous Monitoring and Intervention	restricted	2013	https://ieeexplore.ieee.org/	Bonnie Spring, Marientina	Magazine Article
Internet Improves Health Outcomes in Depression	restricted	2006	https://ieeexplore.ieee.org/	G. Culjak, M. Spranca	Conference Paper
A Method Based on Fast Fourier Transform for Online Supervising of Power System and	restricted	2021	https://ieeexplore.ieee.org/	Parastou Fahim, Ali Karimp	Conference Paper
Reinforcement Learning based Orchestration for Elastic Services	restricted	2019	https://ieeexplore.ieee.org/	Mauricio Fadel Argerich, B	Conference Paper
Ubiquitous Learning: ASystematic Review	restricted	2019	https://ieeexplore.ieee.org/	Fetnanda P. Mota, Fetnan	Conference Paper
Java interface for relaxed object storage	restricted	2013	https://ieeexplore.ieee.org/	Michal Danihelka, Michal I	Conference Paper
Sensing, Understanding, and Shaping Social Behavior	restricted	2014	https://ieeexplore.ieee.org/	Erez Shmueli, Vivek K. Sing	Journal Article
Acceptability of a team-based mobile health (mHealth) application for lifestyle self-	restricted	2016	https://ieeexplore.ieee.org/	Andrea L. Hartzler, Anusha	Conference Paper
Beyond the Share Button: Making Social Network Sites Work for Health and Wellness	restricted	2011	https://ieeexplore.ieee.org/	Sean Munson	Magazine Article
Event Detection System Based on User Behavior Changes in Online Social Networks:	no	2020	https://ieeexplore.ieee.org/	Renata Lopes Rosa, Mariel	Journal Article
AI-supported Health Coaching Model for Patients with Chronic Diseases	restricted	2019	https://ieeexplore.ieee.org/	Mohammed Tahri Sqalli, D	Conference Paper
Inferring Social Influence of Anti-Tobacco Mass Media Campaign	restricted	2017	https://ieeexplore.ieee.org/	Qianyi Zhan, Jiawei Zhang,	Journal Article
A Cognitive-based scheme for user reliability and expertise assessment in Q&A social	restricted	2011	https://ieeexplore.ieee.org/	Konstantinos Pelechrinis, V	Conference Paper
Collaborative assessment of information provider's reliability and expertise using	restricted	2011	https://ieeexplore.ieee.org/	Konstantinos Pelechrinis, V	Conference Paper
Level of awareness on environment and energy; a survey of the freshmen at Habib	restricted	2017	https://ieeexplore.ieee.org/	Zareen Tabassum, Samina	Conference Paper
Analyzing Automatic Test Generation Tools for Refactoring Validation	restricted	2017	https://ieeexplore.ieee.org/	Indy P.S.C. Silva, Everton L	Conference Paper
Analyzing human's continuous learning processes with the reflection sub task	restricted	2015	https://ieeexplore.ieee.org/	Tomohiro Yamaguchi, Kou	Conference Paper
Energy node locator â€” A pathway to track energy at the point of use, remotely, in	restricted	2014	https://ieeexplore.ieee.org/	Sameena Khan, Muhamma	Conference Paper

Analysis and Evaluation of Control Action End-State Impact on Manufacturing System	no	2018	https://ieeexplore.ieee.org/	Jing Zou, Qing Chang, Jorg	Journal Article
Inferring Social Influence of anti-Tobacco mass media campaigns	restricted	2016	https://ieeexplore.ieee.org/	Qianyi Zhan, Jiawei Zhang,	Conference Paper
Impact of eco-feedback on the behavior of campus users	restricted	2017	https://ieeexplore.ieee.org/	Paul PichÃ©, Elhadi Belgha	Conference Paper
Security architecture for UAV	restricted	2021	https://ieeexplore.ieee.org/	Vasilisa D. Mikhailova, Ma	Conference Paper
A Joint Framework Based on Accountable AI for Driving Behavior Assessment and	restricted	2022	https://ieeexplore.ieee.org/	Yue Gao, Shu Zhang, Jun S	Conference Paper
Assessment of the Energy Efficiency Programmes within the Internal Operations	restricted	2022	https://ieeexplore.ieee.org/	Audrey Adhiambo Obwan	Conference Paper
Numerical Study Of Microparticles Acoustophoresis In PDMS Channels Using	restricted	2021	https://ieeexplore.ieee.org/	Jun-long HAN, HONG HU, Y	Conference Paper
Effective use of Problems in Learning Environments for Attaining Environmental	restricted	2017	https://ieeexplore.ieee.org/	Azmahani Abdul Aziz, Khai	Conference Paper
A framework for designing healthy living web-based intervention to promote health	restricted	2014	https://ieeexplore.ieee.org/	Siti Noorsuriani Maon, Sha	Conference Paper
Use of field and lab-calibrated real-time communications effects to assess end-to-	restricted	2014	https://ieeexplore.ieee.org/	Dennis Bushmitch, Richard	Conference Paper
Application of Wavelet Transform in Single Training Sample Extraction of VEP	restricted	2008	https://ieeexplore.ieee.org/	Zhang Zhen, Sheng-li Liu	Conference Paper
Influence of Gamification Elements on Explicit Motive Dispositions	yes	2022	https://ieeexplore.ieee.org/	Taygun B. Durmaz, Jose L.	Journal Article
The Sample Feature Extraction of Visual Evoked Potentials Based on Wavelet	restricted	2009	https://ieeexplore.ieee.org/	Zhang Zhen, Cheng Cheng	Conference Paper

Light viewing literature review papers

title	relevant	year	link	authors	notes
<b>Circadian<b> regulation of glucose lipid and energy	no	2018	https://pubmed.ncbi.nlm.nih.gov/29195759/	Poggiogalle E, Jamshed	
Recommendations for daytime evening and nighttime	yes	2022	https://pubmed.ncbi.nlm.nih.gov/35298459/	Brown TM, Brainard	Highly relevant!
<b>Optimal<b> schedules of <b>light<b> <b>exposure<b> for	yes	2014	https://pubmed.ncbi.nlm.nih.gov/24722195/	Serkh K, Forger DB.	Highly relevant!
Optimization of <b>light<b> <b>exposure<b> and sleep	yes	2021	https://pubmed.ncbi.nlm.nih.gov/34101742/	Yin J, Julius AA, Wen JT.	Highly relevant!
Individual differences in <b>light<b> sensitivity affect	yes	2021	https://pubmed.ncbi.nlm.nih.gov/33049062/	Chellappa SL.	
Dim <b>Light<b> <b>Exposure<b> and Myopia in	no	2018	https://pubmed.ncbi.nlm.nih.gov/30347074/	Landis EG, Yang V,	
<b>Circadian<b> Rhythm and the Skin A Review of the Literature	no	2019	https://pubmed.ncbi.nlm.nih.gov/31641418/	Lyons AB, Moy L, Moy	
In a Heartbeat <b>Light<b> and Cardiovascular Physiology	no	2017	https://pubmed.ncbi.nlm.nih.gov/29104560/	Chellappa SL,	
<b>Circadian<b> phase response curves to <b>light<b> in older	maybe	2007	https://pubmed.ncbi.nlm.nih.gov/17623102/	Kripke DF, Elliott JA,	
Twentyfour hours <b>light<b> <b>exposure<b> experiences	no	2009	https://pubmed.ncbi.nlm.nih.gov/18950766/	Tsai SY, Barnard KE,	
Shining the <b>Light<b> on the MotionWatch8 <b>Light<b>	yes	2021	https://pubmed.ncbi.nlm.nih.gov/33681717/	Falck RS, Crockett RA,	
Natural <b>light<b> <b>exposure<b> of young adults	no	1986	https://pubmed.ncbi.nlm.nih.gov/3823171/	Savides TJ, Messin S,	too old
Melatonin and the <b>circadian<b> system	no	2014	https://pubmed.ncbi.nlm.nih.gov/24996495/	Reiter RJ, Tamura H,	
Personalized Office Lighting for <b>Circadian<b> Health	maybe	2020	https://pubmed.ncbi.nlm.nih.gov/32824032/	Papatsimpa C, Linnartz	
Dynamics of Nonvisual Responses in Humans As Fast as Lightning	no	2019	https://pubmed.ncbi.nlm.nih.gov/30890907/	Prayag AS, Jost S,	
Visual impairment and <b>circadian<b> rhythm	no	2007	https://pubmed.ncbi.nlm.nih.gov/17969867/	Lockley SW, Arendt J,	
The pupillary <b>light<b> reflex distinguishes	no	2018	https://pubmed.ncbi.nlm.nih.gov/30261080/	McGlashan EM, Burns	
Entrainment of Arabidopsis roots to the <b>light<b>dark cycle	no	2018	https://pubmed.ncbi.nlm.nih.gov/29314066/	Nimmo HG.	
Ambient <b>Light<b> <b>Exposure<b> and Changes in	maybe	2016	https://pubmed.ncbi.nlm.nih.gov/27383113/	Obayashi K, Saeki K,	Relevant if I expand past
A framework of artificial <b>light<b> management	no	2021	https://pubmed.ncbi.nlm.nih.gov/34898651/	Pereira J, Mouazen	
Blueblocking IOLs decrease photoreception without	yes	2010	https://pubmed.ncbi.nlm.nih.gov/19883931/	Mainster MA, Turner	Could affect recommendations
Sensory <b>exposure<b> of neonates in singleroom	no	2018	https://pubmed.ncbi.nlm.nih.gov/28970325/	Best K, Bogossian F,	
Out of synch with society an update on delayed sleep	yes	2014	https://pubmed.ncbi.nlm.nih.gov/25160887/	Nesbitt AD, Dijk DJ.	A bit old, but survey on delayed

Melatonin and stable <b>circadian<b> rhythms	no	2014	https://pubmed.ncbi.nlm.nih.gov/24132226/	Reiter RJ, Tan DX,	
Entrainment of the Human <b>Circadian<b> Clock to	yes	2015	https://pubmed.ncbi.nlm.nih.gov/26144935/	Ritchie HK, Stothard ER,	Can pull from experiences in this
Elderly as a Highrisk Group during COVID19 Pandemic Effect	maybe	2020	https://pubmed.ncbi.nlm.nih.gov/33015537/	Cardinali DP, Brown	If I want to include age as a
<b>Light<b> treatment for sleep disorders consensus report VIIJet	no	1995	https://pubmed.ncbi.nlm.nih.gov/7632990/	Boulos Z, Campbell	Too old
The Role of Daylight for Humans Gaps in Current Knowledge	yes	2020	https://pubmed.ncbi.nlm.nih.gov/33089192/	MÃ¼nch M, Wirz-Justice	
Winter Depression Integrating mood <b>circadian<b> rhythms	no	2009	https://pubmed.ncbi.nlm.nih.gov/20160896/	Lewy AJ, Emens JS,	
Chronic <b>exposure<b> to dim <b>light<b> at night	maybe	2022	https://pubmed.ncbi.nlm.nih.gov/36268694/	Liu JA, Walton JC,	Relevant if I expand past
A ModelBased Approach to Optimizing Ultradian Forced	yes	2017	https://pubmed.ncbi.nlm.nih.gov/28954576/	Stack N, Barker D,	Can give an indication on how
<b>Circadian<b> disruption and remedial interventions effects	no	2012	https://pubmed.ncbi.nlm.nih.gov/22299812/	Forbes-Robertson	
Suppression of sleepiness and melatonin by bright	no	2004	https://pubmed.ncbi.nlm.nih.gov/14996033/	Lowden A, Akerstedt T,	
Intrinsic period and <b>light<b> intensity determine the	yes	2005	https://pubmed.ncbi.nlm.nih.gov/15834113/	Wright KP Jr, Gronfier	
The <b>circadian<b> basis of winter depression	no	2006	https://pubmed.ncbi.nlm.nih.gov/16648247/	Lewy AJ, Lefler BJ,	
A broken <b>circadian<b> clock The emerging neuroimmune	no	2022	https://pubmed.ncbi.nlm.nih.gov/36281466/	Su K, Din ZU, Cui B,	
<b>Light<b> at night increases body mass by shifting the time	no	2010	https://pubmed.ncbi.nlm.nih.gov/20937863/	Fonken LK, Workman	
BlueEnriched <b>Light<b> Enhances Alertness but Impairs	no	2018	https://pubmed.ncbi.nlm.nih.gov/29867659/	RodrÃ-guez-Morilla B,	
Mars 520d mission simulation reveals protracted crew	no	2013	https://pubmed.ncbi.nlm.nih.gov/23297197/	Basner M, Dinges DF,	
Wrist actigraphic approach in primary secondary and tertiary	yes	2021	https://pubmed.ncbi.nlm.nih.gov/34377218/	Acker J, Golubnitsch	Study using light exposure data

User Testing Data Collection Agreement

Request for participation to study using wearable light sensor and mobile app

Background and Purpose
This study is a research project for the Norwegian University of Science and Technology (NTNU). It is part of an IT3920 Master's Thesis for MSIT about ICT for Health & Well-being in Built Environments. The aim of the study is to gather and correlate light and location data with a timestamp, as well as studying whether an app and wearable light sensor can help change attitude and knowledge about light exposure's importance for sleep. The data will also be aggregated and anonymized completely to be made available for further research after this thesis.

What does participation in the project imply?
The participation includes your response to two interviews as well as wearing a sensor and using a mobile app for two days.

What will happen to the information about you?
All personal data will be treated confidentially. It will be stored on a secure server pseudonymously, with location data being the only personal data. The participants will not be recognizable in any of the publications that report the results from this study.

All personal data will be treated confidentially. The data that is gathered will be stored on secure servers, ensuring anonymity of the respondents. The participants will not be recognizable in any of the publications that report the results from this study.

Voluntary participation
It is voluntary to participate in the project, and you can at any time choose to withdraw your consent without stating any reason. If you decide to withdraw, all your personal data will be deleted. You can also gain access to the data, request corrections, restriction of processing and receive the data in a format suited for data portability. You also have the right to complain to the Norwegian Data Protection Authority.

Legal Basis for Processing Personal Data:
The processing of personal data for this study is based on the participant's consent, in compliance with Article 6(1)(a) of the General Data Protection Regulation (GDPR). By giving your consent to participate in this study, you are providing the legal basis for the collection, storage, and processing of your personal data, including location data and light data with a timestamp from a wearable sensor, as described in this consent form.

If you have any questions concerning the project, please contact:

Vegard Rognstad Smines, NTNU, email: vegardrsmines@gmail.com

Sobah Abbas Petersen, NTNU, email: sap@ntnu.no

You can also contact NTNU's Data protection officer at:

Thomas Helgeresen, NTNU, email: thomas.helgesen@ntnu.no

Sikt's privacy services have given us advice on how to conduct this research project. If you have questions for Sikt related to this project, you can contact them by:
email: (personverntjenester@sikt.no)
or phone: 73 98 40 40

Date: April 2023

Consent for participation in the study

I have received and understood information about the project to wear a light and sensor and use an app in an experiment on changing light viewing behavior using ICT. I give consent:

- ☐ To share position data tracked on phone as well as light data with timestamp from a wearable sensor, to be stored pseudonymously until the master thesis is finished (18/06/2023), before being aggregated and anonymized entirely and made available for further research
- ☐ To participate in an interview before and after using the sensor and app

Introduction to participant:
Explain the concept and context this would be used in. Important to mention that this will be used for research in my Master thesis.
The feedback will not be connected to them, their personal information will not be recorded.
Explain the purpose of the interview. (improve usability, select features)
Please give honest feedback, do not hesitate to make negative comments about the design.
Rather say too much than too little. If you are unsure whether the feedback is relevant or not, give it anyway.
Explain framework (tasks, think-aloud, post interview)
Check if they have questions before we begin

Think-aloud methodology:
Describe your thoughts out loud while you are doing it. Please be "absurdly" specific, as in: "I want to click this button because it says "next" and I feel like I am finished on this page". Also mention any observations and impressions you get while navigating the app, such as whether you think it looks good or bad, and if anything confuses you or is overwhelming.
I may interrupt you to ask you to clarify your thought process or to ask your opinion on a specific feature.

Participant “demographic”:

Tasks:
Set-up task:

Morning task from notification:

Change goals from app homepage:

Test understanding of homepage elements:

Post interview questions:

General impressions

What was your initial impression? Your first thoughts when you saw the design

How easy or difficult was it to understand what to click and do? Any particular points you were confused or had to think about it?
(If yes, what confused you and how could it have been clearer)

Would you feel confident that you could use the app on your own without guidance/onboarding?

Concept evaluation

Do you think an app like this is useful? If not, why not?

Is there any part of the app or concept you felt was unnecessary or unhelpful?

There are many ways a more active approach could be used to facilitate behavior change. I want your opinion on the following potential features that are not used in the design you saw:

- Connecting light viewing behavior to current habits. The design would facilitate for the user to identify current habits at key times and connecting it to a positive light viewing behavior. For example, if the user starts every morning with a cup of coffee, they could drink it outside.
- Notifications at key times. If the sensor registers a lot of light close to bedtime, or very low light in the morning it pings the user, reminding them of their goals.
- Gamification features, such as progress, badges, rewards, etc.
- Social features where users can compare themselves to others within a group.

Pitch other potential concepts (habits, etc.)

Visibility
Was there any feature that was hard to find?

Feedback
Did you feel like you got sufficient feedback when clicking buttons and performing actions (perhaps rephrase feedback as it could be ambiguous)?

Affordance
Was there any point you were unsure what a button or feature displayed or did?

Problem areas
If something went "wrong" during testing:
What caused the confusion?

How easy/hard was it to get "back on the path"?

Desired features
Are there any features you think could have improved the app? It can be both a specific small thing or a fundamental part of the concept

[swap to homepage]
Do you have any suggestions for ways we can display progress and goal adherence on the homepage?

Any other suggestions or comments that you have not yet mentioned?

Remember to thank participant!

Introduction to participant:
Explain the concept and context this would be used in. Important to mention that this will be used for research in my Master thesis.
The feedback will not be connected to them, their personal information will not be recorded.
Explain the purpose of the interview. (improve usability, select features)
Please give honest feedback, do not hesitate to make negative comments about the design.
Rather say too much than too little. If you are unsure whether the feedback is relevant or not, give it anyway.
Explain framework (tasks, think-aloud, post interview)
Check if they have questions before we begin

Think-aloud methodology:
Describe your thoughts out loud while you are doing it. Please be "absurdly" specific, as in: "I want to click this button because it says "next" and I feel like I am finished on this page".
Also mention any observations and impressions you get while navigating the app, such as whether you think it looks good or bad, and if anything confuses you or is overwhelming.
I may interrupt you to ask you to clarify your thought process or to ask your opinion on a specific feature.

Participant "demographic":

Participant 1: Bachelor informatikk. Går 3 året på industriell design integrert master.
Participant 2: Studerer økonomi og administrasjon første året
Participant 3: Arkitektur 3. år.

Tasks:
Set-up task:

Participant 1: Liker ikke fet skrift på introen. Ser mer clean ut med mer luft. Liker ikke bunnbaren, føler man kan dra opp. Kanskje vis heel firkanten. Bare highligh firkanten du er på ikke der. Mer margin på toppen. Gjør next knappen mindre. Lite margin på sidene, mer luft. Ha samme margin på alt nedover. Dårlig kontrast på progress bar. Mindre tekst på set your goals.

Burde gjerne kunne scrolle rett på set your goals siden istedenfor overlay. Bruk 100k istedenfor mange nuller. Lyst på mørkt er slitsomt for noen, men greit med mørkeblå.
Participant 2: Prøver å trykke ikke swipe. Swiper feil vei. Start knapp mer i midten på første. Skjønte at man kan dra. Skjønner timepicker. Mer gult i design. Ser ut som en forskningsapp. Kan kanskje få referanse verdier før sett your goals. Skjønte om du har klart målet greia. Likte byttet i bakgrunn.
Participant 3: Prøvde å trykke, swipinga går feil vei. Designet er fint og enkelt og beskrivende. Skjønte drag. Beskrivende at det står verdi over. Blå barren over betyr hvor langt man har kommet. Skjønte time picker. Enkelt design, funker bra. Hvis den hadde fungert ekte. Liker ikke lik skrift størrelse på overskriftene. Bedre overskrift størrelser på set goal.

Morning task from notification:

Participant 1: Antar jeg skal rangere. All teksten føles veldig lik (størrelse font). Gjør det lettere å se hva som er overskrift. Kanskje bare sette 0 5 10 og tallet du er på. Review: Skjønner ikke hva de to grafene er. Må ha legend. Ville gjette farga er hva jeg fikk.

Litt mer forklaring når jeg først bruker appen. Men ikke for mye så brukeren bare spammer gjennom. Ville ikke hatt tallene. De tar veldig mye plass. Skjønner det er en skala med ikonene. Trenger ihvertfall ikke plussen. Igjen 10k over 10000. Positiv til teksten.
Participant 2: Skjønte første siden. (report) Likte beskrivende tips på review. Skjønner ikke blå strek. Skjønner farget strek. Vil ha legend. Kanskje symbol først og så tallet
Participant 3: Hvis jeg var fornøyd med det ville jeg trykket next. Review: Punktene for tydelige, symbolene for tydelige. Skjønner klokkeslett, usikker på lux aksen. Tenkte først det er lux. Skjønte ikke symbolene. Lurte på om det da handlet om hvor lyskilden er fra fremfor verdien. Kunne evt. Flytta symbolene til andre siden av grafen. Kan stå med liten skrift at det er referanse.

Change goals from app homepage:

Participant 1: Burde ha navbaren nede fortsatt, rart at det ikke er noen måteå gå ut. Burde ikke se lik ut som første siden. Burde ikke trenge å trykke deg gjennom.
Participant 2: Hadde prøvd å scrolle ned. Så ikke navbaren under. Knappen ser ikke ut som en meny, ser ut som settings.
Participant 3: Hadde likt at det var en innstilling knapp. Ville tenkt at den er oppe i høyre hjørne. (Iphone greie lurer part2 på. Kunne også vært at man trykker på your goal. Så på navbaren som en del av mobilen, hadde skjønt at det var en del av appen på egen mobil. Ville heller hatt et tannhjul.

Test understanding of homepage elements:

Participant 1: For mye fet tekst.

Alt har samme utheving.

Hun tenkte pila viser hva du har nå. Ville gjort mer forklaring rundt det. Månen er alt for stor. Kanskje bare putt tallet i midten. Ser ikke sammenhengen. “Hvorfor er det delt på 0.2?”.
Generelt kan alt gjøres mindre.

Nummer to er hvor bra du har truffet hva du skulle i løpet av uka. Usikker på om det er at jeg har fått målet over eller under.
Vis hvordan du har truffet målet på morgen og kveld separat.
Konkret henvisning til målene du har sagt.
Hvor nærme er jeg å nå målet mitt?

Health appen på apple. Kunne endre tidsperspektiv. (time, dag, uke etc.)

Kult med å ha målet mot hvor jeg er akkurat nå. Weird der teksten.

Kanksje hatt det som en innstilling med dark mode, men positiv til det. Hvis mobile er på dark mode bare ha på dark mode hele tiden. Ikke gjør pila større på sola, holder med fargeendring.

Foretrekker “your goal” fra light mode over den på dark mode. 750 > 10.

Grafen på light mode har dårlig kontrast i forhold til UU.

Grafen føles “busy” i light mode.

Participant 2: Kult design.

Lysintensitet. 0.1

Kunne gjerne hatt så man kan se målene på hjemmesiden.

Så etter en stund at verdien under er tallet man har nå.

Participant 3:Månen viser hvor høyt lux nivå det er, pilen viser reelt, your goal viser målet ditt.

Tankte først pila viser i løpet av dagen totalt, men når han så endring til sol tenkte han det viser akkurat nå.

Tror grafen betyr 50% ut ifra eget mål, men kunne også vært ut i fra referanse verdi. Liker fargene. Liker at den bytter bakgrunnsfarge. Tallet som står under er ikke intuitivt. Regner med at den viser samme som pila. Bakgrunnsgridet er for tydelig. Føler grafen ikke kommer tydelig frem på lys særlig. Føler man burde kunne trykke på ting så kommer det opp en forklaringsboble.

Post interview questions:

General impressions

What was your initial impression? Your first thoughts when you saw the design

Participant 1: Ikke noe spesielt. Mer space, mer variasjon i tekst osv., mer hierarki. Kan gjøre ting mindre enn man tror. Bør ha css som funker med stor tekst, men er liten. Lite som finnes av det allerede
Participant 2: Likte det generelt. Skrifttypen kunne vært penere noen steder, særlig titler. Likte godt mørkt på natta og lyst på dagen. Likete pil på sola.
Participant 3: Generelt bra. Kunne gjort noen småting for å gjøre det enklere å skille mellom elementene. De er litt nærme kanskje. Månegreiene og solgreiene er forståelig og beskrivende.

How easy or difficult was it to understand what to click and do? Any particular points you were confused or had to think about it?

(If yes, what confused you and how could it have been clearer)

Participant 1: Dekket alt i think aloud
Participant 2: Hadde nok klart det uten veileding.
Participant 3: Stort sett lett. Ga mening.

Would you feel confident that you could use the app on your own without guidance/onboarding?

Participant 1: Ja

Participant 2: Ja
Participant 3: Tror det, med veileder greia på starten. Tror den retter seg på et bra nivå, du skal være litt interressert får å bruke det. Andre hadde nok fått det til da.

Concept evaluation

Do you think an app like this is useful? If not, why not?

Participant 1: Tror det hadde vørt nyttig ,god bevisstgjøring.
Participant 2: Tror de kunne hatt nytte av det.\,har dårlig søvn.
Participant 3: Ja, godt å vite mer om lyseksponeringen min.

Is there any part of the app or concept you felt was unnecessary or unhelpful?

Participant 1: Nei
Participant 2: Nei, egentlig ikke.
Participant 3: Ikke egentlig. Kanskje med unntak av referanseverdi symbolene.

There are many ways a more active approach could be used to facilitate behavior change. I want your opinion on the following potential features that are not used in the design you saw:

- Connecting light viewing behavior to current habits. The design would facilitate for the user to identify current habits at key times and connecting it to a positive light viewing behavior. For example, if the user starts every morning with a cup of coffee, they could drink it outside.
- Notifications at key times. If the sensor registers a lot of light close to bedtime, or very low light in the morning it pings the user, reminding them of their goals.
- Gamification features, such as progress, badges, rewards, etc.
- Social features where users can compare themselves to others within a group.

Participant 1: (Måtte hoppe over pga dårlig tid)
Participant 2: Usikker
Participant 3: Knytte til vaner virker vanskelig. Varslinger kunne vært lurt, men forsiktig med å ikke plage brukeren for mye. Usikker på verdien av Gamification eller sosiale features, måtte blitt løst på en god måte-

Pitch other potential concepts (habits, etc.)

Participant 1: Ingen ideer

Participant 2: Ingen ideer
Participant 3: Har ingen

Visibility

Was there any feature that was hard to find?

Participant 1: Svart i think aloud
Participant 2: Svart i think aloud
Participant 3: Innstillinger, endre mål

Feedback

Did you feel like you got sufficient feedback when clicking buttons and performing actions (perhaps rephrase feedback as it could be ambiguous)?

Participant 1: Ja
Participant 2: Ja
Participant 3: Ja

Affordance

Was there any point you were unsure what a button or feature displayed or did?

Participant 1: Svart i think aloud
Participant 2: Svart i think aloud
Participant 3: Svart på i think aloud

Problem areas

If something went "wrong" during testing:

What caused the confusion?

Participant 1:
Participant 2:
Participant 3: Finne målsetting

How easy/hard was it to get "back on the path"?

Participant 1:

Participant 2:
Participant 3: Gikk aldri “av” veien, så ikke noe problem

Desired features

Are there any features you think could have improved the app? It can be both a specific small thing or a fundamental part of the concept

Participant 1: Ikke noe jeg kommer på.
Participant 2: Kanskje kunne se utviklingen over lengre periode, så man kan velge uke måned år etc.
Participant 3: Lage en widget som man kan ha på hjemmesiden på telefonen. Påminnelser. Kan godt være der på samme tidspunkt hver dag, men også fint om den retter på deg.

[swap to homepage]

Do you have any suggestions for ways we can display progress and goal adherence on the homepage?

Participant 1: Ikke noe jeg kommer på
Participant 2:
Participant 3: Nei

Any other suggestions or comments that you have not yet mentioned? This could also be about the interview process we just did.

Participant 1: Nei
Participant 2: I starten kunne det vært en side med “dette er normal, dette er noe du burde få etc.”. Ha det tilgjengelig senere og.
Participant 3: Nei, kanskje jobbe bittelitt med ryddigheten på hjemmesiden så det er lettere å skille de.

Remember to thank participant!

SWELL presentation questions

SWELL Questionnaire

Which department are you in?

I think this app concept is useful 1-10

I could think of using an app like this 1-10

I think this concept would contribute to health and wellbeing in built environments 1-10

I think this concept could benefit the individual's health and well-being 1-10

Do you have any feedback for me (positive/negative feedback, ideas or suggestions)?

In which department do you work?

Dep. of neuromedicine and movement science (INB - MH)

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

Interesting from a public health perspective.
~~[illegible]~~ → Consider population focus vs individual behaviour.
~~[illegible]~~

In which department do you work?

IDI

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)**

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

Consider using dark background for morning review, since it will be a very bright light first thing in the day.
~~En~~ Might be worth also factoring in time of year. In Norway things get very dark in winter and brighter in summer, Maybe give recommendations around that
** ~~I~~ Personally just use very few apps, don't take this as very indicative of your design

In which department do you work? IDI

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely) *

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact) **

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

* definitely. esp. if this can be enhanced in an app (mobile, smartwatch), that also measures ~~...~~ our sleeping quality.

** this is going to be useful for people with insomnia-like problems/challenges.

In which department do you work? IBM

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10 if improved

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10 if improved

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

the app looks to be useful, but it should be more clear in giving goals, informing the user about the app itself and information so they could understand directly the outcome, not only by reading the interpretation.

In which department do you work?

department for neuromedicine and movement science (INB)

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

It might be worth considering the occupation of the user, for example shift workers exposed to artificial light late in the evening. What is the alternative to exposure to strong artificial light for those who need to work late?

In which department do you work?

Department of Civil and environmental engineering (IBM)

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

- If you are in a Cold Season and you are outside and the Sensor going to be Covered by Coat. then the highest amount of lux will be not measured.
- ~~I~~ How the participant that realized they lack the good amount of light lux can have the light?
- If the notification for lacking the light is going to be Sent during the daylight maybe they can use the awareness to go for a walk.

  but that is also going to be problem during winter time that the day time is limited in working hour.

In which department do you work?

On a scale of 1 to 10, how useful do you find this concept? (1 being not useful at all, 10 being extremely useful)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how likely are you to use an app/concept with these kinds of features in your daily life? (1 being not likely at all, 10 being extremely likely)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you believe this concept could contribute to health and well-being in the built environment? (1 being no contribution at all, 10 being significant contribution)

1 2 3 4 5 6 7 8 9 10

On a scale of 1 to 10, how much do you think this concept could positively impact health and wellbeing for an individual user? (1 being no impact at all, 10 being significant impact)

1 2 3 4 5 6 7 8 9 10

Please share any feedback or suggestions you have about the app concept, including positive aspects, areas for improvement, or ideas. (write on the back if you need space)

User Testing Interview Plan

User test

User will be interviewed, wear the sensor for one full day, do the morning review and then be interviewed again. These are the interview questions:

Before trying the app:

Welcome the participant to the interview and thank them for taking part in the study.

Explain the purpose of the interview: to understand their base level understanding of optimal light exposure in relation to sleep before the study.

Explain that their responses will help to evaluate whether attitudes and knowledge about light exposure change after the study.

Explain consent form and confirm consent.

Questions:

1.1: Rate your quality of sleep from 1-10, with 1 extremely poor and 10 being excellent.

1.2: Do you have a desire to improve your quality of sleep?

1.3: Do you feel motivated to change your light exposure habits?

1.4: On a scale from 1-10, how comfortable are you with using technology (e.g. apps, wearables) to track and monitor your health or health-related data? Please rate with 1 being not comfortable at all and 10 being extremely comfortable.

1.5: How do you feel like your general exposure to light throughout the day is, compared to what you think would be optimal for your sleep?

1.6: Do you have any specific habits regarding controlling the type of, or intensity of light exposure throughout the day? (for example lowering screen brightness and using blue blockers at night)

1.7: How important do you believe light exposure is for overall health and well-being?

1.8: What light intensity do you think is healthy the first hours after you wake up? You can answer in terms of some example light sources, such as direct sunlight or average living room light.

1.9: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

1.10: What light intensity do you think is healthy the last few hours before bed? You can answer in terms of some example light sources.

1.11: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

1.12: Place these light sources on the scale I provided. The numbers on the scale are lux, a metric for light intensity.

After trying the app:

Welcome the participant to the interview and thank them for taking part in the study.

Explain the purpose of the interview: to gather feedback on their experience of wearing a light sensor and receiving feedback on their light exposure compared to recommendations.

Explain that their responses will help to evaluate whether attitudes and knowledge about light exposure have changed after the study. It will also help to evaluate the usefulness and usability of the app and sensor.

Questions:

2.1: Describe the practicality of wearing the sensor. Were there any particular problems you encountered?

2.2: Is there another way you would have preferred wearing it?

2.3: How usable was the app?

2.4: How much did you use the app?

2.5: Would you use a sensor and app like this if it was integrated into technology you already have? For example, a sensor in a smartwatch and as a feature in a fitness app.

2.6: Do you think you will change your behavior regarding light exposure after trying the app and sensor? If so, how?

2.7: Do you feel like you know more about what the healthy levels of light exposure are at specific parts of the day after this study?

2.8: Do you feel like you have a better understanding of relative light intensities after this study?

2.9: Did setting specific, measurable goals affect your motivation to change your light exposure habits?

2.10: Did checking your progress against your goals motivate you to adjust your habits?

2.11: In this experiment, you got personalized feedback from the app. Do you think this was more or less useful than getting general recommendations about light exposure?

2.12: Was there anything about the goal-setting process that you found challenging or unhelpful?

2.13: Do you think using the app provided additional value compared to just getting information about reference values and recommended exposure?

2.14: Place the following light sources on a scale of light intensity (the participant will be provided cards with different light sources such as "clear daylight" or "PC screen at max brightness" and asked to place them on a scale from 0 to 100000 lux)

2.15: How do you feel like your general exposure to light throughout the day is, compared to what you think would be optimal for your sleep?

2.16: Are there any specific habits you will implement regarding controlling the type of, or intensity of light exposure throughout the day? (for example lowering screen brightness at night or going outside in the morning)

2.17: If yes, how motivated are you, and how likely do you think it is that the habit will stick?

2.18: How important do you believe light exposure is for overall health and well-being?

2.19: What light intensity do you think is healthy the first hours after you wake up? You can answer in terms of some example light sources.

2.20: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

2.21: What light intensity do you think is healthy the last few hours before bed? You can answer in terms of some example light sources.

2.22: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

2.23: Place these light sources on the scale I provided (quiz below). The numbers on the scale are lux, a metric for light intensity.

2.24: Compare your experience using the app to what you imagine it would have been like if you had received a document with general advice instead. What would have been easier or more difficult, and why?

2.25: Was there any experience when trying the app that surprised you?

QUIZ

Fill out the following light sources in the table below (multiple answers can be in same row, and multiple rows will not have an answer):

A: Direct midday sunlight

B: Typical office lighting

C: Light from a full moon

D: Typical light on an overcast day

E: Typical family living room

50,000-100,000 lux	
10,000–50,000 lux	
5,000-10,000 lux	
1000-5000 lux	
500-1000 lux	
100-500 lux	
50-100 lux	
10-50 lux	
1-10 lux	
0-1 lux	

User Testing Interview Results

Interview before user test

1.1: Rate your quality of sleep from 1-10, with 1 extremely poor and 10 being excellent.

- Participant 1: 5

- Participant 2: 6

- Participant 3: 7

1.2: Do you have a desire to improve your quality of sleep?

- Participant 1: Not really, I sleep okay.

- Participant 2: Yes, I think there's always room for improvement.

- Participant 3: Yes, I believe there's always room for improvement.

1.3: Do you feel motivated to change your light exposure habits?

- Participant 1: Not particularly, I don't think about light exposure much.

- Participant 2: Not really, I've never thought about it before.

- Participant 3: Yes, I've read about the importance of light exposure for sleep.

1.4: On a scale from 1-10, how comfortable are you with using technology (e.g. apps, wearables) to track and monitor your health or health-related data? Please rate with 1 being not comfortable at all and 10 being extremely comfortable.

- Participant 1: 5

- Participant 2: 7

- Participant 3: 8

1.5: How do you feel like your general exposure to light throughout the day is, compared to what you think would be optimal for your sleep?

- Participant 1: I don't really know what's optimal, so I can't say.

- Participant 2: I'm not sure, I've never really thought about it.

- Participant 3: I think it's decent, but could be better.

1.6: Do you have any specific habits regarding controlling the type of, or intensity of light exposure throughout the day? (for example lowering screen brightness and using blue blockers at night)

- Participant 1: No, I don't really think about it.

- Participant 2: No, I don't really think about it.

- Participant 3: Yes, I try to get natural light in the morning and avoid screens before bed.

1.7: How important do you believe light exposure is for overall health and well-being?

- Participant 1: I'm not sure, I haven't thought about it much.

- Participant 2: I think it's somewhat important, but I don't know the details.

- Participant 3: I think it's very important, light exposure can greatly affect our sleep and overall health.

1.8: What light intensity do you think is healthy the first hours after you wake up? You can answer in terms of some example light sources, such as direct sunlight or average living room light.

- Participant 1: Maybe the light from a window?

- Participant 2: Maybe the light from a window?

- Participant 3: Bright natural light, like being outside on a sunny morning.

1.9: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

- Participant 1: I don't know, I guess it's not too bright or too dim.

- Participant 2: I'm not sure, I guess it's not too bright or too dim.

- Participant 3: Bright light in the morning helps to reset our circadian rhythm.

1.10: What light intensity do you think is healthy the last few hours before bed? You can answer in terms of some example light sources.

- Participant 1: No light.

- Participant 2: Maybe red or yellow light?

- Participant 3: Dim light, similar to a bedside lamp.

1.11: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

- Participant 1: Bright light makes it harder to sleep

- Participant 2: I don't know, just assumed because people use blue blockers

- Participant 3: Dim light before bed can help prepare our body for sleep.

1.12: Place these light sources on the scale I provided. The numbers on the scale are lux, a metric for light intensity.

- Participant 1: [Participant places light sources on the scale]

- Participant 2: [Participant places light sources on the scale]

- Participant 3: [Participant places light sources on the scale]

Interview after user test

2.1: Describe the practicality of wearing the sensor. Were there any particular problems you encountered?

Participant 1: It was a bit uncomfortable, would not want to wear it long term.

Participant 2: It was a bit inconvenient to remember to wear it, but it wasn't too bad.

Participant 3: It was fine, a bit bulky.

2.2: Is there another way you would have preferred wearing it?

Participant 1: Maybe if it was integrated into something I already wear, like a watch.

Participant 2: Not really, it was fine as it was.

Participant 3: I think it would be easier if it was part of a smartwatch or something similar.

2.3: How usable was the app?

Participant 1: Pretty good, could have had some more easily accessible feedback (not just once a day).

Participant 2: It was pretty straightforward, I didn't have any problems with it.

Participant 3: It was very user-friendly, I found it easy to navigate and understand.

2.4: How much did you use the app?

Participant 1: I checked it a few times throughout the day, but not constantly.

Participant 2: I used it a couple of times a day to check my light exposure.

Participant 3: I really only opened it for morning review, and right after it was installed.

2.5: Would you use a sensor and app like this if it was integrated into technology you already have? For example, a sensor in a smartwatch and as a feature in a fitness app.

Participant 1: Maybe, if it was part of something I already use.

Participant 2: Yes, I think that would be more convenient.

Participant 3: Definitely, it would be much easier if it was integrated into my existing devices.

2.6: Do you think you will change your behavior regarding light exposure after trying the app and sensor? If so, how?

Participant 1: I might try to get more light in the morning, but I don't know if I'll make any major changes.

Participant 2: I think I'll be more aware of my light exposure, especially in the evening.

Participant 3: I am already pretty aware of my light exposure habits.

2.7: Do you feel like you know more about what the healthy levels of light exposure are at specific parts of the day after this study?

Participant 1: A little bit, I didn’t know the effect was that big.

Participant 2: Yes, I think I have a better understanding now.

Participant 3: Yes, I feel it helped to get some more specific numbers than what I have heard before.

2.8: Do you feel like you have a better understanding of relative light intensities after this study?

Participant 1: Yes.

Participant 2: A bit, but I don’t know if I will remember it.

Participant 3: I already had a pretty good idea.

2.9: Did setting specific, measurable goals affect your motivation to change your light exposure habits?

Participant 1: For me it did not make much of a difference.

Participant 2: Somewhat, it was helpful to have a clear goal to aim for.

Participant 3: Yes, having specific goals made it easier to stay motivated.

2.10: Did checking your progress against your goals motivate you to adjust your habits?

Participant 1: I don’t feel like I got to try it long enough to really know.

Participant 2: Yes, I liked getting an overview of my habits.

Participant 3: Yes

2.11: In this experiment, you got personalized feedback from the app. Do you think this was more or less useful than getting general recommendations about light exposure?

Participant 1: I guess it was a bit more useful, but I didn't pay much attention to it.

Participant 2: I think it was more useful, it felt more relevant to my personal situation.

Participant 3: Definitely more useful, it was nice to see some specific feedback. I would have liked to see feedback for any part of the day though, instead of just having one selected for me.

2.12: Was there anything about the goal-setting process that you found challenging or unhelpful?

Participant 1: No, it was fine.

Participant 2: It was a bit challenging to know what would be realistic to achieve.

Participant 3: Not really

2.13: Do you think using the app provided additional value compared to just getting information about reference values and recommended exposure?

Participant 1: I guess so, it was a bit more interactive.

Participant 2: Yes, it was more engaging and personalized.

Participant 3: Definitely, the app provided much more specific and relevant feedback.

2.14: Place the following light sources on a scale of light intensity (the participant will be provided cards with different light sources such as "clear daylight" or "PC screen at max brightness" and asked to place them on a scale from 0 to 100000 lux)

Participant 1: [Participant places light sources on the scale]

Participant 2: [Participant places light sources on the scale]

Participant 3: [Participant places light sources on the scale]

2.15: How do you feel like your general exposure to light throughout the day is, compared to what you think would be optimal for your sleep?

Participant 1: I think it's okay, I don't really know what's optimal.

Participant 2: I think it could be better, I probably get too much light in the evening.

Participant 3: I think it's pretty good, but there's room for improvement.

2.16: Are there any specific habits you will implement regarding controlling the type of, or intensity of light exposure throughout the day? (for example lowering screen brightness at night or going outside in the morning)

Participant 1: Maybe, I might try to get more bright light during the day.

Participant 2: Yes, I plan to reduce my screen brightness in the evening.

Participant 3: I already have pretty good habits on it, just need to be more disciplined.

2.17: If yes, how motivated are you, and how likely do you think it is that the habit will stick?

Participant 1: I'm not sure, I might try it but I don't know if it will stick.

Participant 2: I'm fairly motivated, I think there's a good chance I'll stick with it.

Participant 3:

2.18: How important do you believe light exposure is for overall health and well-being?

Participant 1: I guess it's quite important, still don’t feel like I completely understand it.

Participant 2: I think it's quite important, especially for sleep quality.

Participant 3: I believe it's very important, it has a significant impact on our circadian rhythm and overall health and energy.

2.19: What light intensity do you think is healthy the first hours after you wake up? You can answer in terms of some example light sources.

Participant 1: Light from my bedroom window.

Participant 2: I think bright natural light, like being outside on a sunny morning.

Participant 3: Definitely bright natural light is best.

2.20: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

Participant 1: It shifts my circadian rhythm.

Participant 2: It wakes me up quicker, and helps my circadian rhythm

Participant 3: Bright light in the morning sets our biological clock.

2.21: What light intensity do you think is healthy the last few hours before bed? You can answer in terms of some example light sources.

Participant 1: Probably dim light, like a lamp.

Participant 2: Definitely dim light, it helps to prepare our body for sleep.

Participant 3: Dim light, it signals to our body that it's time to wind down and prepare for sleep.

2.22: What makes this light intensity healthy, compared to a stronger or weaker light intensity?

Participant 1: I guess bright light might keep you awake?

Participant 2: Bright light before bed can interfere with our body's natural sleep-wake cycle.

Participant 3: Bright light before bed can suppress melatonin production and disrupt our sleep.

2.23: Place these light sources on the scale I provided (quiz below). The numbers on the scale are lux, a metric for light intensity.

Participant 1: [Participant places light sources on the scale]

Participant 2: [Participant places light sources on the scale]

Participant 3: [Participant places light sources on the scale]

2.24: Compare your experience using the app to what you imagine it would have been like if you had received a document with general advice instead. What would have been easier or more difficult, and why?

Participant 1: I think the app was more interactive, but I might have preferred a document for simplicity.

Participant 2: The app was more engaging and personalized, a document wouldn't have provided the same level of feedback.

Participant 3: The app provided real-time feedback and personalized recommendations, a document wouldn't have been as effective.

2.25: Was there any experience when trying the app that surprised you?

Participant 1: Not really, it was pretty much what I expected.

Participant 2: I was surprised by how much my light exposure varied throughout the day.

Participant 3: I was surprised by how much my light exposure in the evening was affecting my sleep.

Quiz before user test

Participant 1

Lux Range	Light Source
50,000-100,000	
10,000–50,000	Sunlight
5,000-10,000	
1000-5000	
500-1000	Overcast Day
100-500	Office, Living Room
50-100	
10-50	
1-10	Full Moon
0-1	

Participant 2

Lux Range	Light Source
50,000-100,000	
10,000–50,000	
5,000-10,000	Sunlight
1000-5000	
500-1000	Overcast Day
100-500	Office
50-100	Living Room
10-50	
1-10	Full Moon
0-1	

Participant 3

Lux Range	Light Source
50,000-100,000	
10,000–50,000	Sunlight
5,000-10,000	
1000-5000	Overcast Day
500-1000	Office
100-500	Living Room
50-100	
10-50	
1-10	
0-1	Full Moon

Quiz after user test

Participant 1

Lux Range	Light Source
50,000-100,000	Sunlight
10,000–50,000	
5,000-10,000	
1000-5000	Overcast Day
500-1000	Office
100-500	Living Room
50-100	
10-50	
1-10	
0-1	Full Moon

Participant 2

Lux Range	Light Source
50,000-100,000	Sunlight
10,000–50,000	
5,000-10,000	
1000-5000	Overcast Day
500-1000	Office
100-500	Living Room
50-100	
10-50	
1-10	
0-1	Full Moon

Participant 3

Lux Range	Light Source
50,000-100,000	Sunlight
10,000–50,000	
5,000-10,000	
1000-5000	Overcast Day
500-1000	Office
100-500	Living Room
50-100	
10-50	
1-10	
0-1	Full Moon

Possible feedbacks and lux reference values

Table 11.1: Light Exposure Recommendations

Morning Light Exposure
You received very little to no light exposure yesterday morning. This can make it harder for your body to wake up and can throw off your circadian rhythm. Try to get more natural light exposure in the morning.
You didn't get much daylight exposure yesterday morning. Try to get outside or open your curtains to let in natural light, which can help boost your mood and alertness.
You received some daylight exposure yesterday morning. Try to get a bit more to fully benefit from the alerting effects of morning light.
You received a good amount of daylight exposure yesterday morning, which is great for synchronizing your circadian rhythm and boosting your mood and alertness. Keep it up!

Table 11.2: Daytime Light Exposure Recommendations

Daytime Light Exposure
You had very low light exposure during the day. This can disrupt your circadian rhythm and make you feel sleepy or less alert. Try to get more light exposure during the day by increasing the amount of light inside or spending more time outside.
Your light exposure during the day was lower than ideal. This can lead to feelings of sleepiness or a dip in mood. Try to increase your light exposure during the day.
Your light exposure during the day was okay, but could be improved. Try to get more natural light, if possible.
You maintained good light exposure throughout the day, which is great for keeping your circadian rhythm on track and maintaining your alertness. Well done!

Table 11.3: Evening Light Exposure Recommendations

Evening Light Exposure
You had high light exposure in the evening. This can significantly delay your body's production of melatonin, making it harder to fall asleep and reducing the quality of your sleep. Try to greatly reduce your light exposure in the evening.
You had quite a bit of light exposure in the evening. This can delay your body's production of melatonin and make it harder to fall asleep. Try to reduce your light exposure in the evening.
Your light exposure in the evening was a bit higher than ideal. Try to dim the lights and avoid screens to help your body prepare for sleep.
You did well in limiting your light exposure in the evening. This will help your body produce melatonin and prepare for sleep. Keep it up!

Table 11.4: Sleeping Environment Recommendations

Sleeping Environment
Your sleeping environment was very strongly lit. This can significantly disrupt your sleep and make you feel less rested in the morning. Try to make your sleeping environment as dark as possible.
Your sleeping environment was quite strongly lit. This can disrupt your sleep and make you feel less rested in the morning. Try to make your sleeping environment darker.
Your sleeping environment was a bit more lit than your goal, but still relatively dark. Try to make it as dark as possible for the best sleep.
Your sleeping environment was very dark, which is great for promoting deep, restful sleep. Well done!

Table 11.5: Spike recommendations (studies[6][10][14][18] have shown that short spikes of strong light are can yield a powerful effect even if the average is not high)

Spike Recommendations
Although you had low average light exposure last morning, you did have a lot of spikes of higher light. This could indicate that you had more positive effect than the graph indicates!
Although you had low average light exposure during the day, you did have a lot of spikes of higher light. This could indicate that you had more positive effect than the graph indicates!
Although you had low average light exposure in the evening, you did have a lot of spikes of higher light. Even very short exposure to light suppresses melatonin which could affect your sleep.
Although your sleeping environment was not very dark, you did have a lot of spikes of lower light. Even very short exposure to light suppresses melatonin which could affect your sleep.
Coverage Feedback
It seems like you are lacking coverage in the morning. For feedback during these hours, keep the sensor on.
It seems like you are lacking coverage during the day. For feedback during these hours, keep the sensor on.
It seems like you are lacking coverage in the evening. For feedback during these hours, keep the sensor on.
It seems like you are lacking coverage during the night. For feedback during these hours, keep the sensor on.

Table 11.6: Melatonin Feedback (X represents percentage effect based on average results in a study)

Melatonin Feedback
This light level would not suppress melatonin by any meaningful amount. This would allow you to fall asleep easily and get good sleep quality. This would also mean your circadian rhythm is not shifted to a later time.
This light level would suppress melatonin by approximately X%. This would allow you to fall asleep easily and get good sleep quality. This would also mean your circadian rhythm is not shifted to a later time.
This light level would suppress melatonin by approximately X%. This would only slightly affect how easily you fall asleep, your sleep quality, and your circadian rhythm.
This light level would suppress melatonin by approximately X%. This would make it a bit harder to fall asleep, somewhat reduce your sleep quality, and shift your circadian rhythm to a later time.
This light level would suppress melatonin by approximately X%. This would make it harder to fall asleep, reduce your sleep quality, and shift your circadian rhythm to a later time.
This light level would suppress melatonin by approximately X%+. This would make it harder to fall asleep, reduce your sleep quality, and shift your circadian rhythm to a later time.

Table 11.7: Phase Shift Feedback (X represents percentage effect based on average results in a study)

Phase Shift Feedback)
This light intensity would actively delay your circadian rhythm, making it harder to wake up in the morning and fall asleep at night.
This light intensity would give X% of the maximum phase shift possible. This means your circadian rhythm would not be affected much. In other words, it would not be actively detrimental but it would not restore it either if you had too much light at night or not enough another morning.
This light intensity would give X% of the maximum phase shift possible. This would somewhat restore your circadian rhythm if you had too much light at night or not enough another morning.
This light intensity would give X% of the maximum phase shift possible. This would have a significant positive effect on your circadian rhythm.
This light intensity would give X% of the maximum phase shift possible. This means your circadian rhythm would adjust to the wake-up time very quickly.
This light intensity would give X%+ of the maximum phase shift possible. This means your circadian rhythm would adjust to the wake-up time very quickly.

Table 11.8: Alertness Feedback

Alertness Feedback
This light level would make you feel sleepy and make you very sensitive to light at night (in terms of melatonin suppression).
This light level would not help your alertness.
This light level would have a somewhat positive effect on your alertness and somewhat reduce your sensitivity to light at night (in terms of melatonin suppression).
This light level would have a significant positive effect on your alertness and significantly reduce your sensitivity to light at night (in terms of melatonin suppression).

Table 11.9: Lux Reference Values

Lux Reference Values
- This light intensity is roughly equivalent to a night sky.
- This light intensity is roughly equivalent to dark twilight or a phone screen at the lowest brightness a meter away.
- This light intensity is roughly equivalent to public areas with dark surroundings.
- This light intensity is roughly equivalent to office building hallway/toilet lighting.
- This light intensity is roughly equivalent to a dark overcast day or somewhat weak indoor light.
- This light intensity is roughly equivalent to office lighting or sunrise/sunset on a clear day.
- This light intensity is roughly equivalent to an overcast day or strong artificial light.
- This light intensity is roughly equivalent to lightly overcast daylight or brighter.