Informatics

Analysis design and prototypical implementation of an in-app parameter extraction process to personalise a smart wake-up light system

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieurin

im Rahmen des Studiums

Software Engineering und Internet Computing

eingereicht von

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Wien, 8. April 2024

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DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieurin

in

Software Engineering and Internet Computing

by

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to the Faculty of Informatics

at the TU Wien

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Vienna, 8th April, 2024

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Wien, 8. April 2024

Alicia Schwabenbauer

Danksagung

An dieser Stelle möchte ich mich ganz herzlich bei allen bedanken, die durch ihre Unterstützung und Mitarbeit maßgeblich zum Gelingen meiner Masterarbeit beigetragen haben.

Ein besonderer Dank gilt meinem Betreuer, Dipl.-Ing. Dr.techn. René Baranyi, für sein kontinuierliches Feedback und seine umfassende Unterstützung während des gesamten Arbeitsprozesses. Seine Expertise im wissenschaftlichen Arbeiten, im methodischen Vorgehen und im Bereich der Medizininformatik waren für die Fertigstellung dieser Arbeit von entscheidender Bedeutung.

Ein herzliches Dankeschön geht auch an das INSO-Team, das in organisatorischen Belangen eine wertvolle Hilfe war.

Die Durchführung mehrerer Nutzertests und Brainstormings im Rahmen der Masterarbeit wäre ohne die Mitwirkung von Tester:innen und Expert:innen nicht möglich gewesen. Daher möchte ich mich bei allen Beteiligten herzlich bedanken, ohne die mein nutzerzentrierter Ansatz nicht realisierbar gewesen wäre.

Ein weiterer Dank geht an das Team von Zeitgeber, das mich durch die Bereitstellung von Ausrüstung und Expertise maßgeblich unterstützt hat.

Zu guter Letzt möchte ich mich bei meinen Freunden, meiner Familie und insbesondere bei meinem Freund Clemens bedanken. Ihre bedingungslose Unterstützung und ihr emotionaler Beistand haben mir sehr geholfen, meine Masterarbeit abzuschließen.

Danke!

Acknowledgements

I would like to take this opportunity to express my sincere gratitude to all those whose support and cooperation contributed significantly to the success of my Master's thesis.

Special thanks are due to my supervisor, Dipl.-Ing. Dr.techn. René Baranyi, for his continuous feedback and comprehensive support throughout the entire work process. His expertise in scientific work, methodological approach and in the field of medical informatics were of crucial importance for the completion of this thesis.

Many thanks also go to the INSO team, who were a valuable help in organisational matters.

Conducting several user tests and brainstorming sessions as part of the master's thesis would not have been possible without the participation of testers and experts. Therefore, I would like to express my sincere gratitude to all participants, without whose contribution my user-centred approach would not have been feasible.

I would also like to thank the team at Zeitgeber, who provided me with their equipment and expertise.

Finally, I would like to thank my friends, my family and especially my boyfriend Clemens. Their unconditional support and emotional support helped me enormously to complete my thesis.

Thank you all!

Kurzfassung

Die Abweichung des zirkadianen Rhythmus, die häufig durch soziale Anforderungen wie Schichtarbeit und frühe Schul- oder Arbeitszeiten verursacht wird, wird mit verschiedenen negativen gesundheitlichen Folgen, wie Übergewicht, Stimmungs- oder psychische Störungen, in Verbindung gebracht. Die Exposition gegenüber elektrischem Licht, insbesondere am Abend oder während der Nacht, spielt eine zentrale Rolle bei der Störung des zirkadianen Rhythmus. Diese Fehlanpassung, die durch den Mangel an personalisierten Einstellungen in bestehenden intelligenten Lichtweckern noch verstärkt wird, stellt ein erhebliches Gesundheitsrisiko dar, insbesondere für junge Menschen mit erhöhtem Depressionsrisiko.

Diese Arbeit befasst sich mit dem Mangel an Personalisierung im Bereich der Lichtwecker und zielt darauf ab, eine umfassende Analyse, Gestaltung und Implementierung einer In-App-Personalisierung für einen intelligenten Lichtwecker zu präsentieren. Der Forschungshintergrund dieser Arbeit liegt in der Variabilität der Lichtempfindlichkeit und des Chronotyps von Menschen, was die Notwendigkeit einer Personalisierung des Lichtweckers unterstreicht, um den individuellen Bedürfnissen gerecht zu werden. Als methodischer Rahmen wurde ein nutzerzentrierter Ansatz gewählt, um den Nutzer in alle iterativen Schritte einzubeziehen und eine hochwertige Personalisierung zu gewährleisten.

Im Rahmen des nutzerzentrierten Designs wurden umfangreiche Literaturrecherchen, kreative Brainstormings, ein Experteninterview, ein Usability-Test und ein User-Test durchgeführt. Das Design der App und die damit verbundenen Anforderungen wurden kontinuierlich verfeinert, um eine Anwendung zu schaffen, die personalisierte Einstellungen ermöglicht und gleichzeitig die Möglichkeit bietet, die Empfehlungen durch Feedback oder Anpassungen täglich zu aktualisieren. Als Ausgangspunkt für die Parameter, die als Input für den Personalisierungsalgorithmus dienen, wurde ein detaillierter Fragebogen entwickelt.

Die Integration von medizinischen Prinzipien der Chronotherapie und fortschrittlichen Algorithmen in Form eines Personalisierungsalgorithmus für die Verschiebung des Chronotyps in die gewünschte Richtugn wurde durch präzise formulierte Anforderungen unterstützt. Die abschließende Auswertung dieser Arbeit zeigt eine signifikante Verbesserung des Wohlbefindens aller Teilnehmer:innen und unterstreicht die Wirksamkeit der in diesem wissenschaftlichen Kontext entwickelten personalisierten Einstellungen für den Lichtwecker.

Schlüsselwörter: Personalisierung, zirkadianer Rhythmus, Lichttherapie, Dämmerungssimulation, Stimmungsstörungen

Abstract

Circadian misalignment, often induced by social demands such as shift work and early school or work schedules, has been linked to various negative health consequences, including obesity, mood and mental health disorders. Electric light exposure, particularly at night, is central in disrupting circadian rhythms. This misalignment, exacerbated by the lack of personalised settings in existing smart light alarm clocks, poses a significant health risk, especially for young individuals at increased risk of depression.

This thesis addresses the lack of personalisation in the smart light alarm clocks domain, aiming to present a comprehensive analysis, design and implementation of an in-app personalisation for a smart light alarm clock. The research background of this thesis lies in the considerable variability of light sensitivity and chronotypes among people, which highlights the need for customisation of the light alarm clock to address individual needs. A user-centred approach was chosen as the methodological framework to involve the user in all iterative steps and ensure high-quality personalisation.

Within the user-centred design, extensive literature research, creative brainstorming, expert interviews and sophisticated usability tests were carried out. The design of the app and the associated requirements were continuously refined to create an application that enables personalised settings and simultaneously offers the possibility to update recommendations daily through feedback or adjustments. A detailed questionnaire was developed as a starting point for the parameters that serve as input for the personalisation algorithm.

The integration of medical principles of chronotherapy and advanced algorithms in the form of a personalisation algorithm for the phase response of the chronotype was supported by precisely formulated requirements. The final evaluation of this work shows a significant improvement in the well-being of all participants, emphasising the effectiveness of the personalised settings developed for the light alarm clock in this scientific context.

Keywords: personalisation, circadian rhythm, light therapy, dawn simulation, mood disorders

Contents

Acronyms

AAL Ambient Assisted Living

DLMO Dim Light Melatonin Onset

UCD User-Centered Design

MEQ Morningess Eveningness Questionnaire

MCTQ Munich ChronoType Questionnaire

CTQ Circadian Type Questionnaire

SAD Seasonal affective disorder

UI User Interface

UX User Experience

CHAPTER 1

Introduction

The introductory chapter of this master's thesis, which deals with the implementation of a prototype app for the personalisation of an intelligent wake-up system, aims to provide an insight into the background of the topic. Many individuals suffer from the consequences of a late-timed internal clock but have to get up early due to social obligations. This master's thesis aims to develop a recommendation on how the use of personalised settings in dawn simulation can help shift the internal clock. The chapter describing the problem emphasises the existing challenges in the area of waking and sleeping. The state of the art provides an overview of current technological advances and research results. The section on objectives and research questions presents the central questions and research objectives of this project.

1.1 Problem Description

A circadian misalignment or mismatch between a person's internal clock and the external environment is associated with various negative health consequences, including cardiovascular disease, diabetes, obesity and mental health disorders. Social demands such as shift work, starting school or work early and travelling across time zones can cause this mismatch. Young people in particular, whose circadian rhythms are out of phase or whose internal and external rhythms show discrepancies, are at increased risk of depression. [1] [2]

Exposure to electric light plays a central role in the discrepancy of the circadian rhythm. Decreased exposure to natural sunlight during the day and increased exposure to electric light during the night can disrupt circadian rhythms and sleep patterns, resulting in a delayed sleep-wake cycle. This can go beyond mere sleep disturbances and potentially trigger winter depression, especially due to the mismatch between circadian sleep rhythms and socially determined wake times influenced by work and school schedules. [3] [4]

Scientific research suggests that targeted light therapy can effectively alleviate seasonal depression and mood swings and enable people to wake up better. Studies have investigated the positive effects of the circadian phase shift. Winter depression, for example, can be treated by simulating dawn, using very dim, graduated light at the end of the night. A combination of bright light exposure in the morning and exogenous melatonin supplementation in the evening can lead to a greater phase shift, which emphasises the effectiveness of light therapy in the treatment of winter depression. [5] [6]

In this context, various light alarm clocks have come onto the market that are designed to make waking up easier and increase well-being by incorporating morning light. However, these products either lack personalised settings or require intensive self-study in the field of chronotherapy to find the optimal setting.

Due to the potential health effects of incorrect light exposure, it is crucial to set the alarm clock ideally to individual needs. Given the inherent variability of individual circadian rhythms and responses to light, a personalised configuration of the lighting system is essential.

As part of a master's thesis, the lack of personalisation in the area of smart light alarm clock settings is being addressed. The aim is to develop a personalised recommendation for setting a light alarm clock. Scientifically relevant parameters are to be extracted by asking the user specific questions and then used as input in an algorithm to provide recommendations tailored to the user. To promote understanding and acceptance among users, a brief introduction is given to the scientific principles of light therapy and the associated parameters.

As user satisfaction is of paramount importance for an app in the medical field with personalised recommendations for sleeping and waking up, the application is being developed as part of a user-centred design. This approach takes the user's needs into account and aims to improve user-friendliness, increase satisfaction and ultimately increase acceptance. By integrating the disciplines of user-centred design, requirements engineering, app design and algorithmics, this holistic approach aims to bridge the gap between personalised technology, scientific understanding in the field of chronotherapy and user acceptance in the context of light therapy applications.

1.2 Aims and Research Questions

The scientific landscape is evolving at an unprecedented pace, propelled by interdisciplinary collaborations that converge fields such as user experience (UX) design, algorithmic, and medical technology. This master's thesis combines these domains, presenting a multidimensional approach that addresses scientific challenges and holds the potential for transformative contributions. In the following the goals of this thesis including the resulting research questions are described.

1. Extract requirements in UX Design and Implementation

User experience design plays a crucial role in the development of digital applications, as the effectiveness of technologies depends on user satisfaction and engagement. One objective of the thesis is therefore to develop an app for the personalisation of light alarm clocks that focuses on user-friendliness, quality and general user satisfaction. To achieve this, requirements are to be worked out that cover both the technical side of the developed recommendation system, including parameter extraction and analysis, as well as user-friendliness and continuous development and improvement.

Research Question 1: What are the requirements for designing an app for a smart wake-up light system that obtains data for a personalized preset and continuous optimization?

To answer research question 1, the methodology involves a user-centred design approach that includes a comprehensive literature review, expert consultation and user testing. Insights from experts in the field of sleep medicine and circadian biology are included to ensure that the app complies with medical guidelines and that the requirements are clearly defined from both a technical and UI/UX perspective.

2. Provide personalization through parameter extraction

   As part of the master's thesis, an algorithm is to be developed that gives the user personalised recommendations for setting their lighting system. However, to provide the algorithm with the appropriate input, the appropriate parameters must first be requested from the user. The aim of the master thesis is therefore to define which parameters and in which form parameters must be requested from the user to provide the algorithm with the appropriate input for the subsequent personalisation. In addition, user-friendliness is to be further guaranteed, which is why the goal is extended to create acceptance by querying the parameters from the user.

   Research Question 2: Which parameters need to be queried, and how can the onboarding process be designed to gather those parameters while achieving acceptance and professionalism?

   To answer research question 2, the literature research in the field of chronobiology and the interview with an expert in the field of sleep medicine, which took place during the design process of the UCD, were used. The parameters queried by the user must be scientifically sound and validated to provide all the important inputs for the algorithm. To additionally ensure acceptance, the design and duration of the extraction process are tested for user-friendliness in the usability test.

3. Solving Medical Challenges through Information Technology

   The master thesis deals with medical challenges through information technology, especially in the field of circadian rhythms and light therapy. One goal is therefore to develop an application that helps to personalise light therapy for individuals by translating user information and applying it in the algorithms. The aim is to bridge the gap between medical needs in the field of chronotherapy and technological innovation.

Research Question 3: How can the algorithm be defined, which is needed to translate the individual parameters into a personalized preset?

Research question 3 is answered by brainstorming and a literature review. The literature research is intended to gather information on the factors that play a role in the personalisation of a smart light alarm clock. The brainstorming is intended to combine the findings from the literature research and the previous research questions and develop an algorithm that uses the parameters collected as input and generates personalised recommendations as output.

The formulated objectives of this thesis harbour the potential to produce interdisciplinary results. The process of requirements definition, as carried out in research question 1, shows an intersection of UX design and requirements engineering. This improves the understanding of how technological solutions can fulfil both user needs and technological requirements. The parameters developed in research question 2 and the possibility of querying them link usability with medical backgrounds. In research question 3, the results of the previous research questions are used to develop a medically and mathematically correct algorithm that contributes to the personalisation of light alarm clocks for a circadian phase advance.

The creation of mockups and wireframes as part of the UCD, followed by the algorithm development, contributes significantly to the scientific discourse by presenting solutions to the research questions posed.

Furthermore, the iterative, user-centred testing and revision phase ensures not only the effectiveness of the application but also its user-friendliness. By developing a testable prototype with personalised recommendations, a result is presented that promises a high level of user acceptance and underlines the practicality of the research.

To summarise, this master's thesis integrates UX design, requirements engineering, algorithmics and medical innovation. It presents a research work that addresses scientific challenges while having the potential to improve the user experience and offer a practical solution for personalising light settings in the medical field for private use.

CHAPTER 2

State of the Art

Current research in the field of personalized light alarm clocks for the treatment of chronotype mismatch and mood disorders represents a state of the art which includes different approaches that are being investigated in the areas of personalized applications, ambient assisted living (AAL), light alarm clocks and light therapy. These approaches focus on specific aspects, be it personalization, medical support or light as a wake-up aid. The focus of this chapter is therefore to provide a comprehensive overview of the various sub-applications related to the personalization of light alarm clocks while pointing out the need for further scientific research.

It should be noted that despite the current interest and progress in this area, there have been comparatively few scientific papers that specifically address the personalization of light alarm clocks. This underlines the relevance and innovative nature of the topic, as there is still plenty of room for in-depth research and development. This chapter therefore not only highlights the current state of research but also shows that the specific topic of the personalization of light alarm clocks has not yet been sufficiently researched scientifically, which emphasizes the need for further investigations and the novelty of the topic of personalizing a smart wake-up light.

2.1 Ambient assisted living systems

In the field of Ambient Assisted Living (AAL) in a medical context, applications are available that aim to support people with disabilities by integrating various technologies such as wireless communication, cloud computing and intelligent sensors. The current state of the art includes a wide range of applications, such as the SenseWear wristband, a wearable body monitor designed for both healthy volunteers and patients with chronic obstructive pulmonary disease. This wristband enables the recording of body movements and energy consumption. [7]

Another example is the Smart Shirt, whose design integrates various sensors to monitor a variety of vital parameters. These include heart rate, electrocardiogram (ECG), respiration, temperature and vital functions. The integration of such wearables and smart clothing into the AAL system expands the possibilities for recording health data and enables comprehensive monitoring of users. [8]

The applications utilise a wide range of sensors in the living environment to collect information on activities, health status and movements. Advanced data analysis techniques enable this data to be transformed into meaningful information, allowing relevant patterns and trends to be identified. In this way, precise recording of health information is made possible. As a result, various environmental parameters such as lighting, temperature and safety measures can be customised to individual needs. This often includes the integration of user-friendly apps that offer easy-to-understand control and a wide range of customisation options to meet the individual needs and preferences of users. [9, 10] [11]
Graphic 2.1 shows these core areas of AAL, monitoring vital data, integrating intelligent sensors, analysing patterns and supporting people with disabilities.

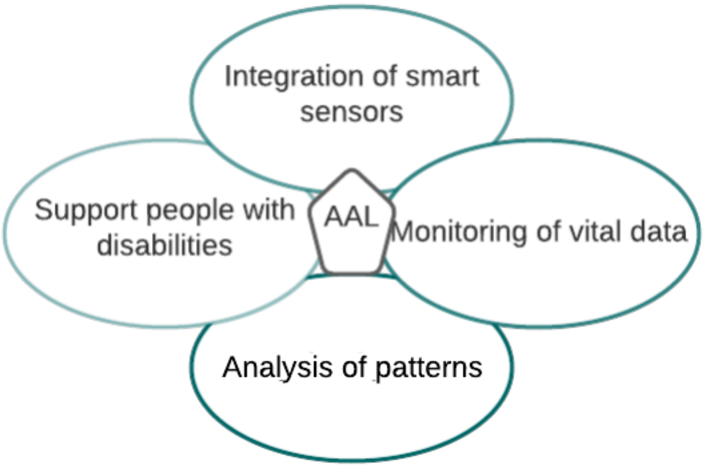

Figure 2.1: Core areas of Ambient Assisted Living

In the area of Ambient Assisted Living, the primary focus is on supporting people with physical disabilities in their everyday environment. In contrast, circadian dysregulation and the treatment of associated health problems are not at the centre of these applications. Traditional AAL systems are mainly designed to improve the autonomy and quality of life of people with physical disabilities by supporting their daily activities and movements. The focus is on recognising emergencies, with sensors serving as the main source of information. The primary objective is to react quickly to unforeseen events, such as a fall or other health emergencies. [11]
Circadian misalignment and associated health issues, particularly concerning light alarm clocks for the treatment of chronotype misalignment, thus receive less attention in conventional AAL applications. This specific area requires further research and development

to develop personalised approaches to assist with such chronobiological challenges.

2.2 Personalised apps

The current state of development of personalized applications manifests itself as a dynamic area with the primary goal of continuously improving the user experience and efficiency by customising application contents to create an optimal user experience and retain the user. Advances in recommender systems and data-driven technologies have made it possible to generate personalized recommendations based on user interactions and preferences. These advances in innovation play a crucial role in tailoring content, functions and user interfaces to individual needs. Many personalisation apps use recommender systems, to achieve a user-tailored presentation of content. [12]

Recommender systems are complex systems that aim to generate personalized recommendations for users based on their behaviour and preferences. The process begins with the comprehensive collection of data from various sources, including user data such as preferences and ratings as well as information on available items. This raw data undergoes careful pre-processing to optimally prepare it for the system. The actual recommender algorithms use different approaches such as collaborative filtering, content-based filtering or hybrid methods to recognize patterns and relationships between users and articles. Whereby [13]:

- Collaborative Filtering: Collaborative Filtering is based on the comparison of user preferences and recommends articles based on similarities between users.
- Content-Based Filtering: Recommends items based on the characteristics of the items and the known preferences of the user.
- Hybrid Methods: Combine multiple approaches to achieve more accurate recommendations.

Feedback loops are integrated during model training to continuously improve the recommendations. The result is personalized recommendations that take into account both individual preferences and similarities to other users. [14] This functionality of a recommender system can be found in graphic 2.2.

The evolution of the Netflix [1] Recommender System illustrates how companies in the digital entertainment sector use algorithms to generate recommendations and optimize user interactions. The continuous adaptation of these strategies reflects technological innovation and a strategic direction that aims to maximize user experience and strengthen competitiveness. Similarly, Amazon[2] and Spotify's [3] recommender systems illustrate

[1]https://www.netflix.com/browse
[2]https://www.amazon.at
[3]https://open.spotify.com/intl-de

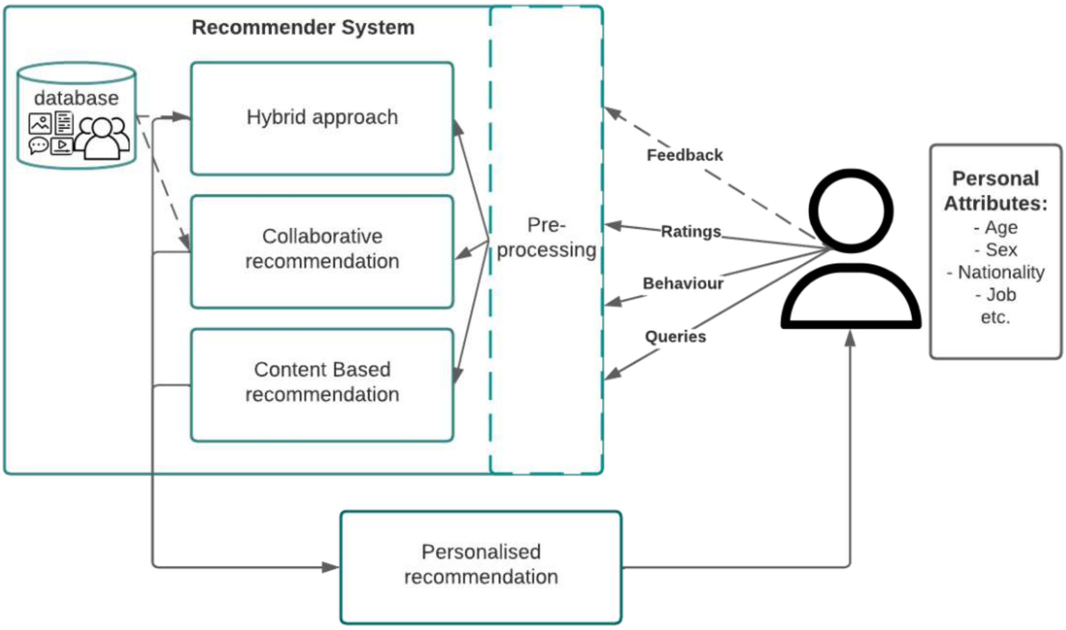

Figure 2.2: Functionality of a recommender system

advanced ways of generating personalized recommendations. Amazon integrates collaborative filtering, content recommendations and machine learning to provide personalized product suggestions. Spotify analyzes listening behaviour, takes playlist compilations into account and integrates social signals for tailored music recommendations. [15]

The paper from Tu et al. [16] on personalized app recommendations based on social media presents an innovative method of how a recommender system overcomes data poverty in terms of individual app usage data. The proposed IMCF+ method uses information from publicly available tweets to estimate individual app preferences. This method opens up new possibilities for personalized app recommendations by tapping into rich social data and improving the efficiency and quality of recommendations.

Companies such as HabitoNews[4], Starbucks[5], Evernote[6] or Calm[7] also use such recommendation systems. HabitoNews, for example, uses information about interactions to provide customized content. Starbucks relies on data-supported personalized offers. In contrast, Evernote and Calm rely on an onboarding process in which certain parameters are requested directly from the user to adapt the application to their individual preferences. These differences emphasize not only the diversity of objectives but also the challenges of offering personalized services that take into account users' health and daily lives. [17]

[4]http://habito.cs.ucl.ac.uk/
[5]https://www.starbucks.com/rewards/mobile-apps/
[6]https://evernote.com/intl/de
[7]https://www.calm.com/de

It is crucial to emphasize that despite the technological advances in the field of recommender systems and personalization, the predominant focus of these personalized applications is on business profitability and advanced operation within the app. The personalized recommendations displayed to the user are mostly aimed at influencing purchasing behaviour. [15]
In the case of personalization, as is the case with Calm or Evernote, the user's input is used to adjust the app to suit the user. It is striking that these types of personalization are not designed to support recommendations for the user in everyday life and concerning health. Careful analysis and integration of ethical considerations are therefore required to ensure that personalized services are not only based on commercial interests but also take into account the well-being and health aspects of users in their everyday lives. This underlines the need for a scientific basis for personalization that targets the user's mental health. [17]

2.3 Light treatment and light alarm clocks

The diversity of individual chronotypes, or natural patterns of sleep and wakefulness, often poses a challenge in synchronizing the innate biological clock with external demands, such as fixed working hours. This misalignment, which can be seen in figure 2.3, can result in disruptions to the sleep-wake cycle, leading to a cascade of negative effects on overall well-being and cognitive performance. These disruptions may manifest as difficulties falling asleep, staying asleep, or waking up feeling refreshed and alert. [4]

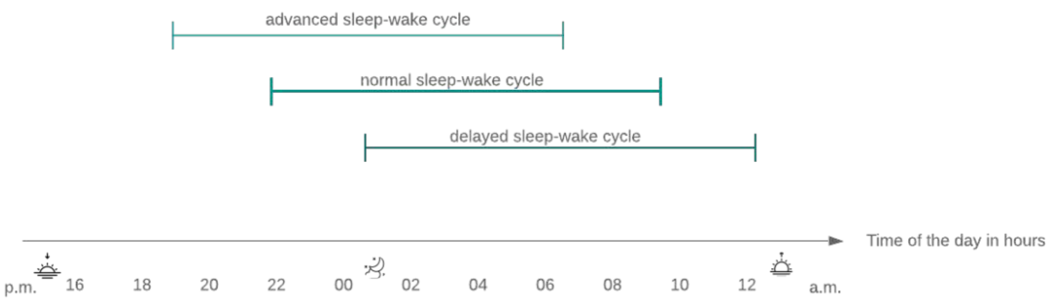

Figure 2.3: Sleep phase disorders (advanced and delayed in comparison with normal sleep-wake cycle)

A promising solution to this challenge is provided by bright light therapy and light alarm clocks, both of which are designed to regulate the sleep-wake cycle by exposing individuals to defined levels of bright light, usually mimicking natural sunlight. This aims to reset the body's internal clock and promotes synchronization with external time cues. It thus not only helps individuals adapt more effectively to their daily schedules but also holds the potential to enhance general well-being and cognitive performance. [18]

Research findings underscore the effectiveness of bright light therapy in the management of circadian sleep disorders, including advanced and delayed sleep phase disorders. Studies have shown that exposure to bright light, particularly in the morning or evening depending on the specific sleep disorder, can effectively shift the timing of the sleep-wake cycle, leading to improvements in sleep quality, mood, and cognitive function. Additionally, light alarm clocks offer a gentle and natural awakening experience by gradually increasing light intensity, which can further support the establishment of a regular sleep-wake pattern and promote overall well-being. By addressing the root cause of sleep disturbances and promoting alignment with the body's natural rhythms, bright light therapy and light alarm clocks offer a holistic approach to enhancing both physical and mental health. Whether used to alleviate the symptoms of circadian sleep disorders or simply to optimize daily functioning, these technologies hold great promise in fostering better sleep habits and improving quality of life. [19]

Research in the field of chronobiology and light therapy continues to advance, with new insights into the precise effects of light on the human sleep-wake cycle driving innovative technologies. The focus here is on developing solutions to make light treatment even more effective and precise. Existing lighting systems such as Philips Hue[8] or TRADFRI[9] from IKEA enable dynamic lighting control via apps. These systems automatically adapt light intensity and colour to natural changes in light and can support the circadian rhythm by simulating the daylight cycle.

Intelligent light alarm clocks such as the Philips Wake-up Light[10], Lumie Bodyclock [11] or Zeitgeber [12] simulate dawn to make waking up more pleasant. These devices imitate the natural sunrise and thus promote a gentle transition from sleep to wakefulness. [20] The functionality of such light alarm clocks can be found in figure 2.4.

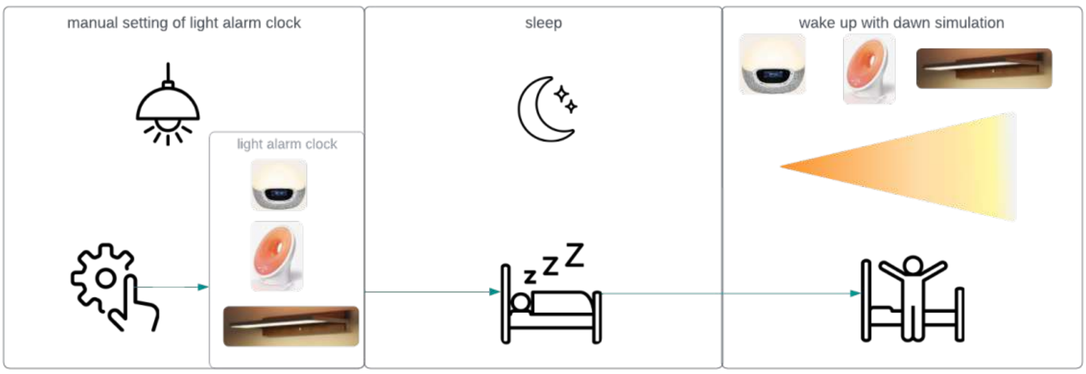

Figure 2.4: Functionality of a smart wake-up light including the light alarm clocks Philips Wake-up Light, Lumie Bodyclock and Zeitgeber

[8] https://www.philips-hue.com/de-at/explore-hue/get-started
[9] https://www.ikea.com/at/de/customer-service/product-support/app-gateway/
[10] https://www.philips.at/c-p/HF3506$_0$6/$wake - up - light/supportXC$000002326
[11] https://www.lumie.com/
[12] https://www.zeitgeber.at/

Despite the positive effects on well-being, existing solutions are not personalised. Users have to make the settings themselves, without specific knowledge in the field of chronotherapy. This can lead to sub-optimal adaptation to the circadian rhythm. There is therefore a need for further developments to create personalised light therapy approaches that can better take individual differences into account.

2.4 Summary

In summary, it can be said, that research in the field of app-based personalization of light alarm clocks for the treatment of chronotype mismatch and mood disorders encompasses various approaches, including ambient assisted living (AAL) systems, personalized apps and light therapy. AAL systems focus primarily on supporting people with physical impairments and pay less attention to circadian rhythms. Personalized apps emphasize user preferences but often neglect medical aspects. Light therapy and light alarm clocks show promising results, but existing solutions often lack personalization. A summarized overview of these existing solutions and their drawbacks can be found in table 2.4.

Table 2.1: Comparision of state-of-the-art solutions in the field of personalisation of light alarm systems

	Ambient assisted living systems	**Personalised apps**	**Light treatment and light alarm clocks**
Focus	Support for people with physical disabilities.	Improvement of user experience and efficiency.	Treatment of chronotype mismatches and mood disorders.
Personalization	Customization for individual needs in daily life and independent living for seniors or people with disabilities.	Customization based on interactions and customer profiles.	Customization from manual settings by user.
Data acquisition	Sensors for emergency detection, movement, and energy consumption.	Interactions, customer and profile data and social networks.	Advances in chronobiology and light therapy.
Lack of science	Focus on physical impairments, not circadian rhythms.	Less medical expertise, primarily geared towards user preferences.	Lack of individualization in existing light therapy systems.

This master's thesis focuses on an innovative approach that aims to develop an app that suggests personalised settings for a light alarm system by specifically querying certain parameters to address circadian mismatch and improve the user's overall well-being. This approach extends the conventional use of light alarms by adding personalised suggestions for individual settings. This creates a new use case in the field of Ambient Assisted Living (AAL) that specifically addresses circadian misalignment and associated health issues, particularly in the context of light alarm clocks for the treatment of chronotype misalignment. Personalisation is used to provide users with tailored recommendations to improve their health. These recommendations are determined by asking specific questions about user parameters and generated using an algorithm.

The novelty of this thesis therefore lies in the development of an app that takes an innovative approach as it offers personalized settings for light alarm clocks by specifically querying certain parameters. In particular, it takes into account circadian misalignments and their effects on health. In contrast to existing light alarm clock solutions, the personalized app creates a new use case in the field of ambient assisted living that specifically targets circadian problems. The app uses an algorithm to generate individual recommendations based on user responses. This approach promises further development in the field of personalized medical applications, particularly for the treatment of winter depression, mood disorders and chronobiological irregularities.

CHAPTER 3

Background

This chapter serves as a basis for deepening the central concepts in the context of the investigation of personalised light awakening therapy systems in the health sector. The circadian rhythm, zeitgebers and chronotypes play a key role here. A sound understanding of these concepts is essential to create a scientific basis for the development of personalised light awakening therapies. In addition, some basic definitions are given and the theoretical basis of the chosen user-centred approach is explained.

A solid understanding of this theoretical background lays the foundation for the development of a personalised recommendation for intelligent light alarm clocks. The user-centred approach aims to generate requirements that take appropriate account of the individual chronotype. This is done by making targeted adjustments to light exposure to precisely regulate the circadian rhythm. The ultimate goal is to enable precise treatment of winter depression and other disorders that can be associated with a disturbed synchronisation of the biological clock and external zeitgebers.

3.1 Definitions

- **Chronotype:** The "chronotype" refers to a person's genetic tendency to be active or quiet at certain times of the day, reflecting their preference for morning or evening activities. [21]
- **Chronotherapy:** The "Chronotherapy" refers to a therapeutic intervention that uses the circadian rhythm of the human body to optimise medical treatments, especially in the field of psychology and sleep medicine. [22]
- **Circadian Rythm:** The "circadian rhythm" is an approximately 24-hour biological cycle that refers to recurring physiological and behavioural patterns that occur during the day, including sleep-wake phases and hormone secretions. [23]

- **Zeitgeber:** A "zeitgeber" is an external stimulus, especially light, that influences the circadian rhythm and helps to synchronise the sleep-wake cycle and other biological processes. [24]

- **Phase-response curve:** The "phase-response curve" graphically describes the response of the circadian rhythm to external stimuli, especially light, and shows the shifts in the phasing of the rhythm depending on the time of exposure. [6]

- **MEQ:** The "Morningness-Eveningness Questionnaire" (MEQ) is an instrument in the form of 19 questions to measure individual preferences about the internal clock, which determines a person's chronotype and provides information on whether someone is more of a morning person, evening person or intermediate type. [25]

- **DLMO:** The "Dim Light Melatonin Onset" (DLMO) is the time at which melatonin production begins in the body in darkness and is used as an important physiological measure of the individual circadian rhythm. [26]

- **UCD:** The "user-centred design" (UCD) refers to a design approach that focuses on the needs, abilities and preferences of the end user to develop user-friendly products or systems, with the user being actively involved in the design process. [27]

3.2 Circadian Rhythm and its impact on health

The circadian rhythm constitutes a fundamental aspect of biological regulation, acting as an internal pacemaker that operates in a cyclical pattern of approximately 24 hours. This intricate system orchestrates a wide array of hormonal, physiological, and behavioural processes within the human body. These encompass not only the individual sleep-wake cycle and body temperature but also the secretion of crucial hormones like cortisol and melatonin, as well as emotional states. The term "circadian rhythm" is aptly derived from "circa," signifying "approximately," and "diem," referring to "day." This choice of nomenclature acknowledges the inherent tendency of the endogenous clock to surpass the standard 24-hour interval, adding a nuanced temporal dimension to its functions. There are different biological preferences as to how the rhythm runs. While one person likes to get up early and therefore goes to bed early, another prefers to sleep late and go to bed late. These different preferences are called chronotypes. At the heart of this chronobiological phenomenon lies the suprachiasmatic nuclei (SCN) in the brain, which is a sort of "master clock" located in the hypothalamus. The SCN, responsive to light stimuli captured by retinal cells in the eye, serves as the central regulator of the circadian rhythm. Maintaining synchrony with the 24-hour sleep-wake cycle necessitates daily recalibration by the SCN. This synchronization is achieved through external cues, often called "zeitgebers". [28] [19] Figure 3.1 illustrates how the circadian rhythm works and how its internal clock and external zeitgeber interact.

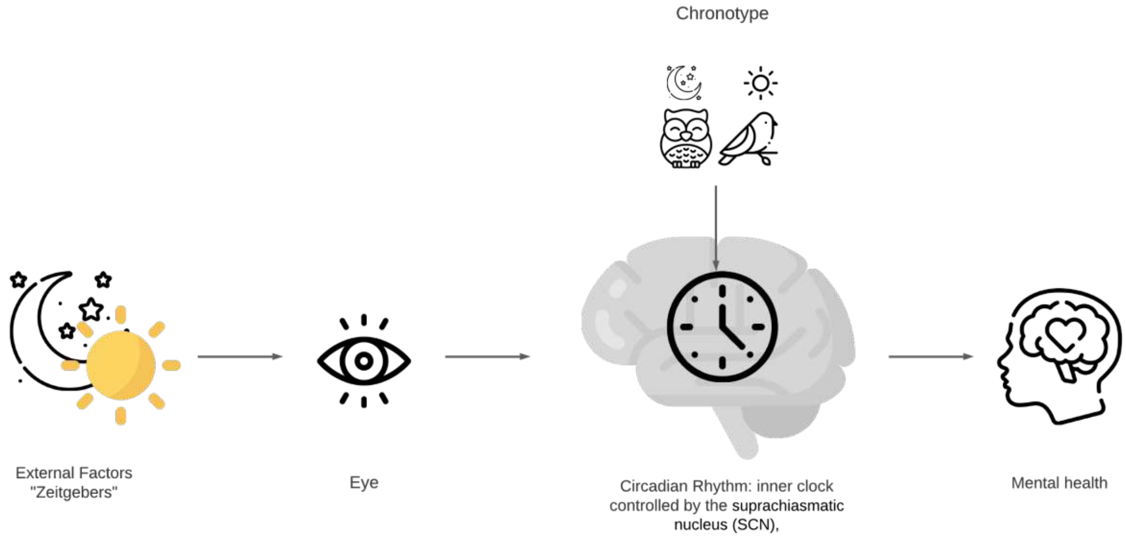

Figure 3.1: Representation of the circadian timing system, the influence of zeitgeber and its impact on chronotype and mental health

3.2.1 Zeitgeber

Zeitgebers are external signals that influence and synchronise circadian rhythms in living organisms. They play a crucial role in adapting these internal rhythms to the environment and the day-night cycle, which is of great importance for the optimal functioning of organisms. They are also responsible for determining which chronotypes people belong to, i.e. whether they are morning mammals or night owls. [29]

There are different types of zeitgebers, including sleep patterns, physical activity, ambient temperature, light exposure and even external elements such as temporal markers and mealtimes that influence the circadian rhythm. [29]However, the most important are :

- **Food:** Food intake can influence circadian rhythms by affecting metabolism and digestion. But also the timing of food intake has an impact on the rhythm of the circadian clock, as single cells or organisms such as liver cells synchronise themselves through food. [29]
- **Social zeitgeber:** Social interactions and activities that occur during specific periods also act as zeitgebers because they influence behaviour. For example, social activity regulates people's activity and sleep phases and determines the change between activity and rest. [30]
- **Light:** Light is the most prominent zeitgeber. Photoreceptors in the eyes, such as intrinsically photosensitive retinal ganglion cells (ipRGCs), are sensitive to light, especially blue light. These receptors send signals to the suprachiasmatic nucleus (SCN) in the brain, which contains the central biological clock. The information

encoded in light is then processed by the SCN and leads to the crucial resetting of the circadian rhythm. This response to resetting depends on several variables, such as the wavelength, intensity and timing of light exposure. For example, exposure to light in the morning suppresses melatonin production and signals that it is time to be awake and active. [30] [31] [32]

The interaction of these zeitgebers with the biological clock helps organisms regulate their activities and functions by the external day-night cycle. Disruption of the zeitgebers can lead to health problems, including sleep disturbances, mood problems and other health challenges. Understanding these external signals and their effects on circadian rhythms is of great importance for maintaining health and well-being. [29] [33]

The natural light and darkness signal is thereby the main zeitgeber for the circadian rhythm. Exposure to light during the morning hours, especially blue light, suppresses melatonin production and signals the body that it is time to be awake and active. The timing of light exposure is crucial, as the same amount of light in the evening can set the clock back, while it sets the clock forward when exposed in the morning. The importance of appropriate light exposure at the right time for maintaining healthy circadian rhythms and promoting well-being cannot be overstated. A better understanding of the interaction between light and the biological clock can help optimise human health and performance, as well as alter chronotypes. [30] [19] Disturbances in the light-timing signal, as can occur with shift work, jet lag or excessive screen time, can upset circadian rhythms and lead to sleep disturbances, mood problems, reduced cognitive performance and even long-term health problems such as cardiovascular disease and metabolic syndrome. [30] [31]

3.2.2 Chronotypes

The variability of the circadian rhythm is further exacerbated by individual differences between people. Dynamic processes such as the regulation of body temperature and hormone secretion show individual fluctuations that are influenced by several factors such as age, gender and the innate tendency towards morning or evening. The individual preference for a specific time of day is a key factor in understanding internal time architecture and its impact on health. These tendencies are known as chronotypes. [34] [35]

The term "chronotype" refers to a person's genetic predisposition to the times of day when he or she is most active or tends to sleep. These variations in the circadian rhythm are closely linked to the body's biological clock and are reflected in the natural sleep-wake cycles. Chronotypes can be roughly divided into three categories: Early risers (morning people), late risers (night people) and neutral chronotypes (in-between). In contrast to evening-orientated individuals, people with a tendency towards morning sleepiness show improved cognitive performance and increased alertness in the morning hours. They also tend to go to bed earlier in the evening due to their sleep behaviour. And vice versa. [36] [37] [38]

Individual differences in chronotypes have a genetic basis. Research has shown that certain genes, particularly those associated with circadian rhythm regulation, can influence an individual's chronotype. These variations explain why some people naturally wake up early and are active, while others are more productive in the evening. However, research has shown that zeitgebers, especially light, have a high influence and can also change the chronotype. [35] [19] [39]

This balance of circadian rhythms can be disrupted by various external factors, and consequently have a significant impact on health and performance. One well-known disruptive factor is the phenomenon of shift work, which requires people to be awake and active at non-standardised times that often do not coincide with their natural circadian rhythm. [40] [41] [42]

But not only shift workers are affected by this problem, while early risers tend to harmonise better with standard working hours, late risers often find it difficult to be active early in the morning. A discrepancy between the individual chronotype and external demands, such as work or school hours can lead evening people into an imbalance because fixed working hours in the morning clash with their internal clock if they have to get up early. This difference between external factors and natural sleep time is called social jetlag. It poses a challenge to the biological clock's ability to effectively regulate vital processes, as a discrepancy between the individual chronotype and external demands, such as work or school hours, can lead to sleep disorders, reduced alertness and mood problems. [28] [43] [44]

3.2.3 Measurement

Various measurement methods are used to capture and quantify these differences in the circadian rhythm. Experimental frameworks are designed to meticulously collect relevant data, with markers such as DLMO (Dim Light Melatonin Onset), core body temperature and cortisol levels serving as important indicators [45]:

- DLMO: DLMO refers to the time at which melatonin production begins in the body when a person is in a dim light environment. This marker is used to determine the timing of a person's circadian rhythm and to characterise their internal biological clock.
- Core body temperature: Core body temperature is another important marker of the circadian rhythm. It follows a specific pattern throughout the day, usually being lower in the morning and rising throughout the day. Recording core temperature helps to identify the phases of a person's circadian rhythm.
- Cortisol levels: Cortisol is a hormone that plays an important role in the circadian rhythm and is normally associated with wakefulness. Measuring cortisol levels throughout the day can provide information about the activity of the circadian system and help to identify individual differences.

At the same time, questionnaires such as the MEQ(Morningness-Eveningness Questionnaire) [46], the CTQ (Circadian Type Questionnaire) [47] and the MCTQ (Munich ChronoType Questionnaire) [48] are used to record individual chronotype tendencies and sleep patterns.

- MEQ: The MEQ is a questionnaire, consisting of 21 questions, developed to capture individual preferences regarding the time of day and asking the questionees whether they consider themselves more of a "morning person" or an "evening person". It is used to determine a person's chronotype and their tendency towards certain times of day. [46]
- CTQ: The CTQ is a questionnaire used to determine a person's circadian type by assessing their activity and sleep patterns. It makes it possible to quantify and characterise individual differences in circadian rhythm. [47]
- MCTQ: The MCTQ is a questionnaire specifically designed to determine a person's chronotype by assessing their sleep and activity patterns, similar to the CTQ. It provides detailed information about individual circadian rhythms and can help in the planning of chronobiology studies. [48]

3.2.4 Light and its impact on chronobiology

Due to the proven link between disrupted circadian rhythms and various health problems, it is of great importance to develop therapeutic approaches specifically aimed at supporting individuals with late chronotypes and adjusting their circadian rhythms. Scientific research has shown that targeted light exposure can be used to treat circadian rhythm disorders. Light therapy has already been shown to be an effective method of treating circadian sleep cycle disorders. It can readjust the timing of falling asleep and waking up according to the desired times, improving sleep quality and daytime alertness. [4] [49]

Bright light therapy and dawn simulation techniques using light for chronotherapy have been particularly proven. Bright light therapy is a treatment used to relieve mood disorders such as seasonal affective disorder (SAD) or winter depression. Patients sit in front of a bright light source that produces at least 10,000 lux for a certain amount of time each day (usually between 20 and 30 minutes). The light is designed to simulate daylight, which regulates the body's circadian rhythm by suppressing melatonin production and stimulating serotonin production. The procedure typically requires regular application over several weeks and ends early in the morning to simulate a natural sunrise. The treatment can significantly improve mood and energy levels, especially during the dark months of winter. [19]

Dawn simulation is designed to regulate the body's circadian rhythm by creating a simulated sunrise in the patient's bedroom. This is accomplished by using special lamps or light clocks that gradually increase in brightness and slowly illuminate the room, similar to the natural increase in light at sunrise. Treatment is usually performed in the morning to support natural sleep cycles and make the transition from sleep to wakefulness smoother. Twilight simulation can be particularly helpful for people who suffer from SAD, sleep disorders, or jet lag. Place the light alarm clock next to the patient's bedside and set the desired alarm time and brightness for a natural and gentle transition to waking up. Notably, in a direct comparison, dawn simulation was superior to bright light therapy. Even light levels reaching sunrise and increasing intensity to 180 lux can cause changes in circadian rhythms, especially in the early morning. [19] A comparison of the functions of Bright lIght therapy and the Dawn simulation can be found in figure 3.2.

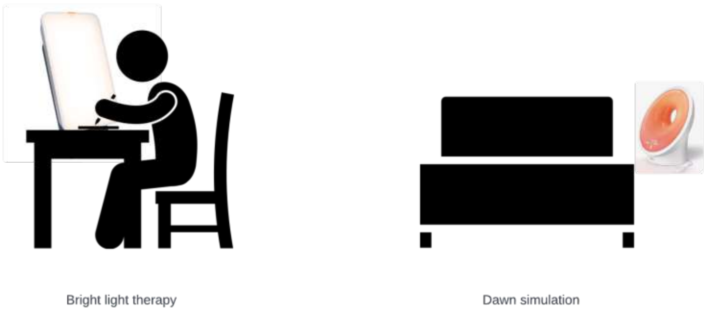

Figure 3.2: Bright light therapy vs. dawn simulation

However, when using light for chronotherapy, it is important to note that individual differences in chronotypes require a personalized approach. This means that solutions need to be customized in terms of light intensity and start time to take into account each individual's specific needs and adjust exposure accordingly. Different circadian clock types can and do affect their responses to light stimulation. Therefore, it is important to tailor chronotherapy to individual needs to achieve optimal results. By taking into account an individual's chronotype, you can ensure that light therapy contributes to optimal regulation of circadian rhythms and minimizes possible side effects. [18] [50]

The development of a personalised light wake-up therapy that is specifically tailored to the needs of late chronotypes could therefore make a decisive contribution to the treatment of circadian rhythm disorders and the associated health problems. Not only late chronotypes can benefit from the recommendation, but the personalised approach can also help to improve overall health and well-being for all users. This approach of developing a personalised light setting recommendation could therefore be a promising way to promote the health and quality of life of people with and without circadian rhythm disorders. [19]

3.3 User-Centered Design

User-centred design (UCD) is a proven methodological approach to designing products and services that involve later users from the very beginning. This ensures that the structure, content, and design of the final product are largely driven by the users' needs and expectations to deliver a high level of user satisfaction. According to Goalm et al., [51] whose paper can be seen as the basis of UCD, three principles are recommended:

- The early focus on users and tasks: The aim is to understand the user and their needs by examining their characteristics when accomplishing a task.
- Empirical measurement: the target user should use the prototype and be observed and analysed.
- The iterative design: The product is developed, tested and improved in repeated cycles. Feedback and insights from previous iterations are used to make incremental and continuous improvements until the desired end product is achieved.

3.3.1 Phases

The UCD process can be roughly divided into two main phases: the initial design phase and the iterative development phase. The initial design phase focuses on the conceptualization and planning of the product. Its goal is to find out about the user's behaviour in solving tasks. The iterative development phase is crucial to continuously improve the quality and usability of the product or service. The International Organization for Nominations (ISO), has captured UCD in ISO 9241-210 ("Human-centered design for interactive systems"). [51] [52] It results in the following iterative process, which can also be seen in figure 3.3:

1. Specify the context of use: This involves carefully examining the needs, capabilities, preferences, and constraints of the target audience. This is usually done by conducting user research, such as user interviews, surveys, and observations
2. Specify requirements: Clear requirements and targets are formulated, which must be met for the product to be successful. This helps to measure the system and to see if the development is right on track.
3. Produce design solutions: Designers generate creative ideas and concepts that address user needs. This involves prototyping and wireframing to visualize basic design directions.
4. Evaluation and Feedback of design: In this phase, the designed concepts and prototypes are presented to users for evaluation. Their feedback is invaluable in identifying potential problems and improvements.

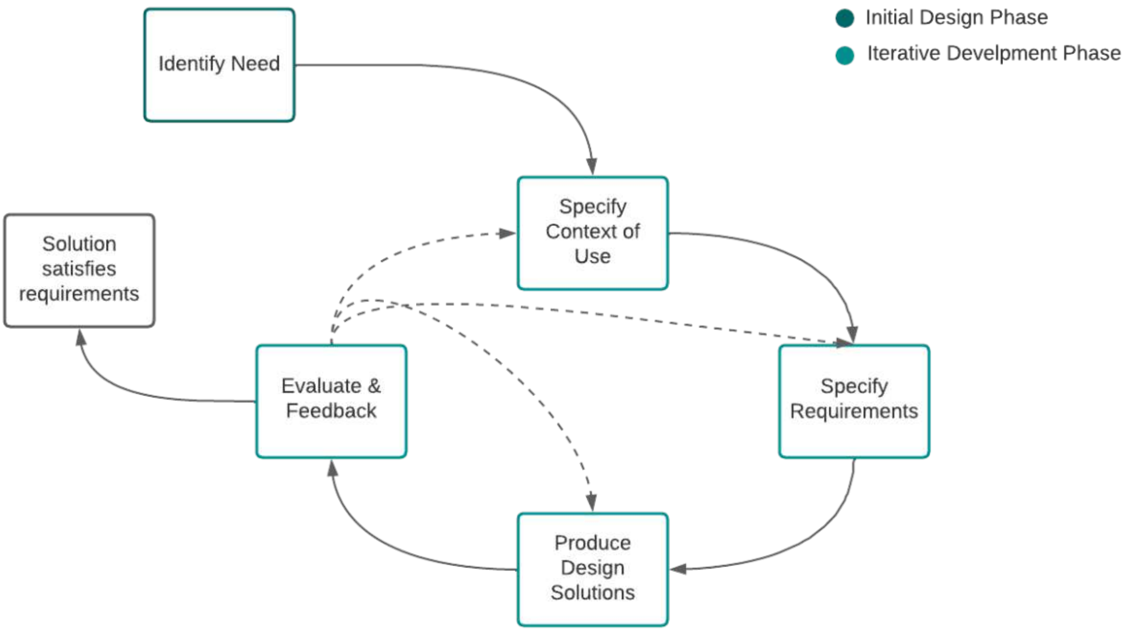

Figure 3.3: Interdependence of human-centred design processes according to ISO 9241-210 [52] adapted to UCD according to Goalm et al. [51]

3.3.2 Methods

User-centred design (UCD) is a methodical approach to product development that aims to optimise the user-friendliness and user experience of an application. When implementing UCD, various methods are used to align the design process with the needs, abilities and preferences of the end user. A fundamental method is the continuous involvement of users in the development process through techniques such as interviews, surveys and focus groups. These methods enable a deep understanding of the needs and requirements of the future user. However, prototyping and usability tests are also crucial methods for obtaining feedback from users early on in the development process. Prototypes enable the visualisation of interaction possibilities, while usability tests validate the actual user experience. These methods provide valuable insights to iteratively improve the design and ensure that it meets user needs. [51] [53]

In addition to these basic methods, advanced techniques such as eye-tracking analyses, heat maps and user flow diagrams can be used to gain detailed insights into user behaviour. The combination of these diverse methods within the framework of user-centred design helps to develop products that are not only functional but also user-friendly and tailored to the needs of the target group. [54] [55]

Interviews

Interviews are an essential method in user-centred design for gaining in-depth insights into the needs, expectations and usage context of users. The structured one-on-one conversations enable a targeted extraction of information and requirements. They can be used in both, the initial design phase and the iterative development phase. [54]

Good preparation is crucial when conducting interviews. This includes the definition of clear interview objectives and the creation of a guide with predefined questions. It is essential to be present during the entire interview and to make a fixed appointment in advance. This makes it possible to ask spontaneous follow-up questions and respond flexibly to the interviewee's answers. During the interview, the interviewer takes notes but it is recommended to also record the session to conduct a more profound analysis. Introducing the purpose of the interview and collecting demographic information helps to better contextualise the answers. Open-ended questions are used to elicit detailed responses, while specific questions are embedded in the overall context to understand relationships. Documentation takes place either in real-time or through recordings, followed by systematic analysis. [56]

Successful interviews require neutrality on the part of the interviewer to avoid influencing the answers. It is also important to be open to surprises to discover new aspects. Adapting the interview guide as necessary and emphasising confidentiality promote open communication and thus enable in-depth analysis of user perspectives within the framework of the UCD. [56]

Questionnaires

The use of questionnaires is a valid approach for UCD and is used both in the initial design and in iterative development. [54] Standardised questionnaires, which are filled out with closed questions, checklists or free expressions of opinion by users, are used to collect quantitative data on opinions, habits and preferences. The use of questionnaires enables uniform data collection, as all participants answer the same questions. This facilitates the comparability of results and enables the extraction of clear quantitative findings. The structured questions in these questionnaires are designed to capture specific information and thus offer a targeted approach to data collection. The questionnaire should be formulated in such a way that it is short, easy to understand and easy to answer. Open questions are rather uncommon, whereas preferred question types are checklists, clear yes/no questions or rating scales. This allows easy quantification of responses. Including questionnaires in the UCD thus offers an efficient way of collecting quantitative data while leaving room for individual perspectives through open questions. [56]

Brainstorming

Brainstorming sessions are essential in user-centred design as they allow team members or users to freely express ideas and solutions without restrictions. These creative meetings serve to promote the exchange of ideas and increase creativity in the design process. It is also a proven method for requirements engineering. [57]

Preparation plays a decisive role in practical implementation. Clear objectives are set for the topic or problem to be addressed, and the selection of diverse participants with different backgrounds ensures a wide range of perspectives. Providing suitable materials such as whiteboards or post-its makes it easier to document the collection of ideas. [58]

The introduction to the brainstorming session emphasises the open nature of the thought process. It is made clear that every idea is welcome, regardless of its feasibility. Facilitators play a crucial role in ensuring that these rules are adhered to and encourage participants to inspire each other and combine ideas. [58]

Prototyping

The creation of interactive models or prototypes is a crucial step in UCD, which serves to visualise the design and obtain feedback from users at an early stage. Tools such as wireframes or mockups are used to visualise the product at an early stage. Through this approach, these visual aids not only enable better visualisation of the design but also facilitate iterative adjustments based on the user feedback obtained. This process ensures that the final product not only meets the design requirements but also fulfils the needs and preferences of the users. [59] [27]

Usability Test

Tests such as usability tests or user tests that involve user testing the product and its functionalities offer a comprehensive way of evaluating user-friendliness and effectiveness. Users are invited to use the product in a realistic environment and perform specific tasks. During this process, their interactions and reactions are recorded by observers to generate valuable feedback. [53]

The process of a usability test involves guiding users through predefined tasks. These tasks are designed to test various functions and aspects of the product, allowing an identification of weaknesses in the design. The observations during the test make it possible to understand not only the actions of the users but also their emotions and hurdles. [60]

The documented results provide developers and designers with valuable insights into the actual user experience. By identifying challenges and ambiguities, targeted improvements can be made to optimise usability. Iterative adjustments based on user feedback lead to a progressive development process that ensures that the final product is not only technically smooth but also intuitive and user-friendly. [61] [60]

Think aloud

During the "Think Aloud" process, users actively share their thoughts and reactions out loud while interacting with the product. The main goal of this method is to gain deeper insights into users' perceptions and expectations. By continuously verbalising their thoughts during use, users enable the development team to gain direct insight into their cognitive process. This approach promotes transparent disclosure of the user experience, as both positive and critical aspects as well as immediate reactions can be authentically and directly recorded during the interaction. In addition, the user comments allow weak points to be found directly when the problem occurs. This creates a valuable basis for identifying the strengths and weaknesses of the product from the user's perspective. [62]

3.3.3 Sampling

Sampling is crucial in user-centred design as it is used to understand the behaviour, needs and preferences of users and take them into account when developing software solutions. UCD focuses on developing software solutions with the needs, abilities and preferences of users in mind. To make this possible, it is important to gain a deep understanding of the users and their context. Sampling plays a key role here, as it makes it possible to systematically collect and analyse data from the real world, be it through questionnaires, interviews or literature research. The process of sampling refers to the selection of a group of elements, known as a sample, from a usually larger group of interesting elements, called a population. [63] [64]

A sample is representative if it adequately reflects the characteristics of the entire population. This means that the selected elements provide a reliable picture of the entire population. In practice, this means that the characteristics and properties of the sample should be similar to those of the population as a whole. A historical example of understanding the sampling process is the three-stage model, consisting of population, sampling frame and sample. Here, the population acts as the totality of the elements of interest, while the sampling frame is an incomplete list from which the sample is selected. The sample itself is a subset of the sampling frame and is intended to reflect the characteristics of the overall population. However, many sampling approaches used in software engineering research cannot be categorised in this model. [63]

There are various methods used for sampling, which can be categorised into non-probability, probability and multi-stage approaches and are used for different purposes and backgrounds: [63]

1. Non-probability sampling
    - Convenience sampling: Selection based on availability or convenience. The sample is often not representative.
    - Purposive sampling: Selection according to a certain logic or strategy, but not randomly.
    - Referral-chain (snowball) sampling: Selection based on the relationship to previously selected elements.
    - Respondent-driven sampling: Advanced form of snowball sampling to minimise selection bias.
2. Probability sampling
    - Whole Frame Sampling: Selection of all elements in the sampling frame.
    - Simple Random Sampling: Random selection of elements.
    - Systematic Random Sampling: Selection of every xth element from a random starting point.

- Panel Sampling: Repeated analysis of the same sample at different points in time.

3. Multistage sampling

- Stratified/Quota Sampling: Subdivision of the sample frame into subgroups with proportional representation.
- Cluster sampling: Subdivision of the sample frame into groups from which a subset is selected.

The concept of sampling is multifaceted. At its core, it is about selecting data that is representative of a larger group using different approaches. For example, qualitative studies such as interviews or case studies often use non-statistical sampling to generalise selected data. On the other hand, quantitative studies, such as surveys, sometimes use statistical sampling to generalise data to a wider population. In a review of 120 articles in Software Engineering, Baltes and Ralph [63] found that purposive and random sampling are the most common sampling methods. Furthermore, they found out that, statistical sampling is found to be rarely used, while non-statistical sampling is widely used. This raises questions about the generalisability of the research results. It also raises the question of whether the lack of clear sampling guidelines can affect the representativeness of the data and if sampling is often misunderstood. In their paper, Baltes and Ralph propose recommendations for improving sampling methodology and reporting. These include clarifying the research objectives, explaining the methods used and avoiding over-representation of representativeness. [63]

UCD uses a variety of sampling methods, as it often includes multiple interviews, observations, surveys and usability testing. It thus gains a comprehensive understanding of the user perspective. By applying best practices, researchers can improve the quality and reliability of their sampling and thus strengthen the usability and acceptance of their developed solutions. [64]

3.4 UI/UX Design Principles

The design of user interfaces (UI) and user experiences (UX) is essential in the development of successful mobile apps. In the following, the basics of UI/UX design for apps are introduced, with a particular focus on the design principles that serve as guidelines for the design of visual elements and interactions. [65]

Usability refers to the ease of use of an application or system and how easy it is for users to interact with it, achieve goals, and perform tasks efficiently. High availability is critical to application success because it helps minimize frustration, maximize user productivity, and increase satisfaction. User experience (UX) encompasses the entire experience a user has when interacting with an application, including their emotions, impressions, and perceptions. A positive user experience occurs when an application is not only functional, but has an appealing design, provides added value to the user, and enables pleasant interactions. By providing a positive user experience, apps can enhance user engagement, increase loyalty, and improve brand image. [66]

UI/UX design for apps encompasses the visual design of user interfaces as well as interaction and user guidance within the app. Effective UI/UX design strives to create a seamless, intuitive, and engaging user experience that fulfils the needs and expectations of the user. The design process is supported by methodologies such as user-centred design, design thinking and agile UX design, enabling iterative development and ensuring the user is at the centre of the design. Modelling tools like Adobe XD, Sketch, and Figma help designers create prototypes and quickly visualize and test design concepts and are used to evaluate the usability and effectiveness of a user interface in a usability test. Adhering to standards and guidelines like Material Design and the Web Content Accessibility Guidelines (WCAG) ensures a consistent and accessible user experience. [65]

The Gestalt principles are fundamental concepts from Gestalt psychology that help to understand the perception and organisation of visual elements. In UI/UX design, Gestalt principles are used to improve user guidance, direct the user's attention and create a consistent visual aesthetic. Some of the most important design principles can be found in figure 3.4 and are [65] [67]:

- Law of proximity: Elements that are close to each other are perceived as belonging together. This principle is used to form groups of elements and facilitate the organization of content.
- Law of similarity: Elements that are similar in shape, colour, or size are perceived as belonging together. This principle is used to create visual hierarchies and emphasize the importance of elements.
- Law of continuity: Elements that have a linear or flowing direction are perceived as belonging together. This principle is used to create visual flow lines and facilitate navigation through the application.
- Law of good figure: Elements that form a clear, recognizable figure are perceived more easily. This principle helps in designing visual elements that are easily identifiable and understandable.
- Law of common region: Elements within the same enclosed area or region are perceived as belonging together. This principle aids in organizing content and grouping related elements.
- Law of closure: Elements that form a closed shape or contour are perceived as belonging together, even if parts of the shape are missing. This principle helps to complete visual patterns and make the viewer recognise discrete elements as belonging together.

- Law of common fate: Elements that move in the same direction or manner are perceived as related. This principle helps design interactive elements that respond cohesively to user actions.

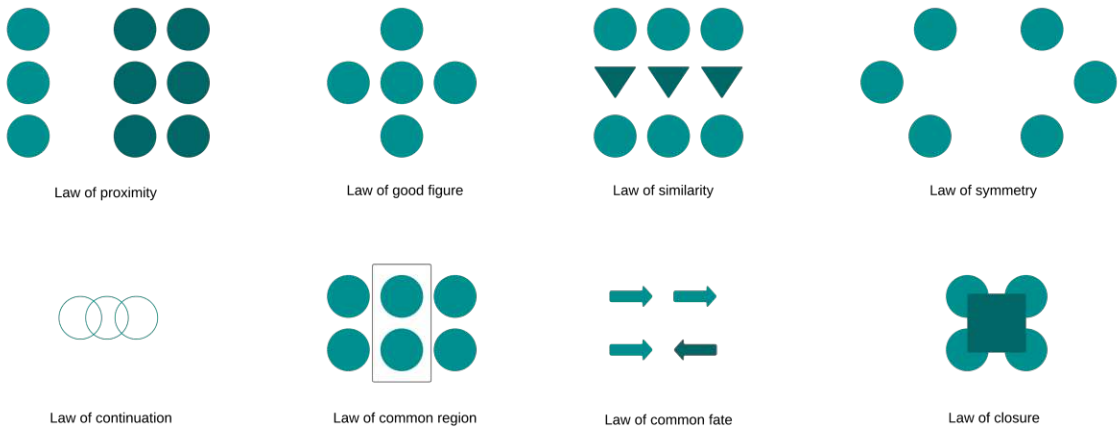

Figure 3.4: Gestalt principles [65]

When developing apps, the Gestalt principles are applied to create a consistent and user-friendly user experience. This includes the design of user interfaces, the organisation of content, navigation through the app and the visual presentation of information. Through the targeted application of design principles, developers can ensure that their apps are intuitive, appealing and easy to understand. [65]

UI/UX design plays a crucial role in the development of successful mobile apps. The Gestalt principles provide valuable guidelines for the design of visual elements and interactions. Through the targeted application of design principles, developers can create apps that offer a seamless user experience and exceed user expectations.

3.5 Requirements of personalised apps in the medical field

The rapid development of technology has had a significant impact on the healthcare sector. Medical apps have become an integral part of healthcare as they are personalisable and help to improve patient retention, engagement and therapeutic outcomes. In this context, the importance of design guidelines and carefully designed requirements is increasing as the design and relevance of a mobile health app are critical to its acceptance and ultimate success. The careful application of requirements engineering, both in general and in the medical context, ensures a solid foundation for the development of reliable software solutions that meet the highest standards in terms of functionality, security and user experience. [68] [69]

Requirements engineering is an indispensable cornerstone in the software development process, focusing on the systematic capture, analysis, specification and management of requirements. Accurate requirements definition is critical to guide the development process and ensure that the final software product fully meets the needs and expectations of stakeholders. The requirements elicitation process marks the starting point of requirements engineering. Identify and document the needs of all relevant stakeholders, including end users, customers, and development teams. Various methods such as interviews, surveys, and observations help to comprehensively record functional and non-functional requirements. [70] Whereby:

- Functional requirements: Functional requirements describe specific functions, operations, or tasks that a system or product must perform. They determine what operations the system should perform and thus which functional aspects are visible to the user. [71]
- Non-functional requirements: Non-functional requirements define attributes and quality characteristics that are not directly related to specific system functionality. They address aspects such as performance, security, reliability, availability, and scalability. [71]

When developing medical apps, developers must handle an immense volume of health data. This data includes patient records, insurance information as well as monitoring data, for example from outpatient monitoring of epilepsy patients. Furthermore, the context in which mobile health interventions operate and the consequences of their implementation must be considered in their design. This personalisation requires a thorough consideration of various factors to ensure the effectiveness of the apps. [68] [69]

There are clear requirements for personalisation of medical apps:

1. **Patient profile and medical history:** Personalisation should be tailored to each patient's individual health status, medical history and preferences. A comprehensive capture of the context of each user enables precise customisation of app functions and recommendations. [68] [72]
2. **Real-time monitoring and data integration:** The integration of real-time data, such as health metrics and clinical lab results, allows for continuous monitoring of the patient's condition. Thus, an app should be able to collect, analyse and transform this data into relevant recommendations for action while remaining performant and productive. [68] [73]
3. **Adaptive content and interactions:** Given the ever-changing medical histories of patients and the resulting varying needs, an app should have the ability to adapt its content according to the changing needs of patients. In addition, the app should have the capacity to create links between these dynamic needs and individual patient information. This ensures that the information and services presented always remain relevant and up-to-date. [72] [68]

4. **Privacy and security:** Due to the increased use of medical apps and the diversity of users with different medical histories, the need for security and privacy measures is becoming increasingly important. An app should therefore meet the highest standards of privacy and security to ensure the confidentiality of patient data. [74] [75] [72]

5. **Usability and accessibility:** Personalisation should consider usability and accessibility for different user groups, including older people or people with disabilities. Usability and perceived quality from the user's point of view are crucial aspects of medical apps. [73] [69] [72]

These special requirements for medical apps emphasise the importance of a thorough requirements analysis when developing applications in a medical context. In particular, the aspects of personalisation, privacy and flexible adaptation to changing circumstances prove to be of outstanding importance. Therefore, when designing and developing medical apps, it is necessary to focus particularly carefully on individual needs, data protection regulations and the ability to adapt to dynamic changes. [68]
These findings serve as the basis for the subsequent development phase and lay the foundation for the successful implementation and acceptance of such applications in the medical environment.

CHAPTER 4

Methodology

The methodological approach chosen for this work represents a combination of theoretical investigation and practical analysis. The personalisation app developed for intelligent wake-up light systems is based on the consistent application of the principles of user-centred design (UCD). UCD is a proven method that places the end user at the centre of the design and development process. This ensures that the resulting applications are not only user-friendly but also innovative and high in quality. [65]

The decision to apply UCD in this work is based on the realisation that involving the user not only helps to improve personalisation but also promotes user-friendliness and acceptance of the developed application. This means that the resulting personalisation app meets the individual preferences of users and can also be seamlessly integrated into their everyday lives.

The application of UCD principles for the implemented app for personalising a wake-up light system is particularly relevant for the following reasons:

1. Circadian rhythm variability: Circadian rhythms, which regulate the body's sleep-wake cycle, vary from person to person. They are influenced by factors such as age, lifestyle, and chronotype. A one-size-fits-all approach in wake-up routines fails to account for this variability. [23]
The goal is to present individual recommendations to adjust the wake-up light system to the user's unique circadian rhythm. UCD ensures that these individual variations are integrated into the app, fostering a more accurate and beneficial wake-up experience.

2. Multi-faceted user needs: The domain of sleep and wake-up routines encompasses a diverse range of user requirements, spanning from individuals who prefer subtle wake-up cues to those who necessitate more pronounced light stimuli. The nuanced customization of light settings emerges as an important factor in attaining the desired health benefits associated with these wake-up routines. [19]
In this context, the application of User-Centered Design (UCD) proves instrumental,

facilitating the seamless integration of a multitude of user needs. It ensures that the app is not only adaptable but also tuned to address the specific requirements of each user, creating a personalized and effective experience in the realm of circadian adjustment.

3. User engagement and long-term benefits: The ultimate success in adjusting the circadian rhythm depends crucially on whether users consistently follow the suggested recommendations. The quality of these recommendations, in turn, requires that users are willing to invest the necessary time in answering the initial questions to generate the parameters. Applying user-centred design (UCD) principles helps to improve the usability of the app by conducting iterative tests and integrating user feedback. This leads to a more appealing and intuitive application, which ultimately increases user acceptance and enables long-term health improvements.

Based on the advantages discussed above, the app developed as part of this master's thesis is designed to personalise a smart alarm system using the principles of user-centred design. The focus is on designing the application so that it seamlessly synchronises with the individual circadian rhythm, takes individual user needs into account and provides high-quality wake-up setting recommendations for improved circadian health. Participants and literature were selected according to the requirements of the iteration using different sampling methods, including stratified, convenience and purposive sampling. The specific steps of the UCD process are explained in detail below.

The entire UCD process is divided into two main phases: the initial design phase and the iterative development phase. The entire UCD process can be found in figure 4.1.

Phase 1: Initial Design Phase

In the design phase, the focus was on gaining a comprehensive overview of the topics of circadian rhythm, light therapy, medical requirements and UI/UX design. As requirements engineering formed a significant part of this research phase, the initial requirements were defined and specified. The main sources here were literature research to establish a solid background knowledge and brainstorming, which helped to structure the results obtained. In addition, the iterations of the user-centred design were worked out, whereby it was determined how many participants should be involved in which iteration.

1. **Literature Research and Background Establishment:** The methodology commenced with a thorough literature review, serving a dual purpose: to address the primary research question and to establish a robust background in the field of UI/UX design, circadian rhythms and light-wake systems. The goal was to extract insights from existing studies, ascertain the current state of the art, and identify the requirements for personalized parameter extraction within the app.

2. **Brainstorming:** After completing the literature research, a joint brainstorming session was initiated. This creative process aimed to use the findings of the literature research to generate initial design concepts and ideas for an iterative approach. The initial requirements were identified in parallel and a low-fidelity prototype was

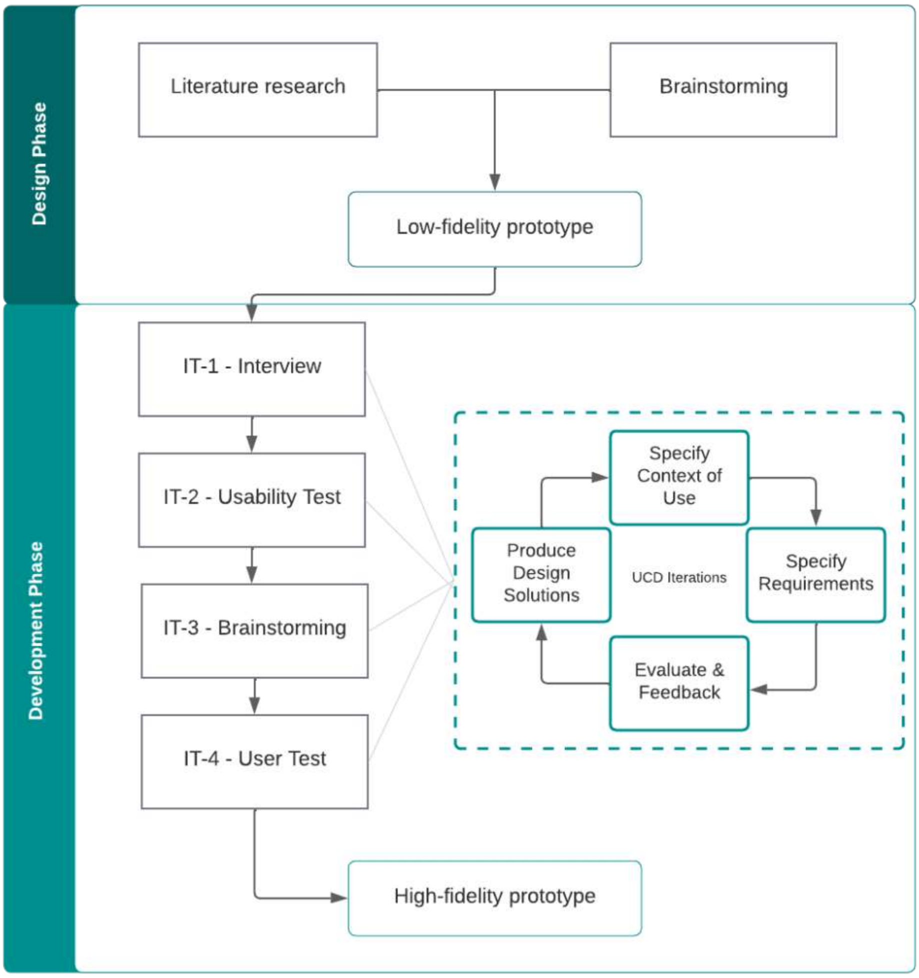

Figure 4.1: Overview of the applied methodology of UCD

created. This prototype acts as a visual representation of the app's interface and functionality, providing an early and easily understandable representation of the planned design direction.

Phase 2: Iterative Development Phase

A central element of user-centred design is the iterative development concept, which aims to continuously improve a system through repeated process loops. This iterative approach not only ensures constant adaptation to evolving requirements but also integrates valuable feedback from users to optimise user-friendliness and effectiveness. In this context, the four key iterations consist of an initial interview, a usability test, a brainstorming process and finally a final user test. This iterative development aims to concretise and specify the requirements from the initial design phase. The two test phases (usability test and user test), which involved a total of 12 users, made it possible to evaluate the app and its requirements under real conditions.

1. **Interview:** As part of the iterative development phase, an interview with an expert from the field of sleep medicine was conducted as an initiating step. This interview aimed to subject the ideas generated in the initial design phase to an expert evaluation and to specify the relevant parameters to be extracted. To ensure high-quality parameters, a qualitative content analysis according to Mayring [76] was implemented as a methodological approach. This made it possible to systematically analyse and interpret the data obtained in the interview to identify well-founded and precise user parameters for further development.

2. **Usability Testing:** Usability tests play a central role in the iterative development phase. This involves actual users interacting with prototypes or mockups, with their behaviour and feedback being carefully observed. [65]
   During the development phase, the usability test conducted with six participants helped to uncover ambiguities in terms of user-friendliness, validate design decisions and thus increase user acceptance. Participants were deliberately selected from different age groups to ensure a comprehensive assessment of usability, taking into account diverse technical skills and background knowledge of the circadian rhythm. This targeted diversity should ensure that the application is equally accessible and user-friendly for people with different levels of experience and knowledge of smartphone use and circadian rhythm.

3. **Brainstorming:** An additional brainstorming session, which included an expert in the field of chronotherapy, was aimed to deepen the findings from the literature review on the medical background of chronotherapy and light treatment. During this session, sound principles were intensively discussed to develop a qualitative algorithm for calculating personalised recommendations for light settings. In addition, the session served to revise and optimise existing design decisions, with the expert providing valuable insights and perspectives. This collaborative brainstorming session thus contributed significantly to the further development and refinement of the algorithm and requirements.

4. **User Test:** User tests provide direct feedback from real users, allowing the user-friendliness and functionality of an application to be comprehensively evaluated. [65]
   In the final phase of the iterative development process, a comprehensive user test was carried out with six participants, whereby participants with diverse demographic characteristics and different backgrounds were deliberately selected. A targeted selection was made under the premise of including people who corresponded more to the chronotypical characteristics of evening people to evaluate the algorithm and the success of the resulting recommendations under these specific conditions.

   The selected participants were asked to use the application in its full range and to test the recommended light settings in conjunction with a light alarm clock over five days. Feedback was then obtained using a structured questionnaire. This approach not only enabled the effectiveness of the recommendations developed to be analysed in detail but also allowed general user acceptance to be comprehensively recorded over a longer period. The integration of evening people into the test process ensured a practical review of the application under realistic scenarios, allowing the adaptability and effectiveness of the algorithm concerning individual chronotypical preferences to be validated over an extended period.

Implementing this user-centred design approach ensured that the entire design process was based on the feedback and needs of potential users. The process was continuously refined to ensure the effective fulfilment of these needs and to ensure the quality of both the algorithm developed and the initial parameter extraction questions. Each step within this approach served to progressively refine the mock-up, ensuring that user feedback was incorporated into the continuous improvement of the app design and usability. The repeated interactions and continuous adjustments to the prototype resulted in an app that can deliver personalised recommendations through targeted parameter queries and science-based calculations. This approach not only promoted the effectiveness of the application but also created a high level of user acceptance through a user-friendly design.

CHAPTER 5

Results

This results chapter is the culmination of a thorough exploration of the User-Centered Design (UCD) process and its application in this master's thesis. This includes, on the one hand, the participants, the target audience, and the interactions conducted in this research, and, on the other hand, an in-depth analysis of the results obtained, which serve as a basis for the successful implementation of User-centered design solutions.

5.1 Preparation of User-Centered Design

Implementing a successful user-centred design approach for developing an app to personalize a smart alarm clock required careful preparation in terms of the target audience, iteration planning and design methods, and participant selection. This section provides an overview of the preparatory steps taken. The theoretical underpinnings were described in more detail in the chapter 3.

5.1.1 Target group

The target audience for the app to be developed was carefully defined and segmented to ensure that the designed solutions would meet the diverse needs of the users. Care was taken to include representatives of all age groups, as the functions of a smart alarm clock appeal to a wide range of users. In particular, health-conscious users in the middle age group should be addressed, as they are willing to monitor their sleep to improve their health. Another important target group is are so-called "morning grouches", i.e. people who find it extremely difficult to get up in the morning and are willing to work on lifestyle changes to improve their health. At this point, it should be noted that the personalised recommendations aim to induce a phase-advance of the circadian rhythm. This means that the application is designed to enable people who tend to be evening people to get up earlier and thereby increase their well-being. The target group is therefore aimed more at individuals who have difficulty being active early in the morning, as opposed to the so-called "early birds", who get up early due to their natural biological rhythm and therefore do not need phase-advance. It should be noted that the application is currently not suitable for people who prefer a phase delay of the circadian rhythm. However, this group could be considered in future research and integrated into the application. For people who are between the extremes, the application offers benefits such as improved mood and increased energy, even without a shift in the circadian phase. These people are therefore also part of the application's target group. To elaborate on the different user groups, personas were created. This segmentation of the target group made it possible to identify relevant characteristics and requirements and integrate them into the design process.

5.1.2 Iterations

The implementation of the user-centred design took place in an iterative approach, which starts with an initial design phase and continuously adapts the prototype in an iterative development phase.

The design phase focuses on defining the requirements and parameters needed to calculate the personalized recommendations. It consists of literature research, interviews, and brainstorming. The literature review was the basis for the science behind chronotherapy, the circadian rhythm, and light as the primary zeitgeber, as well as UI/UX design. The creative brainstorming sessions were used to discuss different approaches to personalization and functionality of the app.

During the iterative development phase, several interactions were carried out to fulfil the current development requirements. Each iteration pursued the goal of generating substantial added value for the users of the application. Key parameters were identified through qualitative interviews. In addition, a usability test was carried out with a low-fidelity prototype to evaluate user-friendliness employing user feedback. A subsequent brainstorming session, which also included the expertise of a specialist, provided in-depth insights into the implemented algorithm. Finally, comprehensive user tests were carried out in which the application was tested by real users under authentic conditions. This enabled the observation of users' behaviour and reactions to the application and its recommendations, providing valuable feedback.

The individual iterations, with their methods, the participants and the resulting result can be found in figure 5.1.

5.1.3 Participants

The participants were selected using various sampling methods. A sampling method adapted to the context of the iteration was used.

- Literature research - IT-0: A multi-stage sampling approach with stratified sampling was used for the literature search in the areas of chronotherapy and UI/UX design:

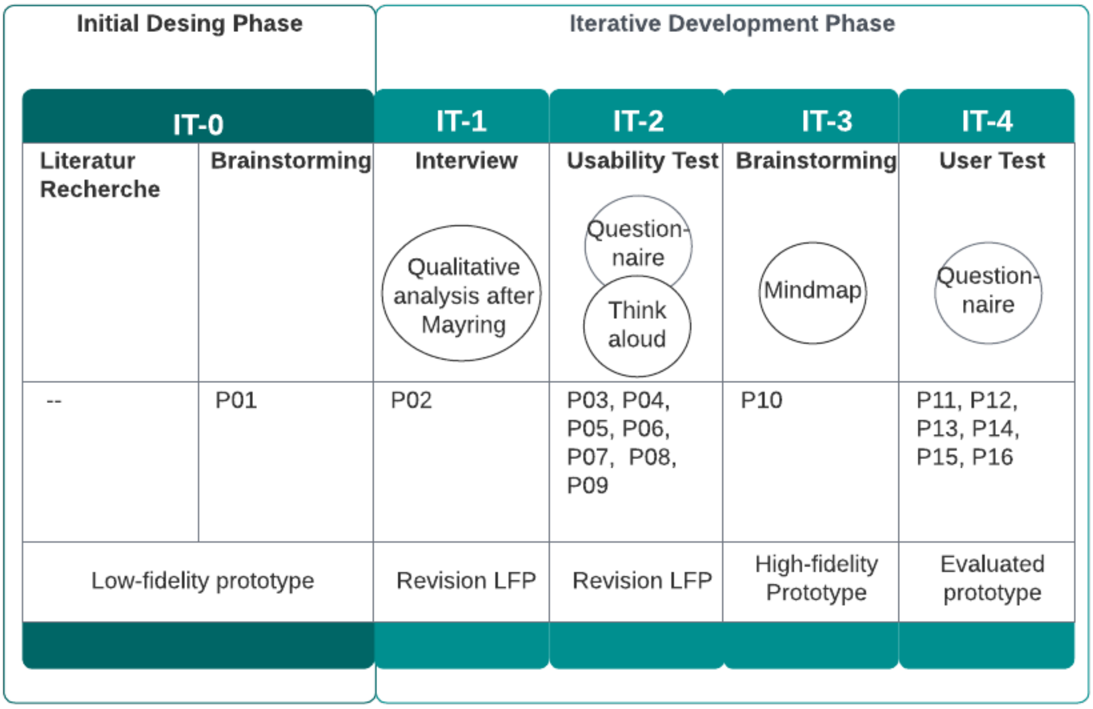

Figure 5.1: Interations of UCD

- Stratification: the literature search is divided into two main groups or strata: Chronotherapy and UI/UX Design. These two strata represent different areas of interest for the research.
- Sampling within the strata:
  Chronotherapy: within this stratum, relevant literature sources on chronotherapeutic approaches are collected. This could include studies on the use of light therapy for sleep disorders or seasonal affective disorder.
  UI/UX design: This stratum collects sources on the design of user interfaces and user experience, focussing on software applications or websites. This could include studies on the development of user-friendly interfaces or the optimisation of user interaction.
- Sampling across strata: Once the relevant sources within each stratum have been collected, a few selected sources from each stratum are further analysed and selected. This allows for a more comprehensive consideration of different aspects and perspectives related to the research question.

By applying the multi-stage sampling approach with stratified sampling, we can ensure that the literature research includes a balanced selection of sources from various relevant areas.

- Usability test IT-2 and user test IT-4: For the usability test with 6 participants from different age groups and genders, convenience sampling was chosen as the main goal is to get a representative but easily accessible sample of participants to evaluate the usability of the software. Convenience sampling was used for the final user test with participants deliberately selected according to a late chronotype, as the selection of participants was based on their availability and convenience. As the aim was to recruit people with a late chronotype, this method was chosen to obtain a suitable sample quickly and efficiently.
- Brainstorming IT-3 and interview IT-1 with experts: Purposive sampling was used for the iterations in which experts were selected based on their specialisation. This method makes it possible to identify and select people with specific expertise and experience to gain valuable insights into the topic.

A complete list of all participants, including the respective iterations in which they participated, can be viewed in table 5.1.

Table 5.1: Participants

Participant-ID	**Gender**	**Age**	**Profession**	**Iteration**
P01	male	29	Entrepreneur	IT-0 (Brainstorming)
P02	male	54	Professor (Research) of Psychiatry and Behavioral Sciences (Sleep Medicine)	IT-1 (Interview)
P03	female	26	Educator	IT-2 (Usability Test)
P04	female	25	Student	IT-2 (Usability Test)
P05	male	28	Accountant	IT-2 (Usability Test)
P06	female	58	Entrepreneur	IT-2 (Usability Test)
P07	female	60	Shop assistant	IT-2 (Usability Test)
P08	male	34	Sales Team Leader	IT-2 (Usability Test)
P09	female	23	Student	IT-2 (Usability Test)
P10	male	55	Professor of Clinical Psychology in Psychiatry (Fokus Chronotherapeutics)	IT-3 (Brainstorming)
P11	female	25	Software Engineer	IT-4 (User Test)
P12	male	28	Student	IT-4 (User Test)
P13	female	30	Regisseur	IT-4 (User Test)
P14	male	40	Accountant	IT-4 (User Test)
P15	male	23	Security Manager	IT-4 (User Test)

P16	female	26	Software Engineer	IT-4 (User Test)

5.2 Design Phase

In the initial design phase, different methods are combined to create an initial low-fidelity prototype. For this purpose, literature research and brainstorming were carried out. These methods play a crucial role in creating a basis for answering research question 1 by defining the initial requirements for personalizing the app and obtaining parameters.

5.2.1 Literature reasearch

In the course of the literature review, an extensive examination using a multi-stage sampling approach with a stratified sampling of scientific papers, articles, and scholarly books was undertaken. The scope of the research encompassed a range of topics, including chronotherapy, circadian rhythm, dawn simulation, as well as design principles.

The results highlight the significant influence of light on human psychophysiological processes and circadian rhythms. It is particularly important to emphasise that there is considerable inter-individual variability in responses to light, underlining the need for personalised light settings. Factors such as age, gender, chronotype and even eye colour are proving to be crucial determinants. For example, older people often show reduced sensitivity to light due to cloudy lenses, while younger people tend to be more light-sensitive. Furthermore, research shows that there are also gender-specific effects of light exposure. However, opinions on this are rather divided. [77] [78]
The findings make it clear that a generalised approach to light management may not be sufficient, as reactions to light can vary greatly from person to person. In particular, consideration of light sensitivity becomes crucial to maximise the effectiveness of personalised light settings. For example, lighting adjustments for light-sensitive individuals and those with a lighter eye colour may require finer tuning to achieve optimum effect. [41] [79]

The circadian system is controlled by a master clock, which is responsible for the sleep-wake cycle, and is synchronised to the 24-hour light-dark cycle via light exposure. This is individual to each person and can also change. The phase response of the circadian rhythm describes the time-dependent change in biological activity in response to an external stimulus, especially light, and shows how these changes influence the internal clock. [80] [81]
These light-dependent circadian responses are, in addition to personal factors such as age and eye colour, also dependent on the time and intensity of light exposure and should therefore be considered in the algorithm. A key determinant that influences the positioning of the circadian rhythm is the individual chronotype. Together with the desired phase shift (advance or delay), it plays a fundamental role in determining the optimal time of light exposure. Exposure to light in the morning leads to a phase shift

in the circadian clock, while exposure to light in the evening has exactly the opposite effect. The chronotype and the intended phase shift (pre-shift or delay) determine the optimum time for light exposure. As the application is specifically focused on a pre-shift, the chronotype is relevant for determining the start time. [82] [83] [4]
To determine the chronotype, the calculation of the MEQ score was identified in the literature research, which is carried out by asking the user-specific questions using the Morningness-Eveningness Questionnaire (MEQ) [46]. [84]

Furthermore, the review highlights the effectiveness of dawn simulation in enhancing the phase misalignment between sleep patterns and other circadian rhythms. Remarkably, it outperforms Bright Light Therapy in head-to-head comparisons. Even modest levels of light, as low as sunrise increasing its intensity up to 180 lux, can elicit shifts in circadian rhythms, given the exceptional retinal sensitivity, particularly during the early morning hours. The ideal timing for such a simulation is approximately 2.5 hours after the midpoint of sleep, with light intensity gradually increasing from 0.001 lux to 300 lux over 90 minutes. The calculated recommended settings should therefore refer to dawn simulation, whereby a future integration of bright light therapy or flashes would be conceivable. [85] [5] [86]

The literature research carried out not only covered medical basics but also included topics relating to the user interface (UI) and user experience (UX). It is evident that ensuring a user-centred design is of paramount importance to enable optimal usability. It is highly relevant to pursue a universal design that ensures broad applicability for various user groups and is intuitive and straightforward at the same time. The essential features include clear structuring, low complexity and user guidance that facilitates navigation through an extensive amount of questions. [87] [88]

Wording texts in the app in an understandable language is important, as is an appealing and uniform visual design to make the user experience pleasant and inviting. This also includes a high-contrast design that clearly distinguishes the background from the text. The application of design principles such as the "principle of continuity", the "principle of commonplace" and the "principle of similarity" are fundamental principles in UI/UX design. Adherence to these principles is essential for a high level of user-friendliness and a clear, appealing design. [65] [89]

Beyond the design basics, the app should implement mechanisms for saving answers step by step and offer the option to pause and resume the questionnaire later. Transparent communication about the progress and importance of the questions asked helps to motivate and engage users. Last but not least, data protection-compliant handling of sensitive information is crucial to maintaining user trust. [87] [88]

Comprehensive requirements engineering is also necessary to fulfil user requirements in terms of design and content. All relevant information must be collected to optimise the system for all future users. The decisive factors here are not only the tasks that the application should fulfil - in this case, collecting parameters from the user to provide personalised recommendations - but also the context in which the application is used, possible deviations and the overarching goal. [90] [65]

The literature review reveals that the deliberate and tailored implementation of dawn simulation, including personalised light intensity and start time holds the potential to induce a shift in circadian rhythms and, in turn, enhance mood and energy levels. An essential consideration is the necessity of individualized adjustment of both the start time and the intensity of the simulation to cater to the specific user. [81] Furthermore, it revealed, that the essential importance of user-friendly design, which can be achieved through consistent adherence to UI/UX principles and a comprehensive definition of requirements. UI/UX principles are a fundamental prerequisite for creating a user-friendly and efficient application platform and ensure a consistent visual design, but also seamless interaction between the user and the application. From structured requirements engineering not only the functional aspects of the application are taken into account, but also the contextualisation concerning the specific requirements and expectations of the user. This enables a detailed specification of all elements, from the user interface to the functional mechanisms. [65]

After the extensive literature research, an initial conceptual framework was formulated, systematically integrating all the gathered information and establishing meaningful connections among them. This conceptual framework serves as the foundational cornerstone for the ensuing brainstorming phase.

5.2.2 Brainstorming

In the subsequent stage of the design process, a brainstorming session was instigated, and conducted in collaboration with a specialist in the field. The fundamental objective of this session was the generation of inventive ideas and conceptual frameworks, predicated on merging the research insights derived from the literature review, prevailing UI/UX principles, and individualized parameters. The subsequent considerations and the resulting low-fidelity prototype play a prominent role in this project.

Commencing the brainstorming session, a mind-mapping activity was undertaken, orchestrating a visual representation of key concepts and associative linkages within the context of the literature review findings. This mindmap served as a dynamic platform, offering a structural schema to structure ideas and explore the different facets of app design.

In this context, the outstanding importance of the Dawn simulation was discussed, emphasising that the calculations should focus on this specific method. In particular, the calculation of the start time and light intensity plays a decisive role here. The execution and presentation of personalised settings allow users to respect their natural sleep-wake cycles and make the morning wake-up phase gentle and biologically appropriate. Users should be provided with a clear presentation of the calculated recommendations, allowing them to set their light alarm clock based on personalised recommendations and chronotypes to optimise their wake-up and well-being. The designed questionnaire should partly contain elements of the MEQ [46] to identify the chronotype. As the

MEQ itself consists of 21 questions and is therefore considered extensive, an interview is planned during the development phase to check the possibility and validity of reducing the questionnaire. This interview aims to gain additional insights and at the same time evaluate the parameters defined in the questionnaire. In addition, a concise scientific overview is provided to give users a better understanding of the background of the calculations.

Another outcome of the session manifested itself in the realisation that UI/UX principles play a central role in ensuring the usability and overall quality of the application. This includes the implementation of an intuitive user interface, the clear visualisation of progress in the questionnaire and an aesthetically pleasing visual design. Finally, it was decided that the development of a questionnaire to collect personal parameters would be extremely useful. This questionnaire should enable users to specify their sleeping habits, chronotypes and personal preferences regarding light intensity and wake-up times. This will enable a customised alarm solution based on the specific needs and preferences of the individual user.

Furthermore, initial considerations were made to obtain feedback from users to enable continuous adaptation and improvement of the recommendations.

In addition to the calculations and respective recommendations of the algorithm, additional considerations were made during the brainstorming session about technical details. In this context, the decision was made to develop a smartphone app that can be used on both, iOS and Android. To ensure this cross-platform compatibility, implementation is planned using Flutter[1].

Concerning the database structure, it was decided to use Firestore. This decision was based on the ability of this database to store information in offline mode, which was considered particularly relevant to the requirements of the application. The selection of Firestore allows for efficient data storage and retrieval, while at the same time providing the ability to ensure smooth functionality of the app regardless of the internet connection.

The results of this brainstorming session, in combination with the previous research findings, form the basis for the development of a promising low-fidelity prototype. This prototype will be further refined and tested in the upcoming phases of the iterative development phase.

5.2.3 Result: Low-Fidelity Prototype

The initial low-fidelity prototype was developed based on the literature review results and brainstorming sessions. To achieve this, requirements were defined, which were applied in the design. The mockups were transformed into wireframes using Figma [2].

[1] https://flutter.dev/
[2] https://www.figma.com/de/

5.2.3.1 Resulting Requirements

The literature research and brainstorming resulted in initial requirements which can be found in table 5.2 and are characterised by a unique ID, a title and an assignment to a specific area of the app. While requirements from the initial design phase are labelled with a "D-" (for design) followed by a number, the requirements from the iterative development phase are labelled with "ID-" (for iterative development) and a corresponding number. This makes it possible to see which phase the respective requirements come from.

The requirements extracted from the initial design phase cover a wide range of aspects. The first requirement (D-01) provides for the consideration of demographic parameters in the algorithm to enable a personalised user experience. It was based on literature research and emphasises the importance of targeted adaptation to different age groups and demographic factors. The second requirement (D-02) focuses on visualising the user's progress. This requirement, also supported by literature research, emphasises the importance of a clear, motivating progress indicator in the UI/UX design. This should encourage users to use the application continuously. The storage of user responses (D-03) is an essential requirement that results from the literature research and requires integration into the database. This ensures the storage of data when the questionnaire is cancelled and the long-term availability of user data for later analysis and use in the algorithm. Another requirement from the initial design phase (D-04) emphasises the usability of the application to ensure that users can use the application easily and effectively. The requirement for data integrity and privacy (D-05) arose from the literature research. Particularly in the medical context, it is important to ensure the accuracy and integrity of medical data while implementing comprehensive protections for user privacy. The requirements D-06 to D-07 originate from brainstorming sessions. D-06 and D-07 focus on the development of a mobile app that allows users to easily access recommendations from their smartphones and ensure portability to iOS and Android. To keep users continuously informed about progress, D-08 implements confirmation of success. In addition, D-08 provides for the use of an initial questionnaire for new users to enable personalised use.

Table 5.2: Requirements from IT-0 literature review and brainstorming

Requirements-ID	Titel	Applicaiton
D-01 (Literature Research)	Consideration of demographic parameters	Algorithm
D-02(Literature Research)	Representation of progress	UI/UX Desing
D-03(Literature Research)	Saving of responses	Database integration
D-04 (Literature Research)	Usability	UI/UX Desing

D-05 (Literature Research)	Data integrity & privacy	Database
D-06 (Brainstorming)	Mobile app	Development environment
D-07 (Brainstorming)	Portability	Development environment
D-08 (Brainstorming)	Confirmation of success	UI/UX Design
D-09 (Brainstorming)	Initial Questionnaire	UI/UX Design, Algorithm

5.2.3.2 Initial Design

During the brainstorming session, the decision was made to create a smartphone app with a responsive design primarily tailored for mobile devices but also compatible with tablets (D-05). This choice was primarily driven by the convenience and widespread availability of smartphones. Users can easily access their settings from the app in the evening and use them to set their alarms. In the evening, most of the users tend to reach for their smartphones, allowing set their alarm clock easily to the provided recommendations.

After considering how to gather personalized parameters, the decision was made to use an initial questionnaire that users must complete to extract the required parameters for the calculations of the algorithm (D-08). It was clear from the literature review that the app should continuously display progress (D-02), and users should have the option to revisit previous sections (D-03). Additionally, an initial decision was made regarding the essential questions needed to obtain all the necessary user information (D-08). The literature suggests that factors such as age, gender, eye colour, and chronotype play a critical role (D-01). To inquire about the user's chronotype, it was quickly decided to utilize the Morningness-Eveningness Questionnaire. In addition to personal parameters, alarm settings, and the user's goals, it would be beneficial to display some background information. The initial mockups can be found in figure 5.2.

From a design perspective, the decision was made to follow a sequence that starts with optional background information, which users can skip. Next, an informational screen explains why the data is being collected and assures users of its confidentiality. Subsequently, the questionnaire is divided into four sections: Personal Information, Chronotype, Alarm Settings, and Goals. The Chronotype section includes questions from the MEQ. The decision to divide the questionnaire into four parts was based on the requirements for usability and the progress display. By splitting it up, the user always has an overview of how many steps there are still to take and does not have to fill out a long, confusing form (D-03, D-01). Finally, a confirmation screen appears to indicate the successful completion of the questionnaire (D-07). The choice of colours fell on the warm colours of dawn, as the theme of the sunrise should be maintained here. The colours yellow and orange also have a warm and energetic effect. Montserrat was chosen as the font because it is clear and easy to read and at the same time looks professional and creative.

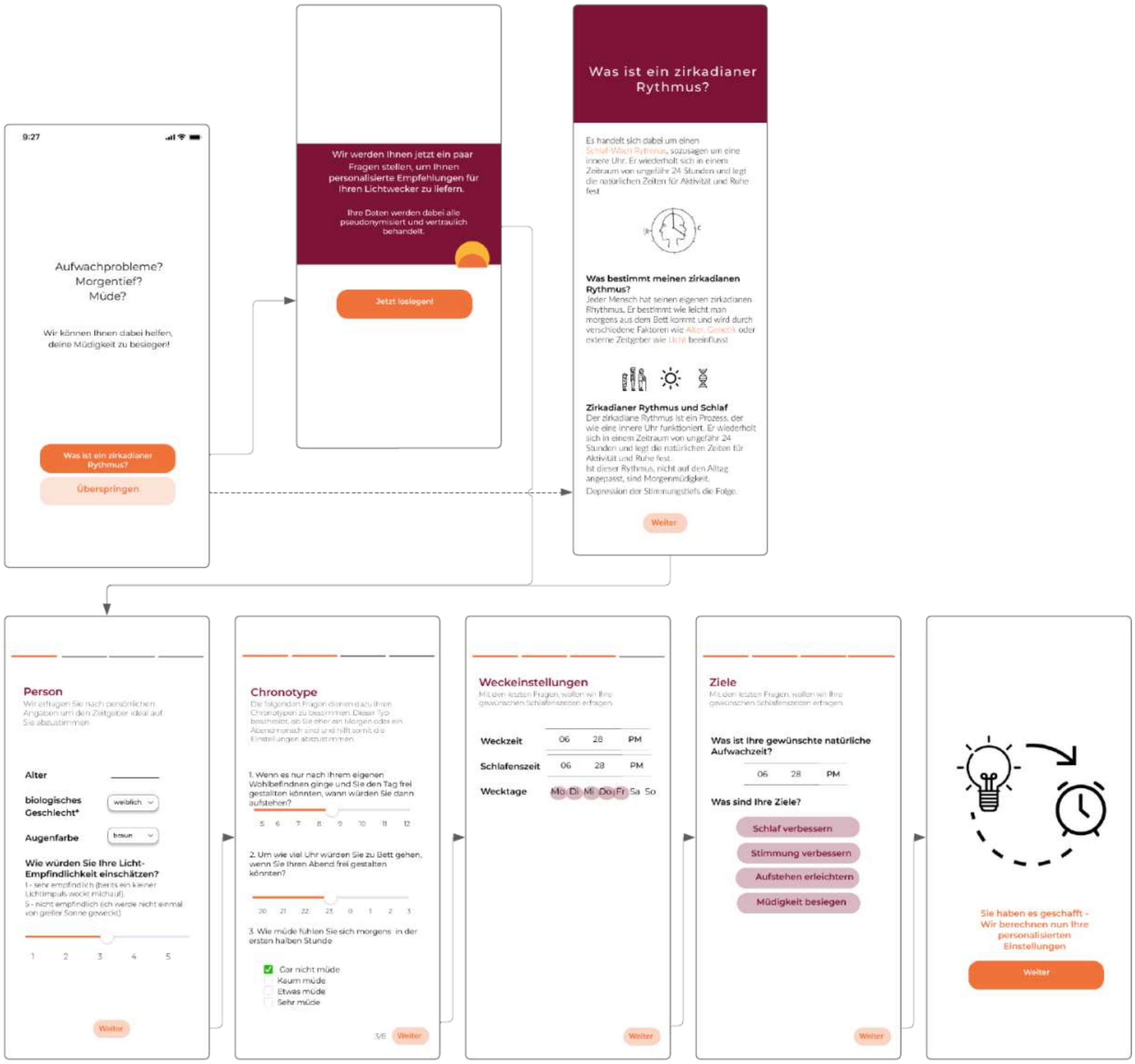

Figure 5.2: Initial mockup flow

5.3 Iterative Development Phase

Following the completion of the initial design phase, the iterative development phase commenced, encompassing user integration and resulting in a continuous adaptation of the design. During this phase, an interview process was conducted, and users were actively engaged through questionnaires and testing. The outcome of this process culminated in the final prototype.

5.3.1 Iteration 1 - Interview

The personalization of light wake-up systems, aiming to optimize individual awakening experiences, involves the consideration of various parameters. These parameters, play a pivotal role in tailoring the wake-up experience to an individual's needs and characteristics. To optimize the design of the questionnaire for personalized user settings, the low-fidelity prototype was employed and assessed as the initial iteration within the iterative development process during an interview. In addition, the interview addresses research question two and defines the parameters that are used for the algorithm.

5.3.1.1 Procedure

The following interview was conducted according in the sense of Mayring's methodology with a predefined guideline structure and focused on questions addressing the potential summation of the Morningness-Eveningness Questionnaire (MEQ), the importance of specific parameters such as age, biological gender, eye colour, and subjective light sensitivity. These parameters provide the basis for the questionnaire, which is asked during the onboarding process and the answers to which form the basis of the algorithm.

The expert, chosen using purposive sampling based on his specialisation in sleep medicine, was probed with questions designed to elicit their knowledge and insights regarding the relevance and weightage of these parameters. The insights gained from these interviews were collated and analyzed to inform the subsequent discussion on key parameters.
After the expert interview, a transcript was made that served as source material for the qualitative content analysis. This transcript was analysed through inductive category formation according to Mayring's methodology.
In the next step, through inductive category development, thematic categories were formed to structure the analysis. The categories include "MEQ use and adaptation", "Personal parameters and their importance", "Factors influencing light sensitivity" and "Ambient light and light sensitivity".
Codes representing different themes and aspects of the interview were then identified. These codes include "MEQ shortening", "Personal parameters for sleep studies", "Influencing factors on light sensitivity" and "Influence of ambient light".

The results were then interpreted and discussed in the context of the research question, addressing the importance of each theme for the application and adaptation of the MEQ in the app. The potential integration of additional parameters and influencing factors is also considered. It is emphasised that light sensitivity and individual sleep patterns are important factors to consider when designing sleep apps. The discussion highlights the complexity of integrating certain factors into the app while emphasising the need to understand and consider the influence of these factors on individual sleep.

5.3.1.2 Evaluation and Redesign

The results of the interview revealed that the parameters of personal attributes, including individual biological characteristics such as chronotype, sleep patterns, light sensitivity, age, and gender, play a pivotal role in the personalized adjustment of the light-wake system. It became evident that there exists an officially reduced version(rMEQ [91]) of the Morningness-Eveningness Questionnaire (MEQ), which can be utilized to streamline the number of questions related to chronotype assessment. Furthermore, gender was found to be relatively under-researched, making it challenging to definitively determine its impact on light sensitivity and circadian misalignment. Furthermore, factors such as the sleep position and the use of sleep masks should be considered for inclusion in the questionnaire, as these can significantly influence light exposure to the eyes. Other variables that were brainstormed, such as alcohol consumption, medication usage, and eye conditions, were deemed complex due to their varied effects and insufficient research in the field.

Additionally, the interview yielded crucial insights for algorithm development. It was apparent that subjective light sensitivity and age must be weighted more heavily than other parameters, and that chronotype predominantly influences the timing of light exposure.

As a result of these findings, adjustments were made to the design phase outcomes. The chronotype questionnaire was shortened to a reduced version containing only five questions instead of the initial nine. Questions related to sleep position and the use of sleep masks were also added. Gender was included for statistical purposes but was not incorporated into the algorithm. The adjustments of the mockups can be found in figure 5.3

A detailed specification of the finalized parameters and the database design can be found in chapter 5.4.1.4.

5.3.2 Iteration 2 - Usability Test

In the next step, the low-fidelity prototype of the design phase, which integrated the adaptations from the interview, was used to improve usability through an informal usability test. In the informal usability test, users were observed interacting with the Figma mockups to identify problems and areas for improvement. The mockups allowed users to navigate within the app, although they could not complete the questionnaire directly. Users were asked to navigate through the questionnaire in 'think aloud' and were then asked questions to provide feedback on usability and their understanding of the science. By using 'think aloud', the user's thoughts and reflections can be verbally expressed and observed during the thought process. This helps to better understand the user's perspective and behaviour and provides valuable insights for improving the user experience. [92] This approach was chosen because it is a valuable method for identifying usability issues and gathering qualitative data to refine the design. The usability test addresses research questions 1 and 3. By involving the users, it is evaluated whether the

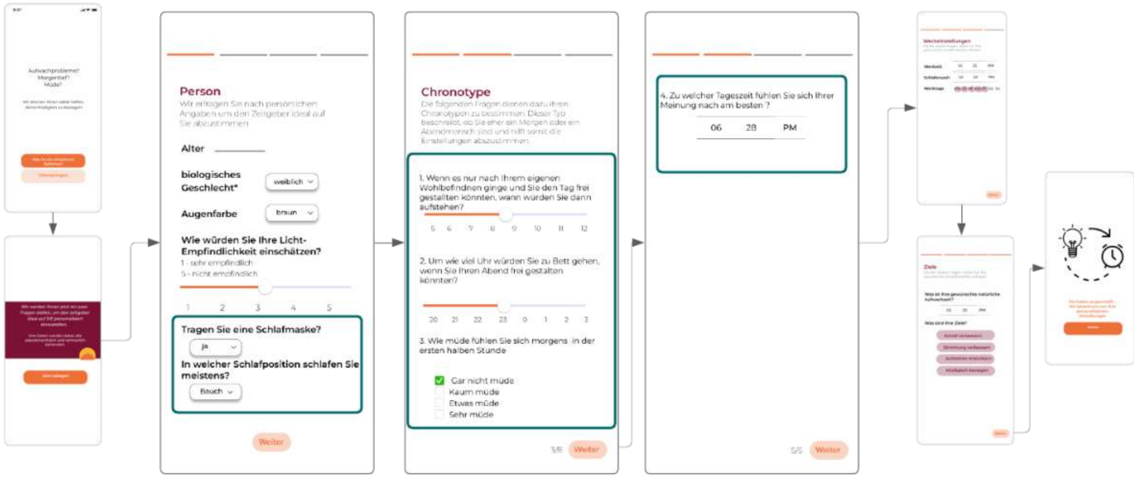

Figure 5.3: Revision of mockup from Iteration 1 (IT-1) - Interview

questionnaire developed to obtain parameters meets with user acceptance. In addition, further requirements are defined to further improve the application.

5.3.2.1 Procedure

As part of the scientific usability test, six participants of different ages and genders were asked to carry out a 10-minute usability test in a controlled setting. The participants were recruited using convenience sampling, to get an easily accessible and diverse sample. They were asked to navigate through the app with the help of mockups. The test took place in the test subjects' familiar environment to simulate a realistic usage scenario. The method used was a qualitatively moderated in-person prototype test carried out in the Figma app. The Figma app enabled the test subjects to navigate through the mockups and was run on an iPhone 13 mini.

The hypotheses investigated focused on the understanding of the scientific background, especially regarding the circadian rhythm, the correct expectations of the product behaviour, the user-friendliness of the app and the willingness of the test persons to use the application. Targeted questions were asked before and after the test to gather information about the perceived user experience, and space was given for open criticism to gain comprehensive insights into possible areas of improvement.

5.3.2.2 Evaluation and Redesign

As part of the scientific evaluation of the usability test, individual questionnaires were filled out by each participant after the user tests were completed. At the same time, the information from the "Think Aloud" sessions was recorded separately in digital form and integrated into the corresponding questionnaires after the tests were completed. The quantitative analysis of the questionnaire responses was used to collect statistical data and evaluate the occurrence and frequency of specific problems, including an assessment of participant satisfaction. In parallel, a qualitative analysis of the transcripts of the "Think Aloud" sessions was carried out to identify potential weaknesses based on the participants' comments.

The analysis showed that the questions were mostly very understandable for the participants, as stated by six (85.7%) participants. The same amount of participants (85.7%) stated, that the length of the questionnaire was perceived as acceptable. Five (71.2%)respondents showed an understanding of why certain questions were asked. All seven (100%) participants found the questionnaire and app easy to navigate, however, five (71.4%) felt that the design could be further refined in terms of aesthetics.

It was found that the majority, with five (71.4%) users, showed an interest in the scientific background, with only two (25.5%) respondents skipping this part. Through the "Think Aloud" method, it became clear that many participants already had background knowledge about the circadian rhythm.

The open critique and 'think aloud' notes pointed out that the lack of a banner for biological sex and information about the duration of the questionnaire was noted. Suggestions for improvement included increasing the size of text and buttons, using dropdowns instead of sliders and adding a more playful design. The evaluation also revealed that users prefer to read text, as stated by five (71.4%) users rather than watch videos, as stated by two (28.6%) users.

Resulting Requirements

The evaluation of the usability test resulted in further requirements that extended the existing requirements of the initial design phase and can be seen in table 5.3.

Requirement ID-01, which emerged from a user's comment in Think Aloud, focuses on the time display in the application. This requirement aims to ensure a clear and user-friendly display of the time in the user interface to provide users with precise orientation.

Another requirement (ID-02), also resulting from the feedback, emphasises the importance of accessibility. This requirement focuses on designing the application in such a way that it is accessible and user-friendly for all user groups. Design elements and functions should be implemented to ensure maximum usability for people with different abilities.

In addition, the usability test resulted in the requirement to be able to skip the scientific part (ID-03), thus emphasising the need for flexible navigation options within the application. The user should only be able to access the pages they want and skip parts that are not necessary.

Table 5.3: Requirements from Iteration 2 (IT-2) - Usability Test

Requirements-ID	**Titel**	**Application**
ID-01	Time indication	UI/UX Desing

ID-02	Accessibility	UI/UX Desing
ID-03	Flexibility in navigation	UI/UX Desing

Redesign

In response, a comprehensive redesign was carried out to significantly improve the user experience. Various modifications were made to the UI/UX design. A new time display (ID-01) was introduced to provide users with precise timewise orientation within the application. This addition made a significant contribution to improving user guidance. Furthermore, the size of the text was increased, as were the buttons, to improve readability and ensure more user-friendly operation, without a specific requirement (ID-02). The original sliders were replaced with more user-friendly choices that were part of a low-fidelity prototype (D-02). The design was further optimised, with a particular focus on playful aesthetics. The rather dominant wine red has been retained in the app, but only for fonts rather than the background. In addition, the contrast of the buttons has been increased and the font enlarged. Based on feedback from a respondent during the "think-aloud" phase, a dark mode was introduced from 20:00. This adjustment demonstrates the reactive nature of the design by responding to specific feedback from the user test situation. To summarise, the design has evolved into an improved UI/UX design that integrates larger buttons, a replacement of the slider in the chronotype questions with option buttons, a clearer time display in the confidentiality notice, and a dark mode in the evening. The revised mockups can be found in figure 5.4.

5.3.3 Iteration 3 - Brainstorming

In the subsequent phase, a further brainstorming session was held with an expert specialising in sleep research to refine the adaptation and personalisation of the algorithm. This mainly involved optimising the dawn simulation, scenarios in which users wake up prematurely during the simulation and developing strategies to personalise the light intensity, start time and duration based on the parameters identified during the interview process. This iterative process was guided by the goal of reviewing and re-evaluating the findings from previous iterations to inform the design of the algorithm. By involving the expert in intensive brainstorming, it was also possible to address research question 3 and determine the algorithm that issues the personalized recommendations.

5.3.3.1 Procedure

Before the brainstorming session, clear objectives and questions were formulated to guide the discussion. The questions posed were aimed at investigating the influence of various factors on light intensity and start time in the context of the Dawn simulation. The questions to be answered included aspects such as the role of eye colour, adjusting light intensity for stomach sleepers, optimising the duration and slope of dawn simulation,

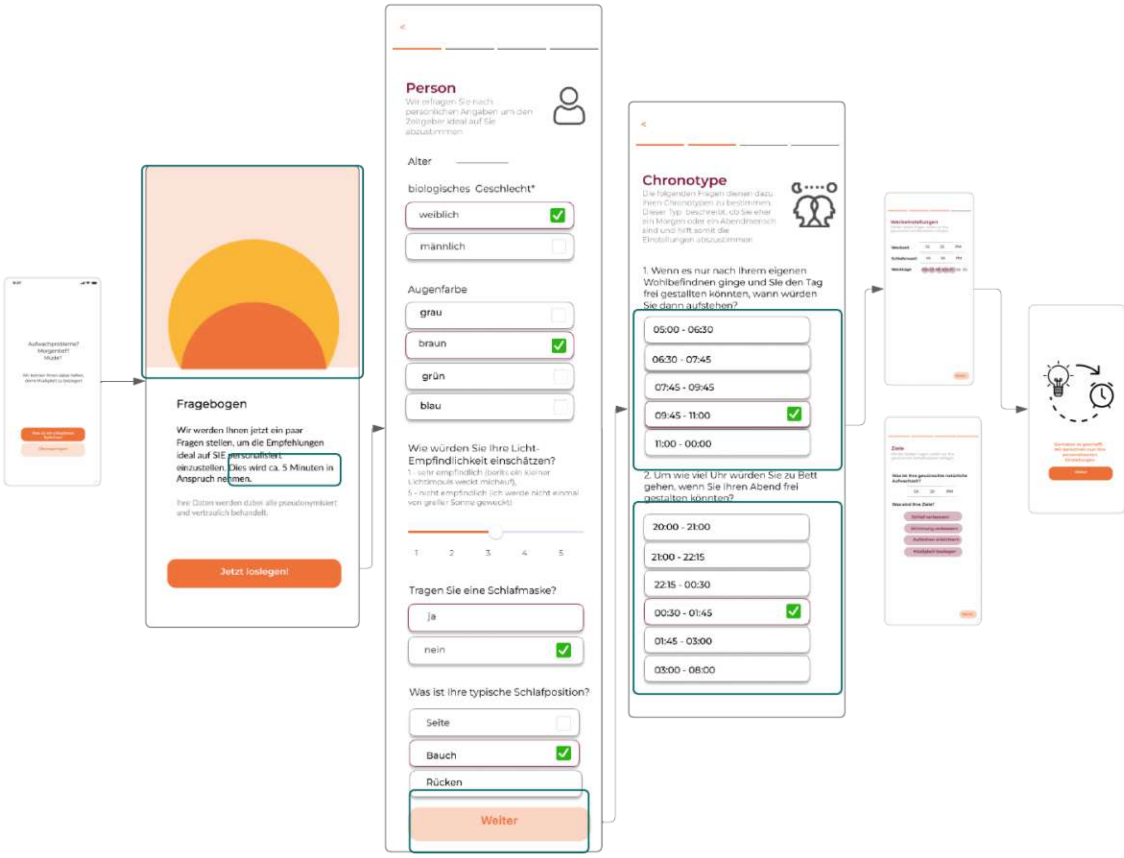

Figure 5.4: Revision of mockup from Iteration 2 (IT-2) - Usability Test

dealing with early wake-up phases, the optimal start time for dawn simulation, adjusting light therapy for light-sensitive individuals and handling night owls who are supposed to start and end their dawn simulation before starting work early. The expert who was consulted to support the brainstorming was chosen based on his expertise in chronotherapy through purposive sampling.

During the brainstorming meeting, these questions were addressed through mind mapping to generate possible solutions, hypotheses and innovative ideas. The discussion took place in an open and collaborative setting, allowing participants to contribute their different perspectives and expertise. This led to a results-orientated discussion that generated a wide range of suggestions and approaches.

The results of the brainstorming session served as a valuable basis for developing and adapting the algorithm to ensure a personalised experience for all users. The solutions and ideas developed helped to consider different facets of dawn simulation and to design the algorithm to meet the individual needs and preferences of users.

5.3.3.2 Evaluation

As a result of the brainstorming session, clear decisions and recommendations emerged for the personalisation of the algorithm as part of the recommendations for the dawn simulation. The dawn simulation should be naturalistic if possible. At the same time, the personalisation is based on the adjustment of the light curve - with higher light sensitivity, the curve starts with lower lux and ends accordingly. The duration of the simulation ideally remains at 90 minutes, with the expected time of waking up after 2/3 of the duration, i.e. after 60 minutes. The ideal start time was set at DLMO + 8.5 hours, where DLMO is calculated by the formulas:

$$DLMO = 25.5 - 0.25 * MEQ$$

$$starttime = DLMO + 8.5hours$$

Personalisation should be carried out daily to allow long-term adjustments to the circadian rhythm. Exposure to light after the adjustment of the rhythm is useful daily to start the day in an energised state. For extreme chronotypes whose wake-up time deviates significantly from the personalised time, the adjustment is made daily by 15 minutes to gradually adjust the rhythm. If the user has to work before the ideal wake-up time, the necessary days off should be adjusted.

The adjustment days are calculated from the end time of the simulation minus the target wake-up time divided by 0.25. The adjustment is made 15 minutes earlier every day until the target is reached. Due to this daily shift, it is advisable to receive a new recommendation every day.

Another brainstorming point concerned the adjustment of the algorithm to the sleeping position and eye colour. For reasons of complexity, the sleeping position was not included in the algorithm. However, light-coloured eyes showed a higher sensitivity to light and should therefore be considered in the algorithm. In addition, daily feedback is integrated to better take individual light perception into account and further adapt the algorithm.

Further insights were also gained in the design aspect, including the integration of feedback and daily recommendations. An initial questionnaire should be completed when using the app for the first time, and the app should then be freely navigable. To still address ID-03 and achieve free navigation within the app, it was decided to add a footer to make it possible to give feedback, view recommendations and access the scientific background. It should only be possible to give feedback once a day so as not to negatively influence the algorithm.

Moreover, users are set to receive a fresh personalized recommendation each day. Here important to incorporate that there might be days when the user opts not to use the alarm clock. However, even on such days, recommendations would be refreshed and the user thus uses "wrong" recommendations on the next day of usage. Furthermore, users may find the current settings satisfactory and choose not to make any changes. A manual recommendation button has been introduced to accommodate this, preventing potential "false" recommendations. Another beneficial addition is the inclusion of a progress overview for users to track their journey.

In addition, the idea was to automatically deliver a new personalised recommendation to the user every day. However, there are days when the user does not use the settings and then finds "wrong" recommendations, and it may also be that the user likes the current settings and does not want to change anything. That is why the decision was made to introduce a button for manual recommendations to avoid possible falsifications of the algorithm. An overview of the user's progress was added as an unplanned feature.

Another unexpected consideration from the brainstorming resulted in the possibility of changing the questionnaire afterwards, as the chronotype and settings can change over time. There should therefore be an option to change these variables retrospectively.

5.3.3.3 Resulting Requirements

The brainstorming resulted in further requirements, all of which relate to the optimization of the algorithm. A list of these requirements can be found in table 5.4

Requirement ID-04 focuses on aligning the algorithm with the user's biological rhythm and the duration of a naturalistic dawn. The starting point and light intensity should be calculated in such a way that the user is offered a gradual and natural increase in light intensity, similar to the natural rising of the sun. This implementation aims to support the user's circadian rhythm and provide a more pleasant experience during light therapy. To customise the start time for the user, it should be calculated using the user's DLMO, which can be calculated from the user's MEQ score. This scientifically based approach ensures that the light therapy is individually adapted to the biological rhythms of the user, which can lead to more effective and targeted treatment.

Requirement ID-05, suggests that users should be able to adjust the maximum light intensity in stages and that the corresponding percentage reduction of the maximum light intensity should be displayed.

The requirement ID-06 provides for the daily dawn start time to be gently shifted by 15 minutes to allow for a gradual adjustment of the circadian rhythm. Due to the longer period, this can take for very late chronotypes - and which is often incompatible with the required work rising times - requirement ID-07 is intended to provide a recommendation for days off.

Furthermore, the requirement (ID-09) arose that users should be able to revise their answers to the questionnaire at any time. Revising the answers to the questionnaire enables users to check answers that have already been given and adapt them if necessary.

Another requirement was the integration of a feedback system (ID-10) that allows the user to provide feedback on their alarm clock experience. This requirement is applied both in the algorithm and the UI/UX design.

The requirements ID-11 and ID-12 arose from the brainstorming as an add-on. ID-11 describes the implementation of a statistics display that allows users to track their progress and usage patterns. ID-12 describes the integration of a function for displaying background information to offer the user in-depth insights into chronobiology.

Table 5.4: Requirements from Iteration 3 (IT-3) - Brainstorming

Requirements-ID	**Titel**	**Application**
ID-04	Start time and duration should be based on naturalistic dawn and chronotype	Algorithm
ID-05	Calculation of light intensity	Algorithm
ID-06	Calculation of required days off	Algorithm
ID-07	Daily adjustment of start time to 15 minutes earlier per day	Algorithm
ID-08	Manual trigger of daily recommendation updates	Algorithm
ID-09	Revision of answers of questionnaire	Algorithm, UI/UX Design
ID-10	Feedback	Algorithm, UI/UX Design
ID-11	Display of statistics	UI/UX Design
ID-12	Display of background information	UI/UX Design

5.3.3.4 Redesign

The brainstorming session not only resulted in additional requirements but also further considerations and revisions for the mockups of the usability design. Although previous design requirements did not change, the decision was made to integrate additional screens into the app.

A feedback option was added to the app to further improve the algorithm and enable more precise recommendations. The ID-03 requirement for free navigation remains in place, and submitting feedback is optional. In addition, an overview of all calculated user recommendations has been added, which displays all relevant advice along with a brief description of the value.

Another requirement that emerged from the brainstorming session concerned the subsequent customizability of the answers to the initial questionnaire (ID-07). For this purpose, an additional page was created on which users can revise individual parts of the questionnaire (person, chronotype, alarm settings, goals).

A statistical overview page was implemented to better track the user's progress (ID-08). The decision was made to best recognize progress based on feedback on waking up in the morning. Therefore, the user is shown both the development of their morning freshness and the ease of getting up.

As part of the usability test, it was determined that the knowledge section could be skipped at any time. However, as a result of the brainstorming, a footer was introduced in the redesign, which led to the decision to make the information section permanently accessible and not just before the start of the questionnaire (ID-09). The decision was made to integrate the most relevant information on chronobiology and to supplement it with an illustrative graphic. In this way, information about the chronotype, the role of light as a zeitgeber and the benefits of morning light was integrated. To ensure a pleasant reading flow, it was decided to create a separate screen page for each topic, which can be scrolled through by simply swiping. The total number of pages is also displayed at the bottom, together with information on which page the reader is currently on. To accommodate the additional screens, a footer was introduced to allow flexible navigation between the different sections. The results of the redesign can be found in figure 5.5.

5.3.4 Result - High-Fidelity prototype

Through several iterations of user-centred design, an application was developed that provides personalized recommendations for setting a smart light alarm clock based on parameter extraction. The process can be seen in figure 5.6 and is as follows:

1. At the beginning, when starting the app, the user goes through a questionnaire that asks for all relevant information. The parameters recorded serve as input for an algorithm running in the background. (implemented in IT-0, IT-1, tested in IT-2, IT-4)
2. The algorithm performs calculations on the start time of dawn, light intensity, etc. and presents the user with its personalized recommendations on a screen. (implemented in IT-3, tested in IT-4)
3. The user can open the application at any time and view their recommendations.
4. To keep the recommendations up to date, the user has the opportunity to provide feedback and to review and revise their answers from the initial questionnaire. They can also track their progress in statistics and view background information on chronobiology. (implemented in IT-3, tested in IT-4)

The application was developed step by step through iterations and revisions. The initial design phase provided the basis for the scientific requirements and produced an initial low-fidelity prototype. The development phase was built on this prototype and improved in each iteration until the high-fidelity prototype was created. Each iteration added a different component to the app: the interview provided the parameters for the

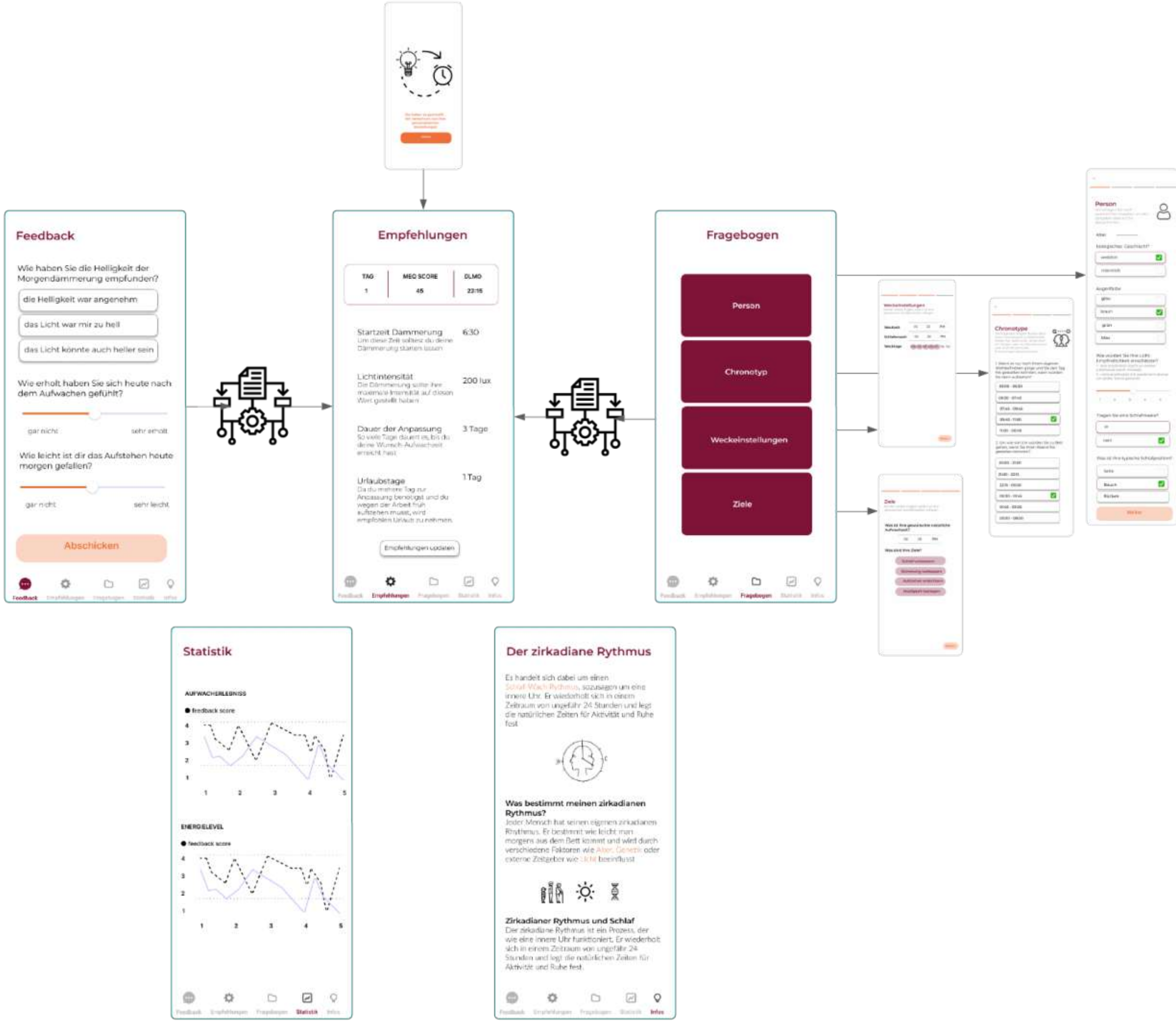

Figure 5.5: Revision of mockup from Iteration 3 (IT-3) - Brainstorming

questionnaire, the usability test brought important design requirements and additional design adjustments, and the brainstorming informed the algorithm and finalized the design based on the algorithm's decisions. The results of these developments were recorded in the form of mockups in figures 5.3, 5.4 and 5.5.

The resulting requirements from all iterations are listed in detail in table 5.5. The algorithm and the individual parameters of the questionnaire are discussed in detail in chapter 5.4. The entire process is illustrated in a corresponding diagram.

This iterative process reflects the continuous improvement and customisation based on user feedback and usability tests as part of the UCD.

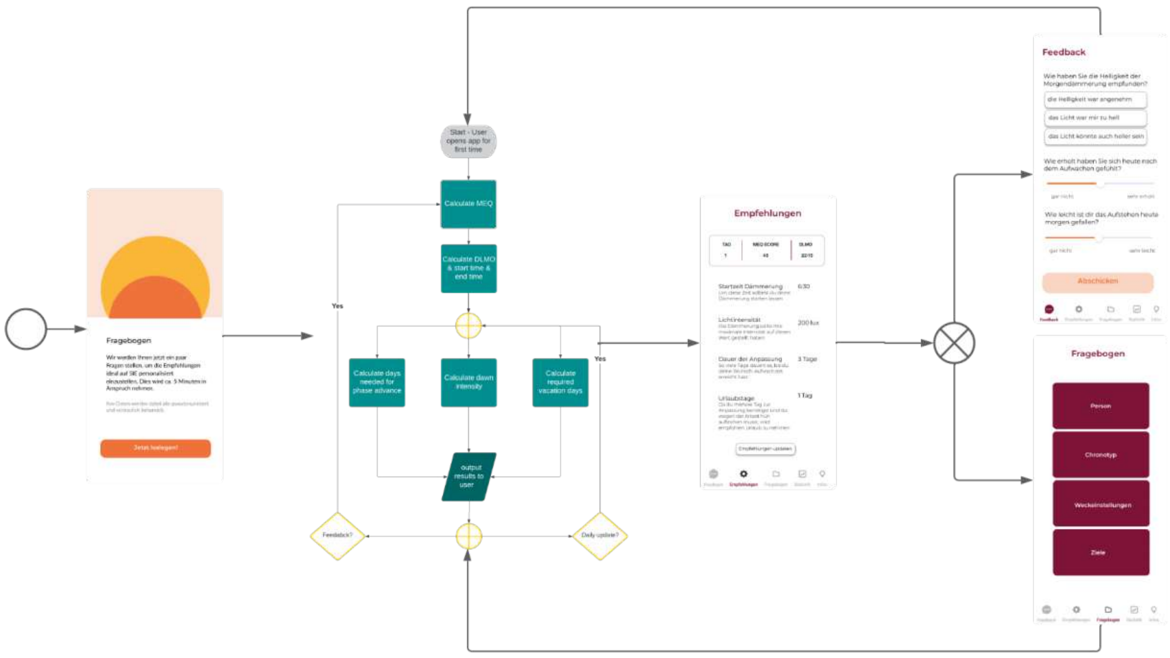

Figure 5.6: Application Process Flow: Beginning with the questionnaire, the algorithm generates recommendations, which are then recalculated based on feedback or revisions.

Table 5.5: Requirements from design (D-01 to D-09) and iterative development (ID-01 to ID-12)

Requirements-ID	**Titel**	**Applicaiton**
D-01 (Literature Research)	Consideration of demographic parameters	Algorithm
D-02(Literature Research)	Representation of progress	UI/UX Desing
D-03(Literature Research)	Saving of responses	Database integration
D-04 (Literature Research)	Usability	UI/UX Desing
D-05 (Literature Research)	Data integrity & privacy	Database
D-06 (Brainstorming)	Mobile app	Development environment
D-07 (Brainstorming)	Portability	Development environment
D-08 (Brainstorming)	Confirmation of success	UI/UX Design
D-09 (Brainstorming)	Initial Questionnaire	UI/UX Design, Algorithm
ID-01 (Usability Test)	Time indication	UI/UX Desing
ID-02 (Usability Test)	Accessibility	UI/UX Desing

ID-03 (Usability Test)	Flexibility in navigation	UI/UX Desing
ID-04 (Brainstorming)	Start time and duration should be based on naturalistic dawn and chronotype	Algorithm
ID-05 (Brainstorming)	Calculation of light intensity	Algorithm
ID-06 (Brainstorming)	Calculation of required days off	Algorithm
ID-07 (Brainstorming)	Daily adjustment of start time to 15 minutes earlier per day	Algorithm
ID-08(Brainstorming)	Manual trigger of daily recommendation updates	Algorithm, UI/UX Design
ID-09 (Brainstorming)	Revision of answers of questionnaire	Algorithm, UI/UX Design
ID-10 (Brainstorming)	Feedback	Algorithm, UI/UX Design
ID-11 (Brainstorming)	Display of statistics	UI/UX Design
ID-12 (Brainstorming)	Display of background information	UI/UX Design

5.3.5 Iteration 4 - User Test

The last iteration, the user test, aims to evaluate the usability and effectiveness of the developed Circadian Rhythm recommendation app prototype. The test approach integrates the application on the subjects' mobile devices as well as the use of light alarm clocks (3 Lumie and 3 Zeitgeber) according to the recommendations suggested in the app.

5.3.5.1 Procedure

Six test subjects (P11 - P16), representative of the app's target group, and recruited through convenience sampling, were selected to participate. Informed consent was obtained from each participant before the start of the test to ensure their consent to participate.

Before the user test, the app was installed on the participants' mobile devices and each participant was given a light alarm clock. Android users received the Android Package (APK) of the app and Apple users got the app installed on their iPhone in "Profile" mode, as it is not yet available in the App Store and must be signed by a verified developer.

For the light alarm clocks, a Lumie light alarm clock [1] and a zeitgeber[2] were provided. The distribution of the light alarm clocks and the platform the test users used can be seen in table 5.6.

Table 5.6: Overview of participants in IT-4 - User Test

Participant-ID	Platform	Light alarm clock
P11	iPhone	Lumie
P12	iPhone	Zeitgeber
P13	Android	Zeitbeber
P14	iPhone	Lumie
P15	iPhone	Zeitgeber
P16	Android	Lumie

As part of the test, the participants then completed an initial onboarding questionnaire in the app to collect relevant information on their sleep habits and daily rhythm. The test subjects then used the app according to their individual preferences. They were instructed to give feedback every day and to use the alarm clock daily according to the new daily settings. The feedback took the form of a questionnaire within the app. The test subjects had free access to statistics, and background information and could revise their initial questionnaire answers within the app.

After the test phase of five days, the users were asked to complete a questionnaire. Therefore the users were first asked short questions about themselves (age, gender, profession), and additional questions were asked about usability, experience and satisfaction with the recommendations. Finally, they were asked on a scale how likely they were to continue using the app. The questionnaire can be found in the appendix.

The collected data was analysed comprehensively, combining qualitative and quantitative methods. This made it possible to identify patterns, strengths and weaknesses of the app.

5.3.5.2 Evaluation

The user test was analysed on the one hand by logging the app usage and on the other hand by quantitatively evaluating the questionnaire.

Analysis

Every action of the user is recorded in the database for analysis purposes. Each user has a data record entry containing their data. Only one user revised his details in the

[1] https://www.lumie.com/de-de/products/bodyclock-glow-150
[2] https://www.zeitgeber.at/

questionnaire during the experiment and set a different alarm time. It is noticeable that all but two users correspond to an intermediate chronotype and only one person required several adjustment days for the target time. Eye colour and subjective light sensitivity varied between users. Interestingly, the subjects who reported being more sensitive to light did not make any adjustments to their light alarm clocks, regardless of their eye colour. This suggests that the algorithm does not set the light intensity too high to accommodate more light-sensitive people. Figure 5.7 shows the distribution of users' subjective sensitivity to light. All users are stomach or side sleepers, with no discernible correlation between sleeping position and results. In terms of goals, all options (make getting up easier, beat tiredness, improve mood, improve sleep) received almost equal approval. The target time for getting up was between 7:30 and 8:00 am for all users.

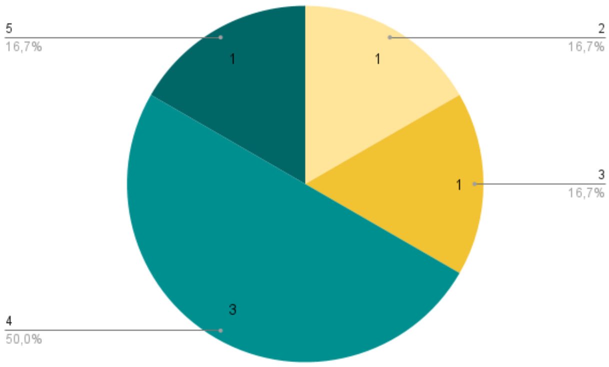

Figure 5.7: Subjective Light Sensitivity Evaluation: Assessing users' subjective light sensitivity on a scale of 1 to 5 (1 being not light sensitive and 5 being very light sensitive), based on responses from the initial questionnaire.

In addition to the demographic data, daily feedback was created for each user, so that each user has five entries for their daily feedback. It is noticeable that recovery and ease of waking up have improved for all users. The data on users' waking behaviour and recovery, as disclosed through their entries in the daily feedback, is illustrated in figure 5.8.

A collection of recommendations was also created for each user, which was extended by one document for each feedback when a user changed a part of the questionnaire or when they manually clicked on a new recommendation. As only one user revised their answers and only one user required an adjustment period of two days, there are a total of five recommendations per user.

On average, the users checked their statistics twice during the experiment and looked at the scientific background 0-1 times. This could indicate that users tend to be less interested in the scientific aspects of the application while checking their statistics is considered more relevant.

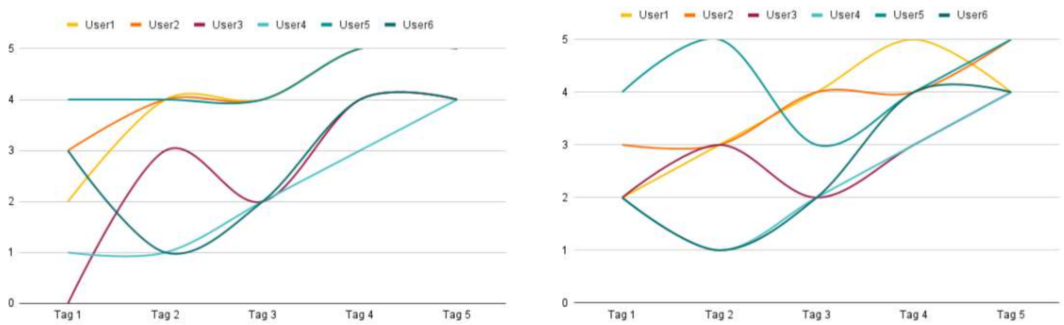

Figure 5.8: Feedback Evaluation: These assessments are derived from users' daily feedback. Left: Feedback on how easy it was to wake up in the morning (1- not at all easy, 5- very easy). Right: Feedback on how refreshed the user woke up (1- not at all refreshed, 5- very refreshed).

Questionnaire

The user test focused on the effects of personalised settings of a smart light alarm clock on the waking behaviour and circadian rhythm of the users. After five days of use, the participants were asked to complete a final questionnaire that asked about various aspects of personalisation, success in getting up and changes in the circadian rhythm.

Before the test began, participants were asked how much their room was darkened, with three response options ranging from 1- very darkened to 3- not darkened at all. It was found that three (50%) users categorised their rooms as slightly darkened, two (33.33%) participants, had a darkened room, and one (16.67%) person slept in a non-darkened room. After the test, all participants confirmed that they had found their way around the app and understood all the processes.

The first question about changes in waking behaviour through personalised settings showed that all six (100%) users stated that their waking behaviour had improved and that waking up had become easier and more pleasant. In terms of recovery after waking up, five (83,3%) users stated that they woke up more comfortably, with one user emphasising that this improvement occurred after the first few days.

A question regarding the change in energy levels throughout the day revealed that all six (100%) of the users participating experienced a positive change. Curiously, none of the participants reported the need to modulate light intensity due to excessive brightness leading to premature awakening.

The next question addressed the willingness of users to purchase a smart light alarm clock after the test and to continue using the personalisation. In this context, three participants (50%) expressed a high willingness to procure and customize a light alarm clock, two (33.33%) users indicated a moderate willingness, and singularly, one (16.67%) individual conveyed a limited inclination due to financial considerations, citing the high costs as the deterrent factor. All of the users (100%) confirmed in the subsequent question that the personalisation, particularly the light intensity setting, helped with the wake-up routine. In this instance, users commented that the guidance provided for light intensity adjustment was particularly beneficial in facilitating their adaptation

In the final question, four (66,66%) users stated that they felt that their circadian rhythm had shifted in the desired direction. In response to this question, one user, stating his rhythm didn't change, commented, that his waking time had not changed significantly, but that the act of waking up had simply become more pleasant. Another participant expressed the wish for a longer test phase to be able to give a more precise answer.

In the free user reviews, almost all, five (83,3%), participants emphasised positively that they experienced an increased sense of well-being and higher energy levels on waking. However, some participants pointed out that it was challenging to get up at a fixed time at the weekend due to longer evening activities, which led to the desire for a longer sleep duration.

It was notable that users whose rooms were darkened or at least partially darkened achieved significantly improved results and were also more likely to make a purchase decision. Equally noteworthy was the consistently positive response from all users regarding improved waking dynamics, which some participants particularly emphasised in their open critique.

5.4 Final Result

The following chapter shows the final result of the user-centred design and its iterations. It is a more detailed description of the High-fidelity prototype from section 5.3.4 and includes a detailed list and description of the requirements, the parameters and the database design, the architecture, the algorithm and the technological stack.

5.4.1 Requirements

In chapter 3.5 has already been emphasised in this thesis that a precise definition of requirements is of crucial importance, especially in the development of applications in the medical field. A user-centred design (UCD) approach was implemented following the principles described in chapter 3.3 to optimally define and comprehensively consider all use cases. During this process, new requirements were identified in each iteration, systematically documented and elaborated in detail in the course of the UCD.

This section serves as a summary of the final functional and non-functional requirements for the smart alarm clock personalisation app and its associated use cases. Particular attention is paid to the use cases questionnaire, information processing, revision of answers and user feedback. Non-functional requirements such as data integrity, data privacy, portability and user-friendliness are also taken into consideration. The primary stakeholders of this project are both the end users of the app, mainly private individuals who attach great importance to their health, and the manufacturers of light alarm clocks, who could potentially benefit from the personalisation of their products.

5.4.1.1 Use Case specifications

In the context of the parameter-extraction app for personalising a smart wake-up light, defining and analyzing possible use cases is paramount. Use Cases are a detailed description of a scenario that shows how a system and its actors interact in a specific situation to achieve a particular goal. It typically consists of a sequence of steps or actions of the actors involved (users or other systems) and the expected results. Use cases are used to understand, communicate and document the functionality of the system. It allows for a structured understanding of the diverse functionalities that the app should encompass. Each Use Case encapsulates a particular functionality or feature, portraying the app's behaviour under various circumstances. [93] [94]

This subchapter explains the use cases for the implemented application for personalizing a smart wake-up light, identified as part of the UCD, providing a comprehensive insight into the planned interactions and functionalities. The main use cases are examined in detail, taking into account different scenarios and contexts to ensure a holistic understanding of the application's functionalities and requirements. The following use cases served as the basis for the further derivation of functional requirements and thus had a decisive influence on system development and optimisation. An overview of the use cases and the interaction with the actor "user" can be found in figure 5.9. The individual scenarios of the use cases are then explained individually.

Conduct initial onboarding questionnaire

The onboarding process in the form of a questionnaire to extract the parameters needed for the subsequent algorithm is crucial for the successful calculation of the personalised recommendations. During the initial design phase, the requirement arose to integrate a questionnaire that captures all essential parameters and utilizes them as input for the algorithm (D-09). The parameter extraction app should be able to collect relevant information about the user to provide a personalised experience. Here, data on sleeping habits, the preferred wake-up time and the individual reaction to light simulations should be collected. The corresponding scenario is shown in table 5.7.

Table 5.7: Scenario 1: Conduct initial onboarding questionnaire

	Conduct onboarding questionnaire
Use Case ID	1
Actors	User
precis	Before using the System, the user has to complete an onboarding process to extract parameters for personalisation. Therefore he has to answer questions step by step until the onboarding is completed.
Requirements	A structured set of questions.
Constraints	A manageable amount of questions.

Justification	To gain personalized recommendations, certain parameters must be questioned to adjust the recommendation according to the user.
Triggering event	The user starts the app for the first time.
Preconditions	The user has downloaded the app.
Assumptions	There is a working internet connection available.
Successful end state	The user completed the onboarding process and all data are stored.
Unsuccessful end states	Data could not be stored.
Normal course	1. The user starts the app 2. The user sees the splash screen and goes to "Jetzt onboarding starten" 3. The user reads instructions on the page 4. The user clicks on “Jetzt Starten!” 5. REPEAT while questions are open 5.1 The user answers questions 5.2 The user goes to the next slide 6. The user reads a confirmation message
Alternatives	4.2. **IF the user missed answering one question** An alert is shown and the user has to fill in the question. 5. **IF there is no internet connection** The user has to check their internet connection. 5. **IF a system error occurs while submitting the completed test to the system.** The user has to try submitting the questionnaire again. 5. **IF the user accidentally cancels the process.** The user has to start all over again.

Revise answered questionnaire

The application aims to help users change their chronotype and get out of bed earlier. To achieve this, it is very important to customise the parameters for each user. As the user’s external circumstances, such as wake-up time, can change due to work, but also his chronotype should change in the course of use, it is important to be able to change

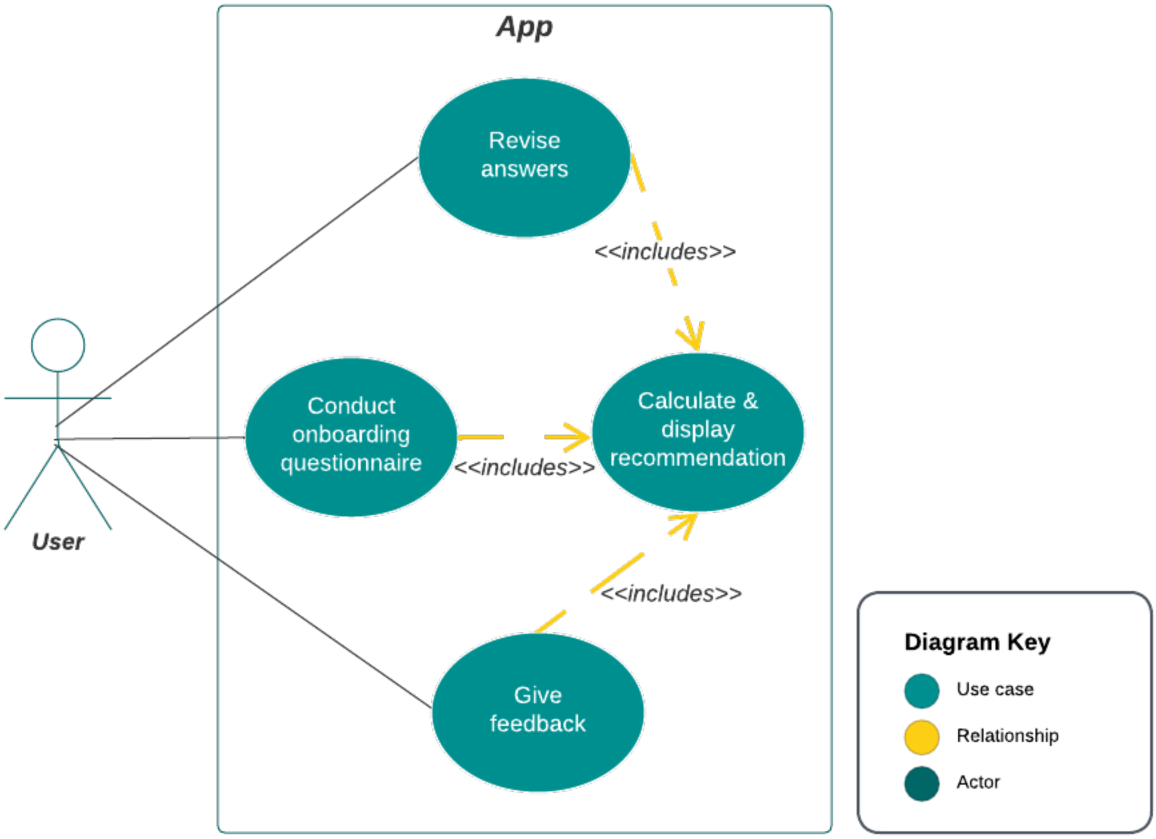

Figure 5.9: Use case diagramm

information retrospectively. The requirement of a revision of the questionnaire answer came up in the brainstorming (ID-09) and the user can therefore revise individual sections of the questionnaire to adapt the calculations to their current situation. Table 5.8 shows the corresponding scenario for revising a questionnaire.

Table 5.8: Scenario 2: Revise questionnaire

	Revise questionnaire answers
Use Case ID	2
Actors	User
precis	While using the System, the user can revise his answered questionnaire to extract and revise parameters for personalisation. Therefore he has to answer questions step by step until the chosen part of the questionnaire is completed.
Requirements	A structured set of questions.
Constraints	A manageable amount of questions.

Justification	To keep the recommendations updated, to the user's current situation and need, one should have the possibility to revise the questionnaire's answers.
Triggering event	The user clicks on the button for the part he wants to revise.
Preconditions	The user has downloaded the app.
Assumptions	There is a working internet connection available.
Successful end state	The user completed the onboarding process and all data are stored.
Normal course	1. The user clicks on the footer on "Fragebogen". 2. The user chooses what part of the questionnaire to revise and clicks on the corresponding button. 3. REPEAT while questions are open 3.1 The User answers the question. 3.2 The user goes to the next question. 4. The user clicks on "Speichern und Schließen".
Variation 1	4.If the user also wants to revise the subsequent part of the questionnaire. 5. The user clicks on "Weiter". 6. REPEAT while questions are open 6.1 The User answers the question. 6.2 The user goes to the next question. 7. The user clicks on "Speichern und Schließen".
Alternatives	5. **IF there is no internet connection** The user has to check their internet connection. 5. **IF a system error occurs while submitting the completed test to the system.** The user has to try submitting the questionnaire again.

Calulate and display personalised recommendation

The app must be able to analyse the collected data and transform it into understandable and useful information for the user. This includes giving the user recommendations on the optimal start time of the dawn simulation, the duration of adjustment and the light intensity (ID-04, ID-05, ID-06, ID-07). Furthermore, this calculation should also be carried out if the user has submitted feedback or manually requests a new recommendation for the next day. All these parameters are to be personalised for the user and calculated by an algorithm. The corresponding scenario is shown in table 5.9.

Table 5.9: Scenario 3: Calculate and present recommendation

	Calculate and present recommendation
Use Case ID	3
Actors	Application
precis	After the completion of the onboarding questionnaire, the system calculates recommendations based on the user's answers. For this, an algorithm is used, and the recommendation is displayed.
Requirements	Completed questionnaire.
Constraints	Working algorithm and database connection.
Justification	To personalise a smart wake-up light system, a personalised recommendation has to be delivered to the user.
Triggering event	The user has completed the onboarding, or the user goes to the result overview screen.
Preconditions	The user has downloaded the app and completed the onboarding questionnaire.
Assumptions	There is a working internet connection available.
Successful end state	The personalised recommendation is shown.
Unsuccessful end state	No recommendation is shown.
Normal course	1. The user starts the app. 2. The completes the onboarding process. 3. The user is shown all recommendations.
Variation 1	2. If the user gives feedback. 2. The user goes to the feedback view.

Variation 2	2. If the user wants to get new recommendations for the next day. 2. The user goes to the summary view. 3. The user clicks on "Empfehlungen updaten".
Variation 3	2. If the user already completed the onboarding and revised a part of the questionnaire. 2. The user goes questionnaire view. 3. The user chooses the part he wants to redo. 4. The user sends his answers.
Alternatives	3.1 **IF no recommendations are shown** the user has to check the internet connection and try again.

Give Feedback

The app should motivate the user to make positive changes in their sleep behaviour and support them in making the right settings on their light alarm clock, as can be seen in table 5.10. In addition, the recommendations should be optimised for the user, so the user can indicate whether the light was too bright for them and how easy it was for them to get up. By providing the possibility to give feedback the recommendations can be updated to further improve the users' settings (ID-10).

Table 5.10: Scenario 4: Give feedback

	Give feedback
Use Case ID	4
Actors	User
precis	After using the recommendation for the smart wake-up light, the user gives feedback about his experience.
Requirements	Completed questionnaire, calculated feedback.
Constraints	Working database connection.
Justification	To improve the personalisation of a smart wake-up light system, the recommendation has to be adapted to the user's experience.
Triggering event	The user clicks on give feedback.
Preconditions	The user has downloaded the app and completed the onboarding questionnaire.

Assumptions	There is a working internet connection available.
Successful end state	Feedback data is stored.
Unsuccessful end state	Feedback data could not be stored.
Normal course	1. The user starts the app 2. The clicks on "Feedback" 3. REPEAT while questions are unanswered 3.1 The User answers the question 3.2 The user goes to the next question 4. The user clicks on "Absenden"

5.4.1.2 Functional Requirements

The functional section of the requirements forms a fundamental aspect of system development by precisely defining the specific functionalities and processes that a software system must offer its users. These functions are the cornerstone and provide a detailed description of the system's behaviour in different contexts. [95]

Extensive requirements were collected during the initial design phase (IT-0) and iterations IT-1, IT-2 and IT-3 of development as part of user-centred design (UCD). However, these were subject to change throughout the iterations. At the same time, use cases were recorded, which were also modified and supplemented with new ones throughout the iterations. All essential functionalities, system reactions, data processing procedures and user interactions, as they occur in the use cases and scenarios described, were extracted.

These functional requirements act as fundamental building blocks for the development phase and have a direct influence on the system architecture, design and implementation. The following table 5.11 presents these functional requirements, which are each specified by an ID, a title, a description, the resulting acceptance criteria and the origin of the requirement from the user-centred design process. A requirement may have resulted from several requirements of the UCD. The requirements shown in the table are only those that were ultimately implemented in the app.

Table 5.11: Selected final Functional requirements

Requirement ID	Titel	Description	Acceptance criteria	Origin
FR01	Complete Onboarding questionnaire	The app shall provide a questionnaire, that questions parameters needed for the personalisation from the user.	The app should show a questionnaire. The app should store all answers.	D-09, D-03
FR02	Calculate and Show Recommendation	The app shall provide an algorithm, that calculates personalised recommendations for the user.	The app should calculate the recommendation in the background. The start time should be calculated based on the DLMO. The DLMO should be calculated based on the MEQ score. The start time should be adjusted 15 minutes per day. The required amount of holidays should be calculated. The app should show all results to the user.	ID-04, ID-05, ID-06, ID-07, ID-08
FR03	Give Feedback	The app shall provide a feedback option, so the user can give feedback and the algorithm can adapt.	The app should provide the user with a feedback option. The app should use the feedback to improve the recommendation.	ID-10

FR04	Revise questionnaire answers	The app shall provide the option to revise the user's answers to the onboarding questionnaire, so the recommendations can be up to date with the user's current needs.	The app should provide the user with an option to revise his answers. The app should use the revision to update the recommendation.	ID-09
FR05	Show statistics	The app shall provide an overview of the user's progress based on the feedback responses.	The app should provide the user with an overview of his progress.	ID-11
FR06	Show background information	The app is designed to allow users to learn about the background science behind the circadian rhythm and recommendations.	The app should provide the user with an option to read some background information. The app should make the scientific background optional to read.	ID-12
FR07	Confirmation of success	The app shall inform the user about completing the questionnaire.	The app should provide the user with confirmation if his answers are successfully stored in the database.	D-02, D-08

FR08	Show indication of progress	The app shall inform the user at any point of the questionnaire where he is in his progress.	The app should provide the user with a progress bar to determine how many forms he already completed and how much he has to fill out. The app should provide the user with a time indication of how long it will take to fill out the questionnaire	D-02

5.4.1.3 Non-functional requirements

Non-functional requirements, also known as quality requirements, present a crucial dimension in the development of software applications in the field of medicine. These requirements describe attributes that affect the performance, reliability, safety and usability of an application without being directly related to its functional operations. [95]

This sub-section emphasises the non-functional requirements that were developed in the context of the user-centred design process, incorporating the perspectives of users and interviewees. The numerous individual requirements were considered and summarised to ensure a comprehensive representation, which can be found in table 5.12. They are each specified by an ID, a title, a description and the origin of the requirement from the user-centred design process. Also, the non-functional requirements may have resulted from several requirements of the UCD and were integrated as part of the UI/UX design (NFR01, NFR05), or were applied in the data storage(NFR02, NFR03) or the entire development setup (NFR04).

Table 5.12: Selected final Non-functional requirements

Requirement-ID	Titel	Description	Origin
NFR01	Usability	The usability of the app is the main focus, as it has a direct influence on the acceptance and use by the user. The app should be intuitive, easy to understand and appealing to ensure a positive user experience. A responsive design shall be used that allows the app to be suitable and compatible with all screen device sizes. The app shall be designed so that it is clear, understandable and can be used by every generation.	D-04
NFR02	Data integrity	Ensuring the integrity of the data collected and processed is of paramount importance. The app shall ensure that the stored data is accurate, consistent and protected from unauthorised access.	
NFR03	Privacy	As the app will collect and analyse sensitive health data, privacy is a key aspect. The app should implement strict privacy policies and mechanisms to anonymise personal data.	D-05
NFR04	Platform compatibility	The app should work efficiently on different platforms and devices to reach a wide user base. Cross-platform ability is therefore important. This requires careful design and development to ensure compatibility and portability. The app shall run on Android and IOS.	D-06, D-07
NFR05	Accessibility	The app should ensure that the buttons and text sizes are big enough to ensure appropriate readability and interaction for users with visual impairments.	ID-02

5.4.1.4 Parameter definition and database design

The parameters identified through the interview (IT-1), brainstorming(IT-0, IT-3) and literature research(IT-0) could be divided into two three main categories: User data, feedback and recommendation parameters. The user data includes individual biological characteristics such as chronotype, sleep patterns, light sensibility, age and gender, which are of central importance for the personalised setting of the light-wake system. The recommendation parameters are influenced by the user data, and set through the algorithm. These include the intensity and duration of the light as well as the time of light stimulation and are provided to the user as a recommendation. Additional daily feedback, given by the user is stored in a feedback collection and used to update recommendations. The combination of user data, feedback and recommendation parameters creates a customised chronotherapy proposal that takes individual needs and biological rhythms into account. The user parameters are created as a document in the database and each recommendation and feedback is saved as a new entry in a collection. The background to this is, that analyses and statistics can be easily created over longer periods by sorting them by date.

In figure 5.10, the depicted database diagram illustrates the resultant structure. Each entity within the diagram serves as a representation of a document within the Firebase database. Notably, the entities 'Recommendation' and 'Feedback' exhibit a one-to-many relationship. This implies that for each entry in these entities, a corresponding new document is persistently stored in the database for subsequent analysis.

5.4.1.5 User parameter

The user parameters are asked directly from the user in a questionnaire. These are all the parameters needed for personalisation. On the one hand, this includes goals and required wake-up times, i.e. parameters that are not properties of the user but are needed, and on the other hand, the personal attributes of the user that play a role in the personalisation algorithm.

- **AlarmSettings:** All information about the user's wake-up times, such as wake-up time due to work, on which days this alarm must be set, which intensity scale (lux oder steps) is used by the light alarm clock,d and when the user usually goes to sleep.
- **Goals:** To design the algorithm according to the user's desired goal, his or her desired wake-up time is asked and what his or her overall goal is for using the app.
- **Person:** All personal attributes that are perceived as important in the interview and that can influence the light sensitivity are asked. This includes age, subjective sensitivity to light, eye colour, whether a sleep mask is used and which sleeping position is preferred.

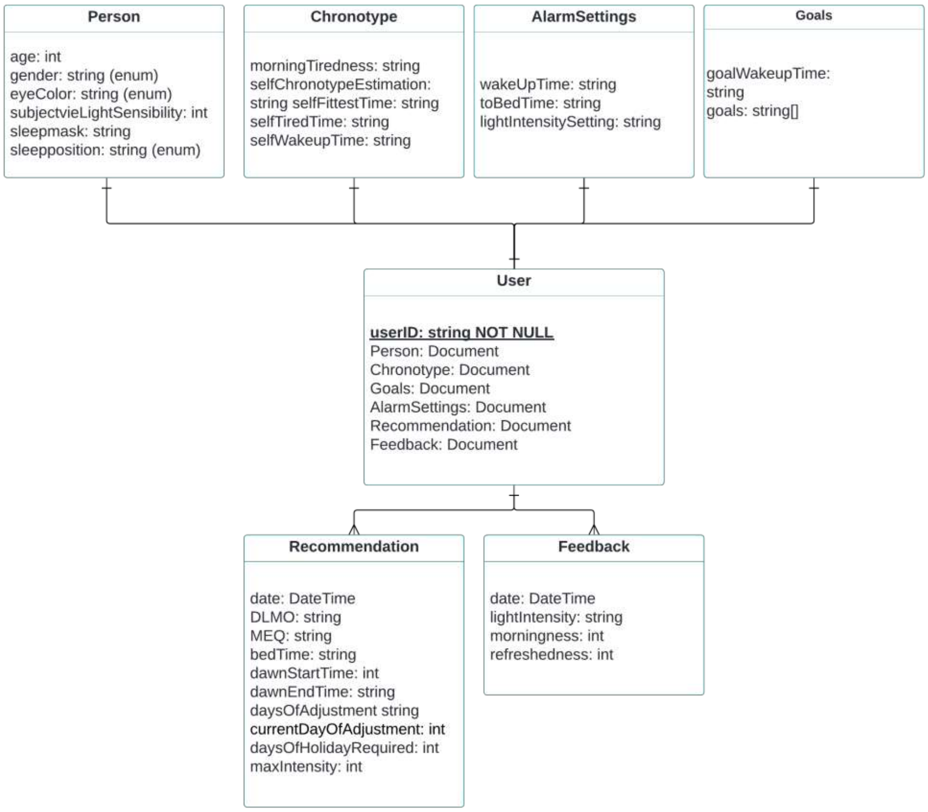

Figure 5.10: Database Diagram

- **Chronotype:** To find out the chronotype of the user without having to ask him 21 questions, which would impair usability, a shortened version of the MEQ [91] is used. There is already a scientifically based shortened version, which is used here and consists of five questions.

5.4.1.6 Recommendations

The system parameters are not requested from the user. They are calculated by an algorithm based on the user data and provide a personalised setting. These parameters were adjusted and finalised through extensive literature review and iterative brainstorming. The following parameters result:

- **DLMO:** To change the circadian rhythm through light therapy, it is essential to adjust the light to the individual's circadian rhythm. A primary marker is melatonin secretion, which defines the subjective night. The dim-light melatonin onset DLMO provides an internal reference for the timing of light therapy. [19] [96]

- **MEQ score:** The preferences of individuals in their sleep patterns are called chronotypes and range from extreme morning types to extreme evening types. This variability makes it important to adjust the timing of light accordingly. To find out the chronotype, Horne and Östberg invented the Morningness-Eveningness-Questionnaire(MEQ) [46], which determines which chronotype someone can be assigned to. [19] [96]

- **bedTime:** To get enough sleep, the user should also be suggested what his or her ideal bedtime would be.

- **daysOfHolidaysRequired:** Extreme evening types often have to get up earlier than their chronotype allows due to social working hours. To ideally adapt the therapy to the user's desired time and to gradually shift the therapy to an earlier time in not too large steps, it may make sense for the user to plan a few days' holidays, as the wake-up times during the therapy are later than his or her wake-up times.

- **dawnEndTime:** The user is recommended a primal time to start light therapy. This can change daily if there is a large difference between the late chronotype and an early desired wake-up time until the desired time is reached.

- **daysOfAdjustmentt:** The discrepancy between the time at the start of therapy and the desired time can vary and be adjusted over days. Here, the days are calculated how long it takes until the desired wake-up time is reached.

- **currentDayOfAdjustment:** So that the user knows how long he has been getting up after the recommendations, the day on which he is currently in his progress is displayed.

- **maxIntensity:** So that the user can adjust the light system to their needs in terms of light intensity, a recommendation is calculated as to the maximum light intensity that can be set on the alarm clock. Depending on the user's specifications in the alarm settings, the light intensity is either specified in lux or levels. This is based on which light alarm clock the user is using.

5.4.1.7 Feedback parameter

The feedback parameters are saved by the user's feedback submission. They are used to update the recommendations by an algorithm. The asked questions and thus collected parameters were adjusted and finalised through iterative brainstorming. The following parameters result:

- **lightIntensity:** To ideally adapt the light intensity to the user and prevent premature waking up due to the brightness or the absence of the dawn effect, the user is asked to select the light intensity.

- **morningness:** The user is asked how easy it was for them to get up for their statistics.

- **refreshedness:** For their statistics, users are asked how refreshed and fit they felt after getting up

5.4.2 Technological stack

The selection of technology for this project was a carefully considered decision, primarily driven by the requirements gathered in the iterations of the user-centred design, as detailed in chapter 5.1. One of the central objectives was to ensure cross-platform compatibility, a crucial factor in achieving a wide-reaching user base. The application was envisioned to seamlessly function on both iOS and Android platforms. Consequently, Flutter[1] was chosen as the primary framework, given its unique capability to enable deployment across both operating systems while maintaining a single, unified codebase.

In the realm of state management, Riverpod[2] was chosen as the preferred solution. Riverpod's appeal lies in its ability to facilitate the creation of multiple providers of the same type, allowing for more fine-grained and granular control over state management. This feature proves especially advantageous when dealing with a multitude of diverse user interface elements. State management encompasses the administration and coordination of various aspects, including the management of UI components, databases, and back-end operations. These components might encompass elements such as text fields, dropdowns, and lists sourced from databases, all of which are intricately interconnected and reliant on the state of one another. [97]
The decision to use Riverpod as a state management solution for the implemented Flutter app for personalizing a smart wake-up light, which includes a questionnaire, feedback and recommendations offers numerous advantages. Riverpod, as an extension of Provider, enables efficient application state management. Particularly in the case of the questionnaire that comprises various parts(person, chronotype, Alarm settings, goals), Riverpod offers a structured way of saving the status of the individual questionnaire sections. Integration with Firebase ensures the seamless transfer and storage of user responses, enabling reliable data synchronisation between the frontend and the database. This integration not only enables smooth feedback collection but also opens up the possibility of generating personalised recommendations based on the data collected.

For the database, FireStore[3] was the chosen platform. The decision was primarily driven by its scalability and serverless architecture, ensuring seamless live data transfer. Furthermore, FireStore incorporates an offline mode, which gracefully handles situations where internet connectivity is lost, ensuring that data can be synchronized when the

[1] https://flutter.dev/
[2] https://riverpod.dev/de/
[3] https://firebase.google.com/docs/firestore?hl=de

connection is re-established. There is also the option to integrate BigQuery for statistical analysis. To complement this, Hive[4] was employed for local storage capabilities.

In terms of model development, Freezed[5] a pivotal role. It was selected for its ability to simplify the generation of data classes, eliminating the need for boilerplate code by simply adding annotations to the classes.

In summary, the project's architecture revolved around the core components of Model, Provider, Services, and Views. Each of these components was meticulously chosen to ensure not only optimal functionality but also to streamline development, maintenance, and user experience. In figure 5.11 the resulting Unified Modeling Language (UML) Class Diagram can be seen.

5.4.3 Algorithm

In the following, the implemented algorithm and the underlying science for personalised recommendations for an intelligent alarm clock system are presented, which enable the adaptation of a light alarm clock by extracting parameters. This algorithm has been designed to consider and adjust to individual circadian rhythms and preferences, enhancing the overall personalization of the wake-up experience.

The requirements for this algorithm were defined as part of a user-centred design (UCD). The functional requirement FR02, which starts with opening the app for the first time to calculate the algorithm and presenting the, is as follows:

1. The user goes through a comprehensive required questionnaire that asks for all relevant parameters for the input of the algorithm.

2. In the background, the algorithm calculates the start time of dawn, the light intensity, the number of adjustment days and the required holiday days. The output of the algorithm, i.e. the recommendations, is presented to the user in an overview.

3. The user now can navigate freely through the app, and:

- has the option of updating their answers in the questionnaire at any time, which leads to new recommendations from the algorithm.
- has the option to generate a new recommendation for the next day, especially if the circadian rhythm is adjusted over several days.
- can provide feedback on their experience with the personalised settings, whereupon the algorithm takes this into account and recalculates recommendations.

The algorithm itself was developed based on the requirements ID-04 to ID-12, which are all included in the functional requirement FR02, and:

[4]https://pub.dev/packages/hive
[5]https://pub.dev/packages/freezedplayed

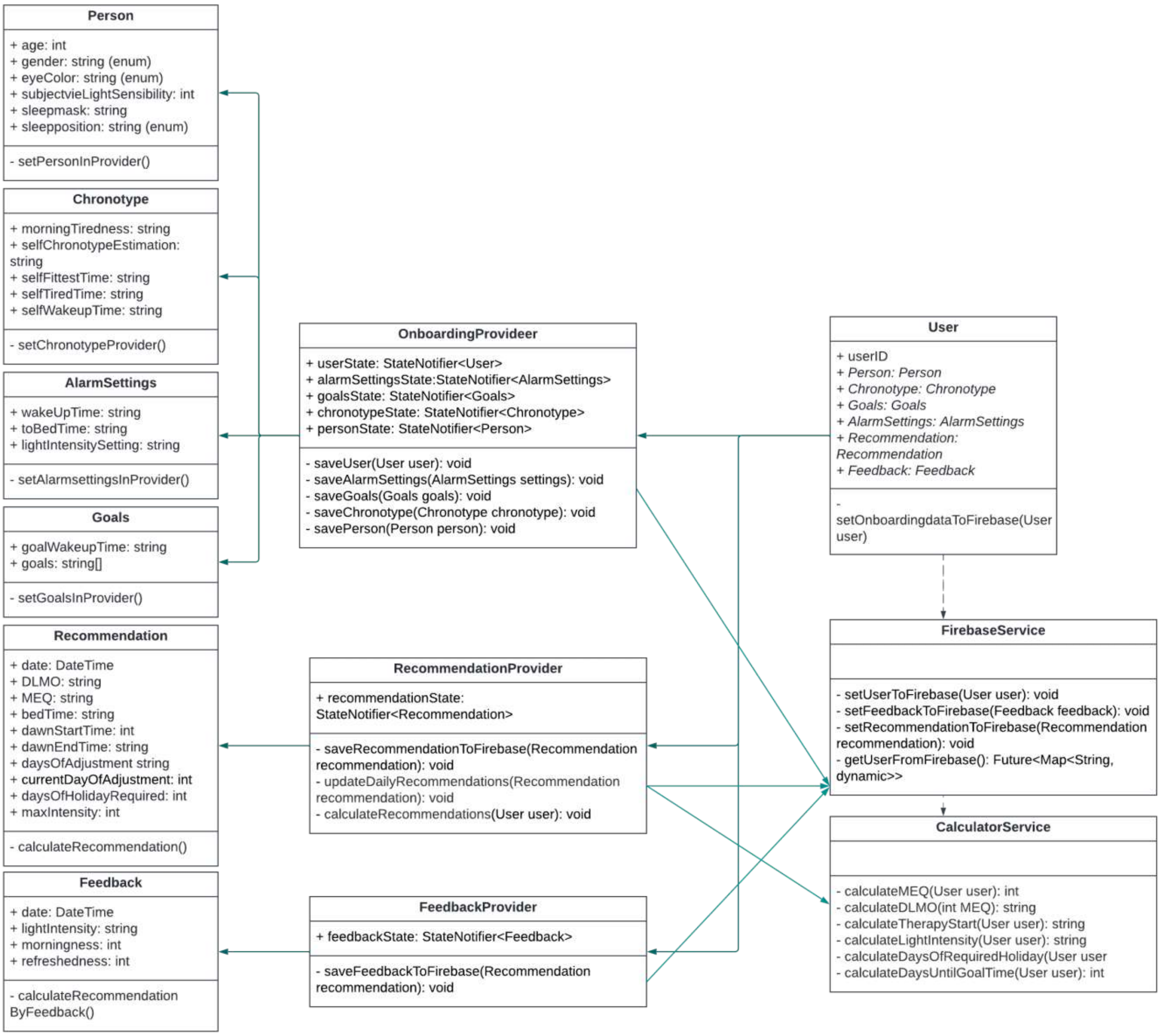

Figure 5.11: UML Class Diagram

- first calculates the start time of dawn based on the user's DLMO (Dim Light Melatonin Onset) (ID-04)
- determines the maximum light intensity based on the user's eye colour and subjective light sensitivity, (ID-05)
- reduces the adjustment of the start time by 15 minutes every day to gently adjust the circadian rhythm, (ID-07)

- in the event of a conflict between the socially predetermined wake-up time and the optimal wake-up time calculated by the algorithm, the algorithm calculates the number of days off the user would need to take to achieve their circadian shift without having to get up early due to work commitments (ID-06).
- When feedback is received or new recommendations are requested manually, the algorithm recalculates the values. (ID-09, ID-08)

The sequence of input parameters in the algorithm and its output can be found in figure 5.12. A more detailed description of the calculations within the steps can be found in the following sections.

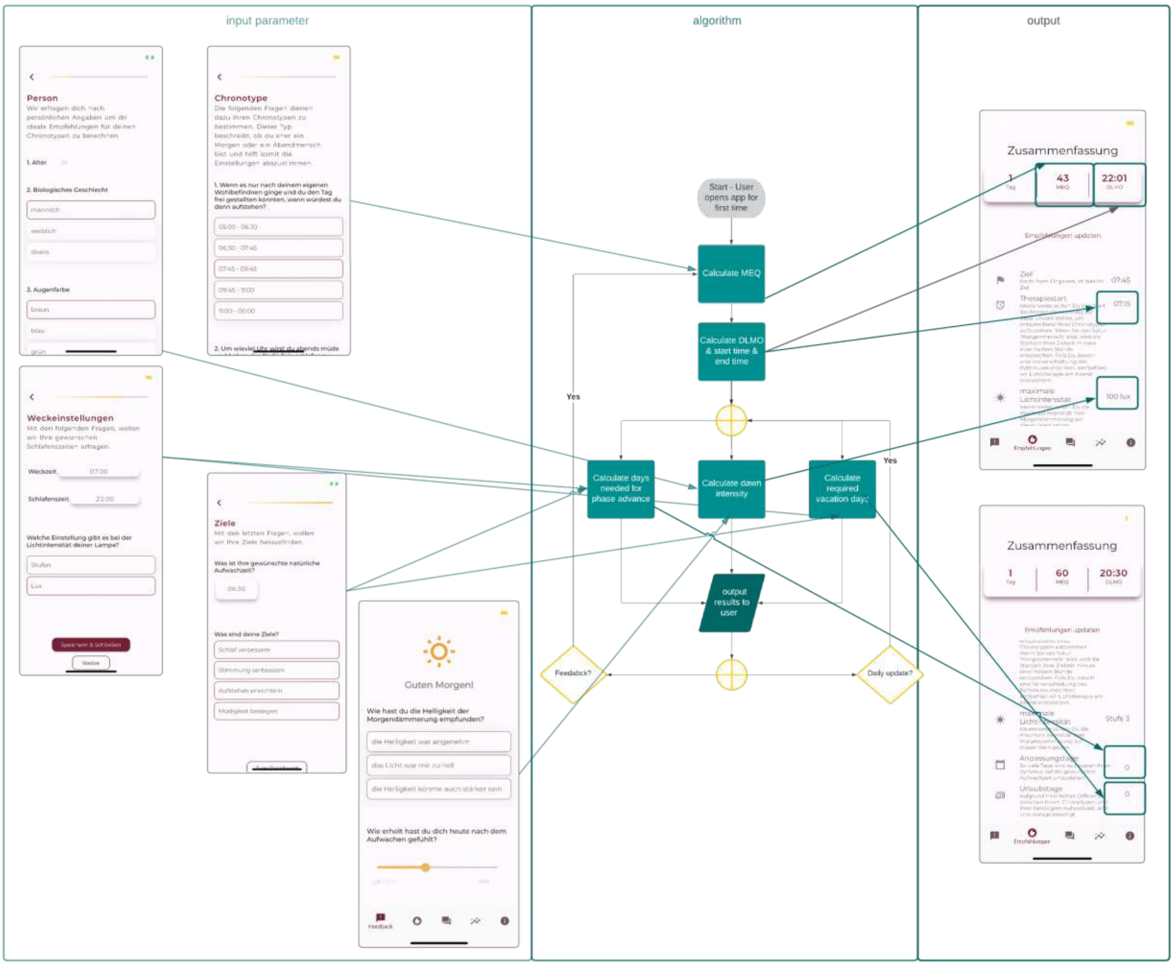

Figure 5.12: Flow of Algorithm Parameters: This illustrates the origin of parameters, where they are utilized within the algorithm, and how they contribute to the recommendations.

5.4.3.1 Scientific background

Dawn simulation has demonstrated efficacy in phase-advancing circadian rhythms, similar to bright light therapy. Gradual exposure to extremely low levels of light during the final stages of the night promotes advancements in circadian rhythm phases. Studies have shown that the use of naturalistic dawn can not only help to shift the circadian rhythm but also make it easier to get up and counteract sleep inertia [98] [5].
The dose-response and the phase response are of decisive importance here. It indicates how the duration and intensity of light exposure influence the shift of the circadian rhythm. e.g. a higher intensity in the morning creates a phase advance and in the evening a phase retardation. The phase response describes how the time of exposure to light influences the internal clock of an organism and whether there is a delay (phase delay) or an advance (phase advance). [84] [99]
By integrating the phase-response curve and the dose-response curve into the algorithm, it is possible to precisely adjust the timing and intensity of the simulated dawn for an effective shift in the circadian rhythm.

Therefore the role of the chronotype and dim light melatonin onset (DLMO) in phase response, i.e. changing the internal biological clock, play a major role, as they are used to assess the timing of the circadian rhythm. The chronotype can be calculated using the Morningness-Eveningness-Questionnaire (MEQ) or the Munich ChronoType Questionnaire (MCTQ). Furthermore, it is shown, that the DLMO varies according to age and is related to the MEQ score. [100] [101].

The underlying algorithm is based on these scientific findings. In the course of the interview during the design phase of the user-centred design, as can be seen in chapter 5.1, the decision was made to use the shortened version of the Morningness-Eveningness-Questionnaire (rMEQ) to calculate the chronotype. This reduced form of the questionnaire was validated and adapted in various languages. It is characterised by good external validity, reliability and convergent validity, making it a useful tool for assessing circadian preference without asking too many questions. This score forms the starting point for calculating the biological dawn time (DLMO), which in turn serves as the basis for the personalised wake-up time. To ensure optimal adaptation to the individual circadian rhythm, social wake-up times due to work commitments are also included in the algorithm. Another notable aspect of the algorithm is the consideration of individual user characteristics, such as eye colour and subjective sensitivity to light. These factors are precisely integrated to calculate the intensity of the simulated dawn.

Dawn itself gradually increases light intensity to mimic the natural sunrise over 90 minutes, going from 0.01 lux to 250 lux. The user is expected to wake up after approx. 60 minutes. An example of the equation for attenuation of the dawn according to Avery et al. [85] is, $y = 259.5/(117862.5e(20.1358x))$ where y = illuminance in lux and x = time after the start of the simulation. The function is similar to a natural sunrise, i.e. it starts with a gradual slope, then a slightly steeper one after 30 minutes and then gradual again. The simulation of a naturalistic twilight, both in terms of time and light intensity, is considered the optimal approach. However, as different light alarm clocks have their own, unchangeable attenuation calculations and only allow the start time, maximum intensity and, in some cases, duration to be configured, the algorithm was developed with self-configurable settings in mind. This means that for light-sensitive individuals, the maximum intensity is shifted by a percentage and the start time is calculated based on the chronotype. The ideal starting point is 2.5 hours after the midpoint of sleep or 8.5 hours after the Dim Light Melatonin Onset (DLMO), as this is when the majority of people are reached. Given that most commercially available light alarm clocks only support a dawn simulation of 30 minutes, this duration is set as the standard. This customisable approach takes into account the biological variability of light sensitivity and chronotypes to ensure a personalised and effective dawn simulation. [85] [19]

The process and its steps are described in more detail below.

5.4.3.2 Procedure

The sequence of the developed algorithm is described in detail below, which is also illustrated in figure 5.13.

1. **Calculation of the MEQ score:**
   In the first step of the algorithm, the Morningness-Eveningness Questionnaire (MEQ) score is computed based on the user's responses to the reduced MEQ questions in the Chronotype section of the initial questionnaire. The MEQ is a widely used instrument for assessing individual differences in circadian rhythm through a questionnaire comprising 19 items related to sleep and wake times. Each response is weighted, and the points are aggregated to yield a total score, which, when placed on a predefined scale, determines the user's chronotype. Natale [102] additionally validated a reduced five-item version of the MEQ, demonstrating its good external validity concerning circadian rhythms. The MEQ serves as a reliable and valid tool for assessing morningness and eveningness, forming the foundation for subsequent calculations in the algorithm and providing insights into the user's circadian rhythm. [46] [25]

   In the developed algorithm, the reduced MEQ [103] is utilized as a template for calculating the chronotype. Each question in the questionnaire, along with the user's response, contributes to a score that is aggregated across all questions and then mapped onto a scale, yielding the reduced MEQ score and consequently determining the user's chronotype. To precisely determine the Dim Light Melatonin Onset (DLMO) in the next step, the reduced MEQ score is further aggregated to obtain the MEQ score. Various equations are employed to transition from the reduced MEQ to the MEQ score, as can be seen in listing 5.1.

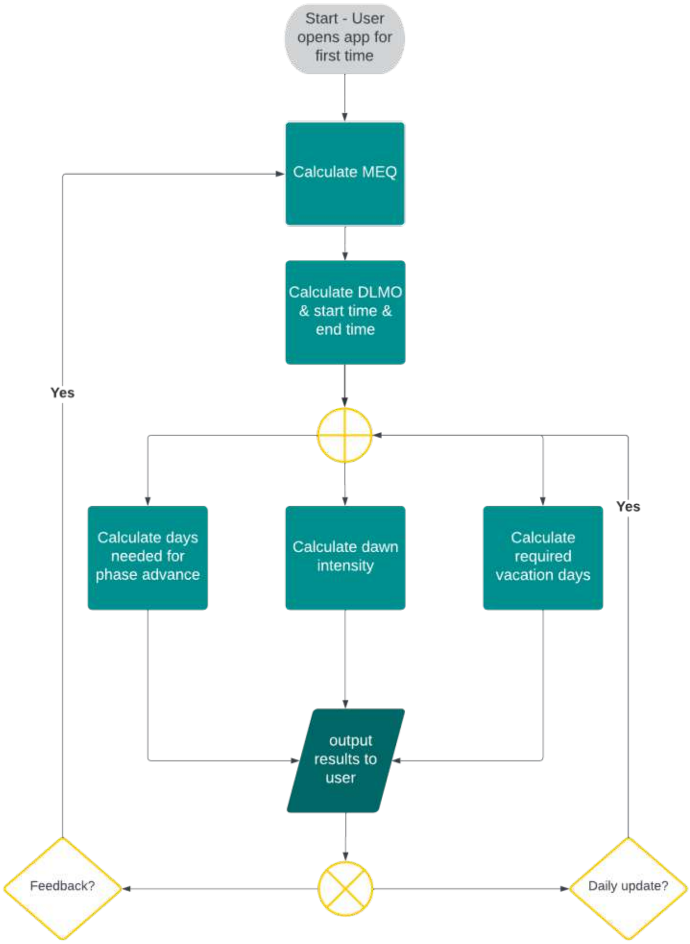

Figure 5.13: Flow diagram of the developed algorithm

```
int calculateMEQScore(){
    int rScore = selfChronotypeEstimationScore +
     morningTirednessScore + selfFittestTimeScore +
     wakeupTimeScore + selfTiredTimeScore;
    int score = rScore;

    // definitive "Evening␣type":
    // reduced MEQScore 4−7 & MEQScore 16−30
    if(rScore < 8){
    score = 4∗rScore +1;

    // moderate "Evening␣type":
    // reduced MEQScore 8−11 & MEQScore 31−41
```

```
    } else if (rScore >= 8 && rScore <= 11){
    score = 3*rScore +8;

    // intermediate type:
    // reduced MEQScore 12-17 & MEQScore 42-58
    } else if (rScore >= 12 && rScore <= 17){
    score = 3*rScore +7;

    // moderate "morning type":
    // reduced MEQScore 18-21 & MEQScore 59-69
    } else if (rScore >= 18 && rScore <= 21){
    score = 3*rScore +6;

    // definitive "morning type":
    // reduced MEQScore 22-25 & MEQScore 70-86
    } else if (rScore >= 22){
    score = 4*rScore - 17;
    }
    return score;
}
```

Listing 5.1: Step 1: Calculate MEQ score

2. **Calculation of the DLMO and the personalised start time:**
Subsequently, the calculated Morningness-Eveningness Questionnaire (MEQ) score is used to determine the Dim Light Melatonin Onset (DLMO). The DLMO serves as a crucial marker for evaluating the circadian pacemaker and can be computed through the MEQ score [26]. The correlation between Dim Light Melatonin Onset (DLMO) and Morningness Eveningness Score (MEQ) has been examined in several studies. Kantermann [100] identified a significant correlation between DLMO and MEQ, with the former being the strongest predictor of the latter. This finding was corroborated by Kennaway [101], who observed that lower MEQ scores were associated with a later DLMO. Terman and Terman [104] described a correlation equation in their study involving 69 participants:

$$DLMO = 25.9 - 0.09 * MEQ$$

The DLMO is a crucial parameter for calculating the personalized wake-up time. A substantial clinical study demonstrated that the maximum phase advance occurs when light is applied 7.5-9.5 hours after DLMO [105]. By calculating the DLMO based on the MEQ score, it becomes possible to initiate the Dawn Simulation at the individually optimal time for the user. During the brainstorming process, discussions with experts led to the decision to set the start time at 8 hours after DLMO. This adjustment acknowledges that the application involves a 30-minute

Dawn Simulation, distinguishing it from Bright Light Therapy, which initiates in the waking state, capturing most individuals at the appropriate time.

$$starttime = DLMO + 8.5hours$$

Adding 8.5 hours to the DLMO, the ideal starting point for dawn simulation is thus calculated, aiming to wake the user during a phase of heightened alertness and activity. For morning types, the dawn simulation may be earlier than the desired target wake-up time. In this case, the start time of the dawn simulation is set 30 minutes before the desired target time to prevent unwanted premature awakening but still enable the desired positive effects of the dawn simulation. The applied calculation of the DLMO and the resulting start time for dawn simulation can be found in listing 5.2.

```
double calculateDLMO(int MEQ){
    double DLMO = 25.9 - 0.09 * MEQ;;
    return DLMO;
}

String calculateTherapyStart(double DLMO, User user){
    double therapyStartTime = DLMO + 8.5;

    if(goalTime >= therapyStartTime){
      therapyStartTime = goalTime - 0.5;
    }
    return therapyStartTime;
}
```

Listing 5.2: Step 2&3: Calculate DLMO and therapy start time

3. **Calculation of days to reach target wake-up time:**

Determining the difference between the calculated optimum wake-up time and the desired wake-up time requires a differentiated examination of the circadian phase shifts. The concept of advancing the wake-up time by 15 minutes each day is in line with the principles of chronotherapy. The gradual adjustment not only reflects an empirically validated approach but is also consistent with the principles of gradual phase shifting, minimising potential disruption to the circadian system. [106] [19] [32]

In the next step, the personal wake-up time is compared with the target wake-up time. The difference between the calculated optimum wake-up time and the desired wake-up time is calculated and therefore how long it would take to gradually adjust the personal wake-up time until the desired wake-up time is reached. In this step, whose calculations can be found in listing 5.3, the wake-up time is also moved forward by 15 minutes every day to enable a gentle adjustment of the circadian rhythm.

```
int calculateDaysUntilGoalTime(int goalTime){
 if(goalTime == therapyEndTime){
  return 0;
    } else if(goalTime > therapyEndTime){
      return 0;
    } else {
      double timeDifference = therapyEndTime - goalTime;
      double days = timeDifference / 0.25;
      return days;
    }
}
```

Listing 5.3: Step 4: Calculation of days to reach target wake-up time

4. **Calculation of possibly needed vacation days:**
The individual sleep-wake cycle and social commitments also influence the ideal starting time. It is crucial to ensure that the Dawn Simulation falls within a timeframe aligned with the natural waking time and the user's daily commitments.

In the subsequent step, as in listing 5.4, the obtained optimal start or end time of the user's Dawn Simulation is compared with wake-up times dictated by social commitments, which are established due to work obligations or other social factors and can be extracted from the questionnaire. If the difference between the calculated optimal time and the social wake-up time is significant, a calculation is performed to estimate the duration required to gradually adjust the personal wake-up time until the desired wake-up time is reached. This is recommended as the required number of vacation days. The concept is to advance the waking time by 15 minutes each day to facilitate a gentle adaptation of the circadian rhythm. The choice of 15 minutes is based on prior research and results from the brainstorming in section 5.3.3 that suggests this duration is a suitable interval for a gradual adjustment.

The days are reduced after each application of the recommendations by the user until they reach 0.

```
int calculateDaysOfRequiredHoliday(){

    // Check if there is a need for holidays
    // and if the goal has already been met
    if(alarm >= therapyEndTime || therapyEndTime <= goalTime){
      return 0;
    } else {
      // Calculate the time difference, between the end of dawn
```

```
        // and the needed wake-up time
        double timeDifference = therapyEndTime - alarm;

        // Calculate the amount of required holidays by
        // calculating how many adjustments of 15 minutes are needed
        double amountOfVacationDays = timeDifference / 0.25;
        return amountOfVacationDays;
    }
}
```

Listing 5.4: Step 5: Calculation of vacaction days required

5. **Calculation of the dawn intensity:**
The intensity and colour temperature of the simulated dawn are critical factors in dawn simulation. The gradual increase in light intensity mimics the natural dawn progression, activating photoreceptive cells in the retina that influence the circadian rhythm. [107]
Research indicates that human light sensitivity is influenced by various factors, exhibiting individual variability among individuals. The role of personal characteristics such as eye color is noteworthy. Individuals with lighter eye colours tend to be more light-sensitive due to lower melanin levels, impacting their responsiveness to dawn simulation. Subjective light sensitivity, on the other hand, considers the individual's perception of light, providing valuable insights into their comfort levels and potential responsiveness to different intensities of dawn simulation. [108]

To tailor the dawn simulation to individual needs and preferences, user-specific data, including eye colour and subjective light sensitivity, are incorporated to calculate the intensity of the simulated dawn. This personalized approach aims to avoid prematurely awakening the user during the simulated dawn through excessive light exposure. Instead, the goal is to achieve a natural awakening experience after the 30-minute simulation period.

As in listing 5.5 the light intensity is adjusted iteratively, based on the user's feedback. This means that the light intensity is increased if the user indicates that the desired recovery effect has not materialised and they would like to increase the intensity, and it is reduced if the user wakes up early from sleep due to too bright light.

```
String calculateLightIntensity(){
    double intensityFactor = 0;
    double maxIntensity = 300;

    // Add user's feedback regarding light intensity
    if(lightIntensityFeedback == 'lower brightness'){
        intensityFactor += 0.25;
        }
```

```
        if(lightIntensityFeedback == 'add brightness') {
        intensityFactor -= 0.25;
    }

    // Adjust light sensitivity based on eye colour
    if (eyeColor == 'braun'){
        // The subjective light sensitivity reduces the
        // light intensity accordingly
        intensityFactor = subjectiveLightSensibility +
                    intensityFactor;
        maxIntensity = maxIntensity / intensityFactor;
        return maxIntensity
    } else {
        // A light eye colour lowers the light intensity
        intensityFactor = subjectiveLightSensibility + 1 +
                    intensityFactor;
        maxIntensity = maxIntensity / intensityFactor;
        return maxIntensity;
    }
}
```

Listing 5.5: Step 6: Calculation of maximum light intensity of dawn

6. **Presentation of the results and customisation through feedback:**
After finalizing the initial questionnaire, the user is provided with personalized recommendations (light intensity, start time, adaptation period, required vacation days) and additional information (DLMO, MEQ). Following the initial computation, the user can generate daily recommendations for the subsequent day by simply clicking a button. All parameters that are adjusted daily are changed, but the DLMO and MEQ remain unchanged, as these parameters are based on the user input and not on the daily progress. The procedure for this can be found in listing 5.6.

```
def updateRecommendation(){
    // Check if the desired wakeup time has already been reached
    if(daysOfAdjustment > 0){
        // If not, decrease the dawn start time by 15 minutes
        var dawnStartTime = dawnStartTime - 0.25;
        // Calculate the new amount of adjustment days
        calculateDaysOfAdjustment();
        var currentDayOfAdjustment = currentDayOfAdjustment +1;
      // Check if the user still needs vacation days
      if(daysOfHolidayRequired - 1 >= 0){
        // If so, calculate new days of required vacation
        calculateDaysOfHolidayRequired();
```

```
        }
    } else {
        var currentDayOfAdjustment = currentDayOfAdjustment +1;
    }
}
```

Listing 5.6: Step 7: Update recommendation driven by user request

Additionally, the user has the opportunity to provide feedback once daily, influencing the generation of new recommendations based on the received feedback. If the user wishes to modify personal data, goals, or alarm settings or wishes to reassess their chronotype, they can revise their information, and the algorithm will generate new recommendations based on the updated values. When recalculating the recommendations based on feedback or changes to the questionnaire, there is no change in the current day in progress, but all other parameters including MEQ and DLMO, as can be seen in listing 5.7.

```
def updateRecommendationByFeedback(){
    calculateMEQ();
    calculateDLMO();
    calcualteTherapyStart();
    calcualteDaysOfHolidayRequired();
    calculateAdjusmentDaysRequired();
    calculateIntensity();
}
```

Listing 5.7: Step 8: Update recommendation driven by user feedback

Consequently, the recommendations are iteratively adjusted by the algorithm, facilitating a responsive approach to the individual needs of the user. This iterative and interactive process ensures that the algorithm remains adaptable and dynamic, providing continuously tailored suggestions that evolve following the user's changing circumstances and preferences.

5.4.3.3 Input and output parameters

The input parameters of the algorithm comprise the data provided by the user, including eye colour, subjective light sensitivity, reduced MEQ questions, social wakewere time and the desired target wake-up time. The output includes the calculated light intensity, the personalised start time, the days required to reach the target and, if applicable, the number of days off required to adjust the wake-up time.

This algorithm for personalising a smart wake-up system makes it possible to customise the wake-up and sleep experience and optimally take the user's circadian rhythm into account. The integration of feedback and continuous adjustment ensures that the personalised

5.4.4 Funcitionalities and Design

Thanks to the user-centred design, the design and functionality of the app were constantly adapted. The final app is described in more detail below. The app is based on a questionnaire, a recommendation, the opportunity to provide feedback, statistics and background information. The questionnaire is divided into four main areas: Person, chronotype, alarm settings and goals. The internal questionnaire must be completed once at the start of the app before accessing the general dashboard. All areas can then be accessed and exited via a footer bar, which enables flexible navigation. The user interface of the app was designed with a particular focus on usability and user-friendliness, whereby the questionnaire was designed to be intuitive and efficient. The design and requirements were constantly revised and improved through the integration of users in the UCD, as can be seen in chapter 5.1.

5.4.4.1 Questionnaire

- **Introduction and confidentiality:** The questionnaire starts with a brief introduction that assures the user that their data will be treated confidentially, as can be seen in figure 5.14. In addition, an estimated completion time of 5 minutes is given to clarify the user's expectations and encourage participation. This is based on the requirements D-04 from the initial design phase and ID-08 from the usability test.

Figure 5.14: Screenshot: Introduction screen

- **Progress indicator:** The four main areas of the questionnaire, namely person, chronotype, alarm settings and goals, are presented to the user with a progress bar 5.15. Each area is marked by a progress bar, with the current section highlighted in colour. This clear presentation makes it easier for the user to orient themselves and gives a sense of progress during data entry. The progress display is based on requirement D-01 of the literature search.

Figure 5.15: Screenshot: Progress indicator

- **User-friendly interface:** The user interface of the questionnaire was deliberately designed to be simple and user-friendly. The selection buttons for answering the questions are intuitive and visible. It is also possible to visit or leave each part of the questionnaire or the scientific background flexibly. In addition, explanations have been added wherever ambiguities may arise. For example, a pop-up appears as soon as you click on MEQ or DLMO to provide explanations and also an explanation has been added directly to all recommendations. This design was implemented after a thorough brainstorming session and the findings from the usability test to ensure that the app is effortless and engaging for users. To meet the requirement of user-friendliness D-03 of the literature research, the app was tested for user-friendliness in the usability test and the design was accordingly provided with larger buttons and without silders in the questionnaire. In addition, a footer, which can be found in figure 5.16, was implemented to ensure easy navigation (ID-10), allowing users to switch flexibly between pages.

Figure 5.16: Screenshot: Footer

- **Validation:** To prevent input errors or missing answers, an input validation was implemented that checks whether everything required has been filled in. If something has been forgotten, it is not possible to go to the next page and a message indicates where the input was forgotten. The error shown on an invalid input can be seen in figure 5.17.
- **Data storage and flexibility:** The app saves the data entered, even if the user cancels the questionnaire, and thus fulfils requirement D-02. This ensures that the user has the option of continuing the questionnaire at a later point in time without

Figure 5.17: Screenshot: Validation of missing input

losing the data of his previous progress. There is also the option to go through individual parts of the questionnaire again if the user wants to check or change their entries.

- **Adaptability:** The user's waking habits, chronotype and goals can change as a result of using the recommendations. It is possible to edit the questionnaire at a later date and receive new, customised recommendations. To avoid having to go through the entire questionnaire again, individual sections can be selected and the original answers can be viewed and edited over a corresponding screen, as can be seen in figure 5.18. This means that requirement ID-07 can be fulfilled in a user-friendly way.
- **Dark mode:** As shown in figure 5.19 the app switches to night mode in the evening. This means that a dark background with light-coloured text is displayed. This is better for falling asleep in the evening, as a bright screen can prevent melatonin production and thus delay falling asleep.

5.4.4.2 Personalised recommendations

Once the user has completed the questionnaire, they are presented with personalised recommendations, as shown in figure 5.20. This can include the optimal wake-up time, dawn intensity and other personalised settings. Users are presented with their recommendations and some additional information on the individual values in a structured

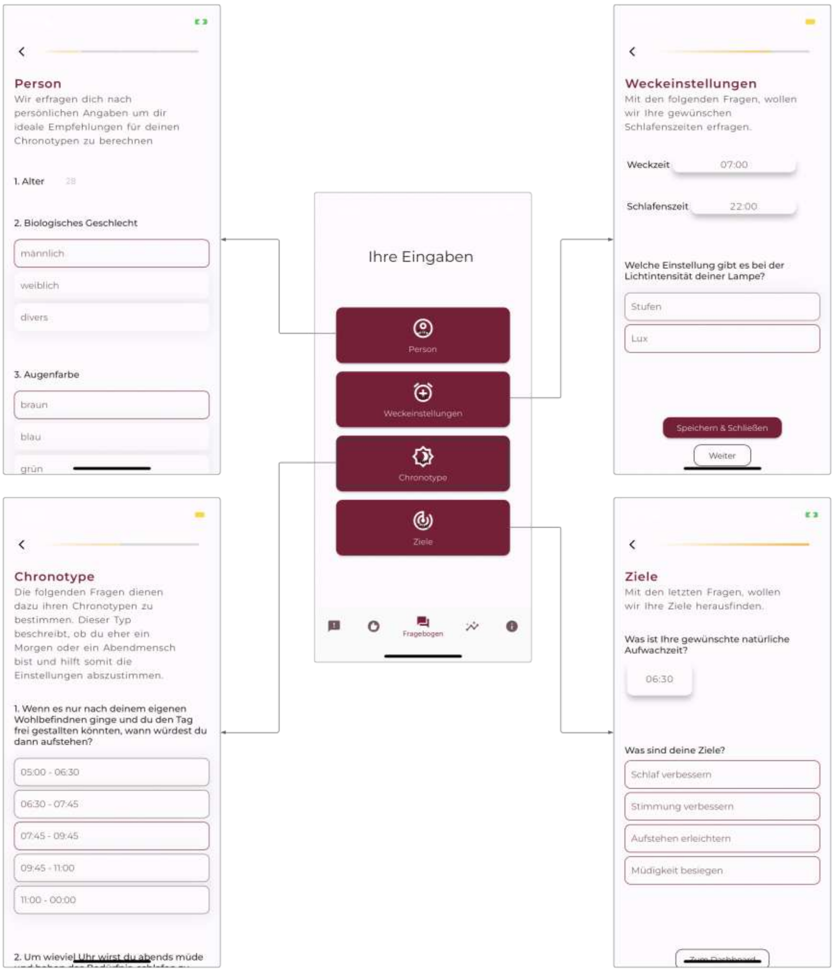

Figure 5.18: Screenshot: Revision of questionnaire answers

overview. By calculating and displaying the personalized recommendations, the functional requirement FR02, which results from several requirements (ID-04, ID-05, ID-06) of the UCD, is fulfilled

5.4.4.3 Daily adjustments and feedback

The app allows the user to provide feedback daily 5.21, resulting in ongoing adjustments to the personalised recommendations. Each day, a new start time for the dawn is calculated and displayed until the user has reached the desired goal. This iterative approach ensures continuous improvement of the app and optimal customisation to the user's individual needs.

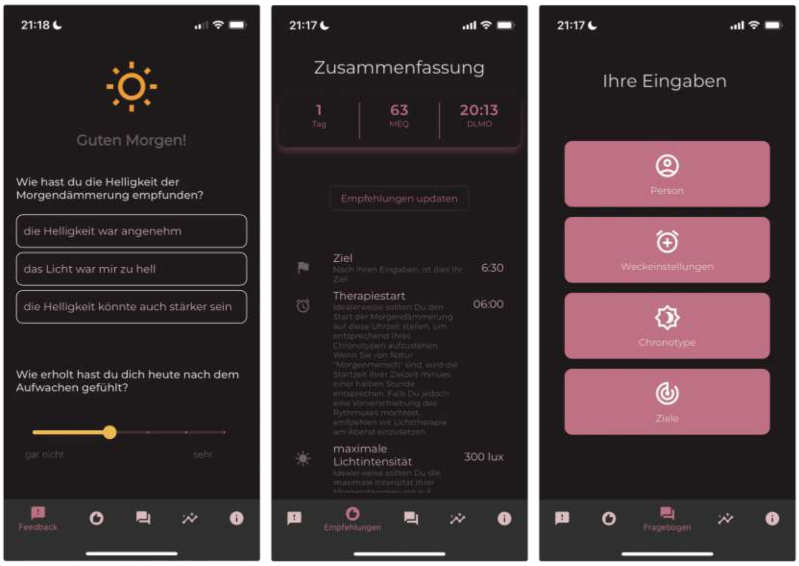

Figure 5.19: Screenshots: Application in dark mode

Figure 5.20: Screenshots: Recommendations

5.4.4.4 Statistics and Background Information

Furthermore, the app offers the option of viewing statistics on the users' waking-up experience and level of refreshment. Therefore a line chart visualises how the user's recovery in the morning and the difficulty of getting up has changed over the days of usage and thus meets requirement ID-08 (FR05).

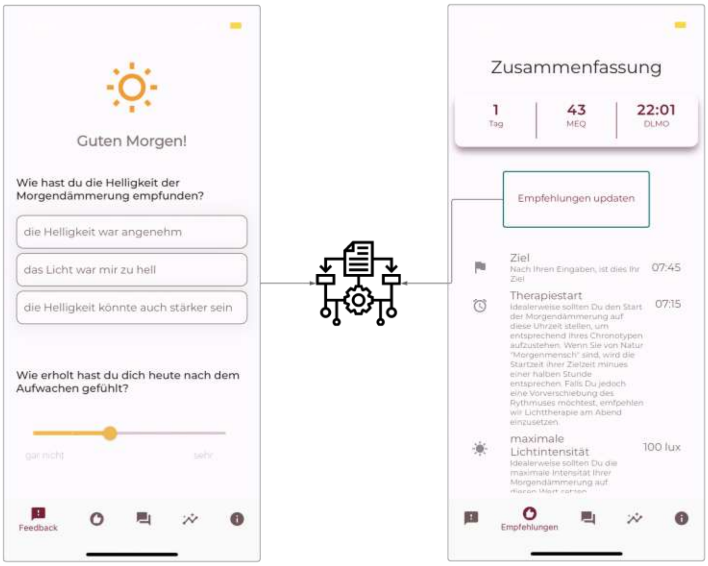

Figure 5.21: Screenshots: Recaculation is triggered by daily adjustments(right) or feedback(left)

The app further offers the opportunity to learn about the science of chronobiology. A background information tab covers several topics, such as the circadian rhythm, chronotypes, light as a zeitgeber and the positive effects of light therapy (ID-09, FR06). Screenshots of these additional features can be found in figure 5.22.

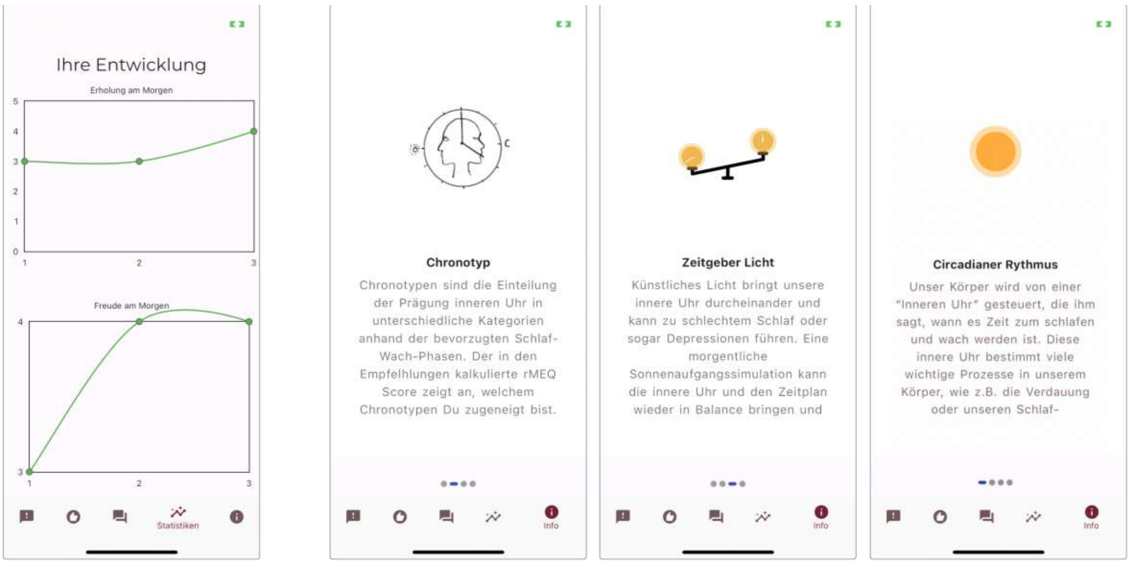

Figure 5.22: Screenshots: Statistics(left) and background information(right)

In summary, the developed application for personalising an intelligent wake-up system provides a user-friendly and efficient method for optimising the sleep-wake experience. By integrating feedback and daily adjustments, the application ensures that the personalised recommendations are always up-to-date and continuously accompany the user on their journey to improved ease of waking up and better well-being during the day. The basis of this approach is the customised calculation of recommendations for the user, which are continuously adapted to their individual needs. This ensures precise adjustment of the light setting to the circadian rhythm of each user. This methodology not only enables a personalised wake-up time and the shifting of the circadian rhythm but also the systematic optimisation of sleeping habits, which in turn has a positive effect on general well-being.

CHAPTER 6

Discussion

This chapter is dedicated to the discussion of the results presented in the previous chapter 5.4. Both the findings from the user test carried out and the answers to the research questions are discussed in detail.

The main objective of this thesis was to realise a prototype development of an app for personalizing a wake-up light by extracting parameters to provide personalized recommendations. The focus was on using smart light alarm clocks efficiently and thus improving the individual well-being of users. By choosing a user-centred approach as the development method, it was ensured that the user had a significant influence on the concept, design and overall development. This enabled the finalisation of a total of four use cases, which were developed in four iterations with five non-functional requirements and eight functional requirements. The samples of the individual iterations were selected using various methods such as multi-stage stratification, convenience and purposive sampling.

The initial phase of the work involved an extensive literature review to establish a solid foundation in the field of circadian health, UI/UX design and light alarm clocks. The research revealed that by individualising the correct timing and intensity of a dawn simulation, a user's circadian rhythm can be shifted and overall well-being enhanced. Although existing light alarm clocks can help to facilitate gentle waking, they are not customised to the person's individual needs and therefore cannot shift the circadian rhythm. In addition, users lack sufficient background knowledge about the intensity, duration and timing settings.

To close the existing gap in state-of-the-art technology, an app was developed that calculates personalised recommendations on wake-up times, light intensity and the duration until their circadian rhythm changes by specifically querying user parameters using a questionnaire. User-centred design played a key role in creating a user-friendly application. The algorithm and questionnaire, providing the input values, were designed in collaboration with experts, and the mockups and final prototype were tested by users.

The development process was divided into an initial design phase and an iterative development phase. The methodology used in the individual iteration steps was based on the requirements of the development process and included brainstorming, an interview, usability tests and user tests. The basis for the iterations in the development phase was formed by the results of a low-fidelity prototype from the literature research and an initial brainstorming session in the design phase. In the development phase, the first iteration included an interview with an expert in the field of sleep research, which laid the foundation for the parameters to be surveyed (personal data, rMEQ, goals and alarm settings). It aimed to find out how tolerant users are to long questionnaires and how usability can be improved to achieve higher user satisfaction. The resulting questionnaire was integrated into the low-fidelity design and analysed in a usability test. The results of this test phase, including the desired time specification, the display of progress and a design adjustment, were integrated and evaluated in a further brainstorming session. Following this, an expert in the field of chronotherapy was consulted in the brainstorming session to ensure the quality of the algorithm and to clarify open questions in the area of light settings. This led to the realisation that a reduction in light intensity is essential for light-sensitive people and should be achieved by scaling the maximum light intensity to a lower level. It should be possible to adjust this further through daily feedback. It was also decided to set the start time of the dawn simulation to 8.5 hours after the DLMO and to wake late chronotypes 15 minutes earlier each day to achieve their desired wake-up time without completely disrupting the circadian rhythm and to achieve long-term success. The final evaluation of the results from a five-day test phase with six users showed a high level of satisfaction with the use of the app and the wake-up process. Every participant stated that they experienced a significant improvement in waking up, and the majority of participants found the personalised recommendations helpful for their individual needs.

Overall, the results of the user test show that the personalised recommendation app developed has a positive impact on the user's waking behaviour and well-being. The integration of parameters enabled individualised adaptation to the user's needs, resulting in more effective use of smart light alarm clocks. The user-centred approach helped to increase usability and acceptance by adapting the app to the actual needs and preferences.

The research questions were successfully answered, with the developed app proven to be able to influence users' circadian rhythms and increase well-being. The insights gained underline the importance of a personalised approach to the development of recommendation apps for smart light alarm clocks, especially concerning the individual differences in users' sleep-wake behaviour. In the following the research questions are discussed in more detail.

6.1 Research question 1

"What are the requirements for designing an app for a smart wake-up light system that obtains data for a personalized preset and continuous optimization?"

To define the requirements for an app for the personalisation of intelligent light alarm clocks, literature research, interviews, brainstorming, usability tests and a user test with six participants were carried out as part of a user-centred design approach. In total five non-functional and eight functional requirements and four use cases were derived from these activities, which are explained in more detail below.

One requirement that arose early on was the development of a cross-platform app that could be used by both Android and iOS users. To this end, the app platform should be independent and not prescribe the use of a specific light alarm clock.

To record the parameters for personalisation by the user, it quickly became clear during a brainstorming session that a questionnaire was required for this. The interview that took place during the initial design phase determined the questions that were integrated into the questionnaire.

Another key requirement is usability. The application should continuously inform the user about their current progress and confirm the successful completion of the questionnaire. This was also confirmed by the usability test, in which users attached great importance to the permanent display of progress. It also became clear that there should be a time indication before the questionnaire is completed so that the user knows how much time they should allow for each step.

To ensure accessibility, buttons and text should be designed in a sufficient size and sliders in the questionnaire should be replaced by selection buttons.

During the development phase of the user-centred design approach, further parameters emerged in the technical area. It should be possible to adjust the light intensity upwards or downwards as a percentage or steps, depending on the user's sensitivity to light and the feedback received. To enable the user to make the personalised setting for the start of the sunrise simulation, the MEQ score must first be calculated, from which the DLMO is derived.

Users change personally over time and thus also their goals, work-related wake-up times and chronotype. These parameters can be modified anytime within the app, as it offers the option of answering and adapting the questionnaire or certain sections again. This enables continuous optimisation and helps users to go through a phase-advance towards being an early riser.

In addition, the app should offer the option of voluntarily providing feedback and loading new recommendations to enable continuous customisation. The generation of feedback and the creation of new recommendations should be voluntary so that users can decide for themselves when and whether they want to receive new recommendations. To make this possible, the user can optionally provide feedback daily, which is integrated directly into the recommendations and updates them. This regular feedback ensures that the personalised recommendations are adapted dynamically.

Other key requirements relate to the privacy and data integrity of the stored information. It is therefore intended that users are anonymised and that the collected data is stored correctly and consistently.

The underlying use cases for these requirements are the implementation of the initial questionnaire, the possibility to customise the questionnaire, the collection and use of recommendations and the viewing of statistics and background information, including the option to provide feedback.

The requirements for an app for personalisation through the extraction of parameters are therefore extremely complex and wide-ranging. Nevertheless, they are essential to provide the user with a pleasant experience and to cater to their individual needs. The findings derived from the usability test analyses revealed that a predominant number of users expressed satisfaction with the length of the questionnaire. Specifically, participants conveyed that the duration of the questionnaire was deemed acceptable, but a display of the duration would be desirable. In response to this feedback, an enhancement was made to the user interface design, incorporating a feature to prominently display the estimated duration of the questionnaire. This adjustment was implemented to address user concerns and provide transparent information about the time commitment associated with the questionnaire, thereby contributing to an improved overall user experience.

6.2 Research question 2

"Which parameters need to be queried, and how can the onboarding process be designed to gather those parameters while achieving acceptance and professionalism?"

During the initial design phase, it was realised that it made sense to use a questionnaire with a progress indicator to ask about the relevant parameters. This was tested for acceptance in the usability test, which showed that the overall length of the questionnaire met with acceptance. However, it was noted that a time indication is necessary before the questionnaire to give the user an orientation of the time required for each step.

The questionnaire consists of six questions about the person, five to determine the chronotype, three for the wake-up settings due to social obligations and two to enquire about the user's goals. The user is asked a total of 16 questions, which take around five minutes to answer. This questionnaire is segmented into four distinct sections for the sake of clarity. Each section is accompanied by brief information about the corresponding interrogative part, clarifying the significance of the inquiries. This approach should enable a better understanding of the comprehensive questions posed.

The personal parameters, including age, gender, subjective light sensitivity, wearing a sleep mask and sleeping position, were collected through literature research and interviews. Age plays a decisive role in light sensitivity, but is not considered separately in the algorithm due to the app's target group (middle-aged people, "evening person" type). Wearing a sleep mask and the sleeping position are essential for the incidence of light, but are not taken into account in the algorithm due to their complexity. However, it is recommended not to wear a sleep mask in order to achieve more successful results. The sleeping position was not taken into account, as different light alarm clocks are positioned differently and therefore also respond to different sleeping positions. However, future consideration would be interesting for further development. Gender is analysed due to differing opinions in the literature on light sensitivity. The most important parameters in the "person" part of the questionnaire are subjective light sensitivity and eye colour, which are decisive for light intensity. A light eye colour indicates a higher sensitivity to light, so this is considered.

Five questions from the scientifically developed MEQ questionnaire are asked in the chronotype section of the questionnaire. As the questionnaire should be kept short, the evaluated, shortened version of the MEQ is used after consultation with an expert in sleep medicine. The five questions record preferences for waking and sleeping times, well-being in the morning and self-assessment as a morning or evening type. The MEQ score, which is calculated from these questions, forms the basis for all further calculations in the algorithm.

In the alarm settings, information is requested on the desired wake-up time, the normal bedtime and the light intensity of the lighting system used. These parameters are used to determine whether the user should request a holiday if they are an extreme evening person but have to get up early due to work commitments and to specify the light intensity in lux or as a level.

To direct the user's personalisation towards their goals and calculate the recommendation accordingly, the last step of the questionnaire asks for the desired rising time after adjustment by the recommendations.

The questionnaire thus collects diverse and variable parameters in as compact a form as possible. It was developed through literature research and interviews and was evaluated for acceptance through usability tests. The usability tests and user tests carried out showed that user acceptance of the length of the questionnaire and the parameters queried is definitely given.

6.3 Research question 3

"How can the algorithm be defined, which is needed to translate the individual parameters into a personalized preset?"

The literature research in the design phase of the user-centred design approach and the brainstorming in the development phase have made it clear that a dawn simulation is useful for the personalisation of lighting systems in connection with a circadian phase-advance. In particular, the light intensity during dawn and the start time play a decisive role in personalisation.

The personalised start time can be effectively determined by calculating the DLMO (Dim Light Melatonin Onset), especially if no external medical devices are used. The MEQ score, which is calculated using the parameters of the "chronotype part" of the questionnaire, is crucial for determining the DLMO. Therefore, the first step in the algorithm is to calculate the MEQ score based on the parameters of the questionnaire. The DLMO and thus the personalised start time can then be calculated as the next step. To suggest additional personalised settings and provide comprehensive chronotype advice, the system also calculates how long it will take for the user to reach their goal based on the parameters asked about the socially determined wake-up times and the desired wake-up time. In addition, it is checked whether it makes sense to start the adjustment at the time of the holiday and how many days this process requires. To successfully enable circadian phase-advance, gradual adjustments are necessary.

The eye colour and subjective light sensitivity parameters are essential for calculating the personalised light intensity of the intelligent alarm clock. These are replaced by a factor and added to the maximum light intensity for dawn.

To enable comprehensive personalisation of the wake-up settings, changes to the user parameters and user feedback are taken into account and the algorithm updates the settings accordingly. This ensures continuous adaptation and optimisation according to the user's individual needs and changes over time.

The evaluation employing user tests, using the final prototype in combination with a light alarm clock provided, resulted in uniform feedback from all participants. They stated that they woke up more comfortably and noticed a general change in their waking behaviour. In particular, they emphasised the support of the personalisation function, which helped them to set the light intensity correctly. Users commented that they often lacked sufficient knowledge, particularly when it came to setting the light intensity correctly, and that the individual adjustment provided by the personalisation function was perceived as helpful.

Although almost all participants had to make adjustments to the light intensity, this was not a problem thanks to the daily feedback. However, it was noticeable that only users of the Lumie light alarm clock had to make adjustments. This points to the challenge that different light alarm clocks have different definitions of their light intensities, which can lead to incompatibilities in the configuration.

It was also noticed that users with darkened rooms in particular achieved better results and had more energy during the day. It can be stated that the algorithm offers helpful recommendations for setting the light alarm clock correctly, adjusting it through continuous feedback and thus contributing to an improved sense of well-being at the start of the day.

However, it should be noted that the algorithm's recommendations have certain prerequisites, including the need for a darkened room and the same daily bedtime rhythm. This can be particularly problematic at weekends, as going out for longer in the evening is an integral part of social life. However, maintaining a consistent routine is crucial, especially during the adjustment period, to create a circadian phase-advance. Furthermore, external factors such as the evening use of smartphones and other light-intensive screens can influence the algorithm's success, as they can cause a delay in falling asleep due to their extreme brightness. To summarise, the application and success of the algorithm described show clear success with users overall, but this success is also dependent on various circumstances.

The implemented algorithm forms a basis for future developments in the field of machine learning. The user data collected in the personalisation questionnaire, including individual characteristics such as chronotype, sensitivity to light and personal goals, can still be taken into account in machine learning and used on a larger scale. In addition, a series of calculations are carried out to generate personalised recommendations. These include the calculation of chronotype, DLMO (Dim Light Melatonin Onset) and the ideal start time for the dawn simulation. By taking into account these individual characteristics and updates, the algorithm adapts to changing conditions over time. The algorithm is designed to respond to user feedback. This enables continuous optimisation and adaptation of personalised recommendations. Machine learning can use this feedback to improve its models and make more accurate predictions for individual users. By taking into account individual biological differences such as chronotype and DLMO as well as self-configurable settings, better and more personalised results can be achieved. At the same time, this enables flexible adaptation to different environments and devices. In the future, this could be used in machine learning to better understand and adapt to individual differences and patterns. Because of these elements, the algorithm forms a solid foundation for machine learning by providing personalised recommendations in the area of circadian rhythm while addressing the individual needs and characteristics of users.

CHAPTER 7

Conclusion and Future Work

In the course of this master's thesis, an app prototype was developed that supports users with personalised recommendations to individually adjust their intelligent lighting system. The applied methodology follows the user-centred design approach, which enables the active involvement of the user in the iteration processes and thus favours the development of a user-friendly and high-quality prototype. This involved in-depth research into the medical principles of chronobiology and light therapy as well as the creative aspects of UI/UX design.

Based on these research results, an initial concept was formulated, which was further developed and refined in successive iterations. Experts were involved in both interview and brainstorming sessions to ensure the quality of the scientific background of the algorithm and the questionnaire. At the same time, users were invited to evaluate mockups and the final prototype in usability and user tests. In total, the feedback from 16 participants was actively incorporated into the development process.

The initial design phase involved collecting and analysing all the ideas from the literature research and the first brainstorming session. These ideas were integrated into an initial low-fidelity prototype, whereby the first requirements were already defined. In the subsequent iterative development phase, a total of four iterations were carried out. The first iteration focussed on the parameters that were recorded in an initial user questionnaire to create the basis for the subsequent algorithm. The second iteration focussed on usability. Users were confronted with the revised low-fidelity prototype in the form of an interactive mockup and then asked about the content and usability of the app in a questionnaire. This made it possible to customise the prototype in a user-friendly way and to define further requirements. In the subsequent brainstorming session, the knowledge from the previous iterations was analysed and the focus was on developing a scientifically sound algorithm. An expert in the field of chronotherapy was involved to evaluate the input parameters and discuss the chronotherapeutic basis for the algorithm. Additional features to customise the algorithm, such as the ability to provide daily feedback, were developed. The high-fidelity prototype resulted from the learnings of the previous iterations and was tested in the final step by users in a real environment for five days with a light alarm clock. Half of the test subjects received a Zeitgeber and the other half a Lumie light alarm clock, so the recommendation could be tested on different light systems.

The implemented prototype and the results of the iterations within the user-centred design enabled the generation of valuable insights and the development of a recommendation that enables users to start the day more alert and fit. Nonetheless, numerous perspectives for future research have opened up.

Test period and number of participants: Conducting a further study with a considerable number of participants is considered sensible as embracing larger sample sizes would enhance the robustness and generalizability of findings. The prototype was tested on six participants as part of the master's thesis. It was noticed that the majority of the test subjects had an intermediate chronotype. Although the recommended personalisation has advantages for every chronotype, it shows the greatest added value, especially for late chronotypes who want to shift their circadian rhythm forward. A targeted, more comprehensive study focussing on late chronotypes would therefore be appropriate and should also be conducted over a longer period in order to enable a sound long-term evaluation. It would also be interesting to carry out a test in which users are first brought to the desired wake-up time by applying recommendations with a light alarm clock and then remove the light alarm clock for a amount of time, while still tracking feedback to check whether the circadian shift and ease of waking up remains after the application is discontinued or the original chronotype is restored.

API integration of light alarm clock: Another promising customisation option for the future is to connect the app directly to the light alarm clock via the corresponding API. Currently, recommendations are given that the user sets independently on their lamp. To further improve user-friendliness, a direct setting of the recommendations on the device would be a useful extension. It would be advisable to record all setting options of the respective light alarm clock directly and include them in the algorithm. As part of the user test, it was found that the Lumie light alarm clock has a gradual setting, but a comparatively low lux intensity as maximum brightness, which meant that the light setting often had to be readjusted by the user. It was also observed that light alarm clocks offer different options for the duration of the simulated sunrise. These parameters could also be integrated into the algorithm to improve the results by taking them directly from the settings of the respective light alarm clock.

Extension to include machine learning (ML): The current algorithm calculates a personalised setting based on the input parameters provided by the user in the questionnaire. The algorithm is then adapted through feedback and manual triggering of new recommendations. This procedure represents an optimal starting point for the integration of machine learning. Further development of the algorithm through the use of machine learning offers the opportunity to improve the effectiveness of the personalised recommendations over time.

One possible approach could be that the system learns how individual adjustments affect actual sleep behaviour and continuously adapts its recommendations. By integrating personal parameters such as eye colour and age into the machine learning process, more precise results can be achieved as individual differences and patterns can be better understood and adapted.
The algorithm developed is designed to respond to user feedback. This enables continuous optimisation and adaptation of personalised recommendations. Machine learning can use this feedback to improve its models and make more accurate predictions for individual users. The integration of these elements thus forms a robust foundation for machine learning in the field of sleep management. Not only are personalised recommendations provided, but the specific needs and characteristics of the user are also taken into account. This integration of machine learning enables an adaptive and highly personalised approach that continuously responds and evolves to individual sleep habits.

The prototype developed as part of this master's thesis manifests itself as an innovative solution that helps to make waking up in the morning easier for all individuals and enables a more restful wake-up phase. In addition, the prototype opens up possibilities to support people with a circadian misalignment by helping them regulate their circadian rhythm. This specific feature not only helps to improve general well-being but can also have a significant impact on users' health by enabling positive adjustments in line with natural biological rhythms.

The application developed not only offers immediate benefits for users but also provides a robust basis for further research, innovative developments and scientific studies. The results and findings of this master's thesis therefore not only represent progress in the field of circadian rhythm management but also offer the potential for further scientific investigations and the continuous optimisation of the developed prototypes as part of future research efforts.

List of Figures

List of Tables

Bibliography

[1] D. Fischer, C. Vetter, and T. Roenneberg, "A novel method to visualise and quantify circadian misalignment," *Scientific reports*, vol. 6, no. 1, p. 38601, 2016.

[2] K. G. Baron and K. J. Reid, "Circadian misalignment and health," *International review of psychiatry*, vol. 26, no. 2, pp. 139–154, 2014.

[3] E. R. Stothard, A. W. McHill, C. M. Depner, B. R. Birks, T. M. Moehlman, H. K. Ritchie, J. R. Guzzetti, E. D. Chinoy, M. K. LeBourgeois, J. Axelsson *et al.*, "Circadian entrainment to the natural light-dark cycle across seasons and the weekend," *Current Biology*, vol. 27, no. 4, pp. 508–513, 2017.

[4] C. Blume, C. Garbazza, and M. Spitschan, "Effects of light on human circadian rhythms, sleep and mood," *Somnologie*, vol. 23, no. 3, pp. 147–156, 2019.

[5] V. Gabel, M. Maire, C. F. Reichert, S. L. Chellappa, C. Schmidt, V. Hommes, A. U. Viola, and C. Cajochen, "Effects of artificial dawn and morning blue light on daytime cognitive performance, well-being, cortisol and melatonin levels," *Chronobiology international*, vol. 30, no. 8, pp. 988–997, 2013.

[6] M. Terman and J. S. Terman, "Circadian rhythm phase advance with dawn simulation treatment for winter depression," *Journal of biological rhythms*, vol. 25, no. 4, pp. 297–301, 2010.

[7] F. Pitta, T. Troosters, V. Probst, M. Spruit, M. Decramer, and R. Gosselink, "Quantifying physical activity in daily life with questionnaires and motion sensors in copd," *European respiratory journal*, vol. 27, no. 5, pp. 1040–1055, 2006.

[8] C. Gopalsamy, S. Park, R. Rajamanickam, and S. Jayaraman, "The wearable motherboard™: The first generation of adaptive and responsive textile structures (arts) for medical applications," *Virtual Reality*, vol. 4, pp. 152–168, 1999.

[9] J. C. Augusto, H. Nakashima, and H. Aghajan, "Ambient intelligence and smart environments: A state of the art," *Handbook of ambient intelligence and smart environments*, pp. 3–31, 2010.

[10] J. Lloret, A. Canovas, S. Sendra, and L. Parra, “A smart communication architecture for ambient assisted living,” *IEEE Communications Magazine*, vol. 53, no. 1, pp. 26–33, 2015.

[11] C. Röcker, “Designing ambient assisted living applications: An overview over state-of-the-art implementation concepts,” in *International Conference on Modeling, Simulation and Control IPCSIT, Singapore*, vol. 10, 2011, pp. 167–172.

[12] L. Van Velsen, T. Van Der Geest, R. Klaassen, and M. Steehouder, “User-centered evaluation of adaptive and adaptable systems: a literature review,” *The knowledge engineering review*, vol. 23, no. 3, pp. 261–281, 2008.

[13] G. Adomavicius and A. Tuzhilin, “Toward the next generation of recommender systems: A survey of the state-of-the-art and possible extensions,” *IEEE transactions on knowledge and data engineering*, vol. 17, no. 6, pp. 734–749, 2005.

[14] L. Lü, M. Medo, C. H. Yeung, Y.-C. Zhang, Z.-K. Zhang, and T. Zhou, “Recommender systems,” *Physics reports*, vol. 519, no. 1, pp. 1–49, 2012.

[15] M. Gorgoglione, U. Panniello, and A. Tuzhilin, “Recommendation strategies in personalization applications,” *Information & Management*, vol. 56, no. 6, p. 103143, 2019.

[16] Z. Tu, Y. Li, P. Hui, L. Su, and D. Jin, “Personalized mobile app recommendation by learning user’s interest from social media,” *IEEE Transactions on Mobile Computing*, vol. 19, no. 11, pp. 2670–2683, 2019.

[17] M. Constantinides, J. Dowell, D. Johnson, and S. Malacria, “Exploring mobile news reading interactions for news app personalisation,” in *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services*, 2015, pp. 457–462.

[18] J. J. Gooley, “Treatment of circadian rhythm sleep disorders with light,” *Ann Acad Med Singapore*, vol. 37, no. 8, pp. 669–676, 2008.

[19] A. Wirz-Justice, F. Benedetti, and M. Terman, *Chronotherapeutics for Affective Disorders: A Clinician’s Manual for Light and Wake Therapy, 2nd.* Karger Medical and Scientific Publishers, 2013.

[20] S. Kumar, D. Dhiraj, C. Cibi, S. Sowmya, and S. Sabitha, “Smart alarm clock,” in *2018 3rd International Conference on Communication and Electronics Systems (ICCES).* IEEE, 2018, pp. 999–1001.

[21] S.-M. Kim and S.-J. Kim, “Psychometric properties of questionnaires for assessing chronotype,” *Chronobiology in Medicine*, vol. 2, no. 1, pp. 16–20, 2020.

[22] D. P. Cardinali, G. M. Brown, and S. R. Pandi-Perumal, “Chronotherapy,” *Handbook of Clinical Neurology*, vol. 179, pp. 357–370, 2021.

[23] G. D. Potter, D. J. Skene, J. Arendt, J. E. Cade, P. J. Grant, and L. J. Hardie, "Circadian rhythm and sleep disruption: causes, metabolic consequences, and countermeasures," *Endocrine reviews*, vol. 37, no. 6, pp. 584–608, 2016.

[24] J. Aschoff, "The phase-angle difference in circadian periodicity," *Circadian clocks*, pp. 262–276, 1965.

[25] A. Shahid, K. Wilkinson, S. Marcu, and C. M. Shapiro, "Morningness-eveningness questionnaire," *STOP, THAT and one hundred other sleep scales*, pp. 231–234, 2012.

[26] S. R. Pandi-Perumal, M. Smits, W. Spence, V. Srinivasan, D. P. Cardinali, A. D. Lowe, and L. Kayumov, "Dim light melatonin onset (dlmo): a tool for the analysis of circadian phase in human sleep and chronobiological disorders," *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, vol. 31, no. 1, pp. 1–11, 2007.

[27] J.-Y. Mao, K. Vredenburg, P. W. Smith, and T. Carey, "The state of user-centered design practice," *Communications of the ACM*, vol. 48, no. 3, pp. 105–109, 2005.

[28] R. G. Foster, "Sleep, circadian rhythms and health," *Interface Focus*, vol. 10, no. 3, p. 20190098, 2020.

[29] T. Roenneberg and M. Merrow, "The circadian clock and human health," *Current biology*, vol. 26, no. 10, pp. R432–R443, 2016.

[30] T. Roenneberg, T. Kantermann, M. Juda, C. Vetter, and K. V. Allebrandt, "Light and the human circadian clock," *Circadian clocks*, pp. 311–331, 2013.

[31] J. F. Duffy, R. E. Kronauer, and C. A. Czeisler, "Phase-shifting human circadian rhythms: influence of sleep timing, social contact and light exposure." *The Journal of physiology*, vol. 495, no. 1, pp. 289–297, 1996.

[32] J. F. Duffy and K. P. Wright Jr, "Entrainment of the human circadian system by light," *Journal of biological rhythms*, vol. 20, no. 4, pp. 326–338, 2005.

[33] V. K. Sharma and M. Chandrashekaran, "Zeitgebers (time cues) for biological clocks," *Current Science*, pp. 1136–1146, 2005.

[34] M. Andrade, A. A. Benedito-Silva, and L. Menna-Barreto, "Correlations between morningness-eveningness character, sleep habits and temperature rhythm in adolescents," *Braz J Med Biol Res*, vol. 25, no. 8, pp. 835–9, 1992.

[35] J. M. Vink, J. M. Vink, A. S. Groot, G. A. Kerkhof, and D. I. Boomsma, "Genetic analysis of morningness and eveningness," *Chronobiology international*, vol. 18, no. 5, pp. 809–822, 2001.

[36] M. Valladares, R. Ramírez-Tagle, M. A. Muñoz, and A. M. Obregón, "Individual differences in chronotypes associated with academic performance among chilean university students," *Chronobiology international*, vol. 35, no. 4, pp. 578–583, 2018.

[37] T. C. Erren and P. Lewis, "Chronotype and beyond: 17 building blocks to reconcile and explore internal time architecture," *Chronobiology International*, vol. 36, no. 3, pp. 299–303, 2019.

[38] T. Roenneberg, A. Wirz-Justice, and M. Merrow, "Life between clocks: daily temporal patterns of human chronotypes," *Journal of biological rhythms*, vol. 18, no. 1, pp. 80–90, 2003.

[39] D. A. Kalmbach, L. D. Schneider, J. Cheung, S. J. Bertrand, T. Kariharan, A. I. Pack, and P. R. Gehrman, "Genetic basis of chronotype in humans: insights from three landmark gwas," *Sleep*, vol. 40, no. 2, p. zsw048, 2017.

[40] T. Roenneberg, L. K. Pilz, G. Zerbini, and E. C. Winnebeck, "Chronotype and social jetlag: a (self-) critical review," *Biology*, vol. 8, no. 3, p. 54, 2019.

[41] B. J. Taylor and B. P. Hasler, "Chronotype and mental health: recent advances," *Current psychiatry reports*, vol. 20, pp. 1–10, 2018.

[42] A. Sharma, S. Tiwari, and M. Singaravel, "Circadian rhythm disruption: health consequences," *Biological rhythm research*, vol. 47, no. 2, pp. 191–213, 2016.

[43] H. P. Van Dongen, G. Maislin, J. M. Mullington, and D. F. Dinges, "The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation," *Sleep*, vol. 26, no. 2, pp. 117–126, 2003.

[44] J. Brainard, M. Gobel, B. Scott, M. Koeppen, and T. Eckle, "Health implications of disrupted circadian rhythms and the potential for daylight as therapy," *Anesthesiology*, vol. 122, no. 5, pp. 1170–1175, 2015.

[45] W. A. Hofstra and A. W. De Weerd, "How to assess circadian rhythm in humans: a review of literature," *Epilepsy & behavior*, vol. 13, no. 3, pp. 438–444, 2008.

[46] J. A. Horne and O. Ostberg, "A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms." *International journal of chronobiology*, vol. 4, no. 2, pp. 97–110, 1976.

[47] S. Folkard, T. H. Monk, and M. C. LOBUAN, "Towards a predictive test of adjustment to shift work," *Ergonomics*, vol. 22, no. 1, pp. 79–91, 1979.

[48] A. Shahid, K. Wilkinson, S. Marcu, and C. M. Shapiro, "Munich chronotype questionnaire (mctq)," *STOP, THAT and One Hundred Other Sleep Scales*, pp. 245–247, 2012.

[49] K. Abbott, "Influence of light exposure on the melanopsin driven pupil response and circadian rhythm," Ph.D. dissertation, 2018.

[50] E. R. Dodson and P. C. Zee, "Therapeutics for circadian rhythm sleep disorders," *Sleep medicine clinics*, vol. 5, no. 4, pp. 701–715, 2010.

[51] J. D. Gould and C. Lewis, "Designing for usability: key principles and what designers think," *Communications of the ACM*, vol. 28, no. 3, pp. 300–311, 1985.

[52] "Human-centred design for interactive systems," International Organization for Standardization, Geneva, CH, Standard, Mar. 2019.

[53] A. Holzinger, "Usability engineering methods for software developers," *Communications of the ACM*, vol. 48, no. 1, pp. 71–74, 2005.

[54] D. J. Mayhew, "The usability engineering lifecycle," in *CHI'99 Extended Abstracts on Human Factors in Computing Systems*, 1999, pp. 147–148.

[55] A. W. Kushniruk and V. L. Patel, "Cognitive and usability engineering methods for the evaluation of clinical information systems," *Journal of biomedical informatics*, vol. 37, no. 1, pp. 56–76, 2004.

[56] J. Nielsen, *Usability engineering.* Morgan Kaufmann, 1994.

[57] N. A. Maiden and G. Rugg, "Acre: selecting methods for requirements acquisition," *Software Engineering Journal*, vol. 11, no. 3, pp. 183–192, 1996.

[58] C. Wilson, *Brainstorming and beyond: a user-centered design method.* Newnes, 2013.

[59] J. Nielsen, "The usability engineering life cycle," *Computer*, vol. 25, no. 3, pp. 12–22, 1992.

[60] J. R. Lewis, "Usability testing," *Handbook of human factors and ergonomics*, pp. 1267–1312, 2012.

[61] C. Abras, D. Maloney-Krichmar, J. Preece *et al.*, "User-centered design," *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, vol. 37, no. 4, pp. 445–456, 2004.

[62] C. Lewis, *Using the" thinking-aloud" method in cognitive interface design.* IBM TJ Watson Research Center Yorktown Heights, NY, 1982.

[63] S. Baltes and P. Ralph, "Sampling in software engineering research: A critical review and guidelines," *Empirical Software Engineering*, vol. 27, no. 4, p. 94, 2022.

[64] S. Kujala and M. Kauppinen, "Identifying and selecting users for user-centered design," in *Proceedings of the third Nordic conference on Human-computer interaction*, 2004, pp. 297–303.

[65] R. Pucher, V. Seibert-Giller, and S. Duda, "Usability and user experience: Exam preparation for the certified professional for usability," 2020.

[66] L. I. Bilousova, L. E. Gryzun, and N. V. Zhytienova, "Fundamentals of ui/ux design as a component of the pre-service specialist's curriculum," 2021.

[67] Nadia Ahmadi, "Gestalt principles in ux design," June 2020. [Online]. Available: https://uxplanet.org/gestalt-principles-in-ux-design-2e0f423bfcb5

[68] T. Broens, A. Van Halteren, M. Van Sinderen, and K. Wac, "Towards an application framework for context-aware m-health applications," *International Journal of Internet Protocol Technology*, vol. 2, no. 2, pp. 109–116, 2007.

[69] T. McCurdie, S. Taneva, M. Casselman, M. Yeung, C. McDaniel, W. Ho, and J. Cafazzo, "mhealth consumer apps: the case for user-centered design," *Biomedical instrumentation & technology*, vol. 46, no. s2, pp. 49–56, 2012.

[70] C. Rupp, M. Simon, and F. Hocker, "Requirements engineering und management," *HMD Praxis der Wirtschaftsinformatik*, vol. 46, no. 3, pp. 94–103, 2009.

[71] C. Ebert, *Systematisches Requirements Engineering: Anforderungen ermitteln, dokumentieren, analysieren und verwalten*. dpunkt. verlag, 2019.

[72] ETSI, "ehealth; standardization use cases for ehealth," Europäisches Institut für Telekommunikationsnormen, Sophia Antipolis Cedex, FR, Standard ETSI TR 103 477 V1.3.1 (2023-01), 2023. [Online]. Available: https://www.etsi.org/deliver/etsi_tr/103400_103499/103477/01.02.01_60/tr_103477v010201p.pdf

[73] J. Doerr, D. Kerkow, D. Landmann, C. Graf, C. Denger, and A. Hoffmann, "Supporting requirements engineering for medical products: early consideration of user-perceived quality," in *Proceedings of the 30th international conference on Software engineering*, 2008, pp. 639–648.

[74] L. Nurgalieva, D. O'Callaghan, and G. Doherty, "Security and privacy of mhealth applications: a scoping review," *IEEE Access*, vol. 8, pp. 104 247–104 268, 2020.

[75] M. P. Craven, K. Selvarajah, R. Miles, H. Schnädelbach, A. Massey, K. Vedhara, N. Raine-Fenning, and J. Crowe, "User requirements for the development of smartphone self-reporting applications in healthcare," in *Human-Computer Interaction. Applications and Services: 15th International Conference, HCI International 2013, Las Vegas, NV, USA, July 21-26, 2013, Proceedings, Part II 15*. Springer, 2013, pp. 36–45.

[76] P. Mayring and T. Fenzl, "Qualitative inhaltsanalyse," in *Handbuch Methoden der empirischen Sozialforschung*. Springer, 2019, pp. 633–648.

[77] S. L. Chellappa, "Individual differences in light sensitivity affect sleep and circadian rhythms," *Sleep*, vol. 44, no. 2, p. zsaa214, 2021.

[78] J. F. Duffy, J. M. Zeitzer, and C. A. Czeisler, "Decreased sensitivity to phase-delaying effects of moderate intensity light in older subjects," *Neurobiology of aging*, vol. 28, no. 5, pp. 799–807, 2007.

[79] T. Bragina, S. Roslyakova, E. Zemlyanova, A. Laushkina, O. Gofman, D. Klimova, I. Filippov, A. Brusnitsyn, and O. Basov, "Impact of personalized lighting on the psychophysical state of a human," in *2021 Joint Conference-11th International Conference on Energy Efficiency in Domestic Appliances and Lighting & 17th International Symposium on the Science and Technology of Lighting (EEDAL/LS: 17)*. IEEE, 2022, pp. 1–6.

[80] R. Y. Moore MD, "Circadian rhythms: basic neurobiology and clinical applications," *Annual review of medicine*, vol. 48, no. 1, pp. 253–266, 1997.

[81] A. S. Prayag, M. Münch, D. Aeschbach, S. L. Chellappa, and C. Gronfier, "Light modulation of human clocks, wake, and sleep," *Clocks & sleep*, vol. 1, no. 1, pp. 193–208, 2019.

[82] D. W. Rimmer, D. B. Boivin, T. L. Shanahan, R. E. Kronauer, J. F. Duffy, and C. A. Czeisler, "Dynamic resetting of the human circadian pacemaker by intermittent bright light," *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, vol. 279, no. 5, pp. R1574–R1579, 2000.

[83] C. Nowozin, A. Wahnschaffe, A. Rodenbeck, J. de Zeeuw, S. Hadel, R. Kozakov, H. Schopp, M. Munch, and D. Kunz, "Applying melanopic lux to measure biological light effects on melatonin suppression and subjective sleepiness," *Current Alzheimer Research*, vol. 14, no. 10, pp. 1042–1052, 2017.

[84] C. Cajochen, J. M. Zeitzer, C. A. Czeisler, and D.-J. Dijk, "Dose-response relationship for light intensity and ocular and electroencephalographic correlates of human alertness," *Behavioural brain research*, vol. 115, no. 1, pp. 75–83, 2000.

[85] D. H. Avery, D. N. Eder, M. A. Bolte, C. J. Hellekson, D. L. Dunner, M. V. Vitiello, and P. N. Prinz, "Dawn simulation and bright light in the treatment of sad: a controlled study," *Biological psychiatry*, vol. 50, no. 3, pp. 205–216, 2001.

[86] J. M. Zeitzer, N. F. Ruby, R. A. Fisicaro, and H. C. Heller, "Response of the human circadian system to millisecond flashes of light," *PloS one*, vol. 6, no. 7, p. e22078, 2011.

[87] N. U. Bhaskar, P. P. Naidu, S. Babu, and P. Govindarajulu, "General principles of user interface design and websites," *International Journal of Software Engineering (IJSE)*, vol. 2, no. 3, pp. 45–60, 2011.

[88] A. Blair-Early and M. Zender, "User interface design principles for interaction design," *Design Issues*, vol. 24, no. 3, pp. 85–107, 2008.

[89] J. R. Lewis and J. Sauro, "Usability and user experience: Design and evaluation," *Handbook of Human Factors and Ergonomics*, pp. 972–1015, 2021.

[90] J. Kramer, S. Noronha, and J. Vergo, "A user-centered design approach to personalization," *Communications of the ACM*, vol. 43, no. 8, pp. 44–48, 2000.

[91] A. Adan and H. Almirall, "Horne & östberg morningness-eveningness questionnaire: A reduced scale," 1991.

[92] Bundesministerium, "Thinking aloud verfahren," February 2021. [Online]. Available: https://www.wissensmanagement.gv.at/Thinking_aloud_Verfahren

[93] R. Malan, D. Bredemeyer *et al.*, "Functional requirements and use cases," *Bredemeyer Consulting*, 2001.

[94] I. Jacobson and A. Cockburn, "Use cases are essential: Use cases provide a proven method to capture and explain the requirements of a system in a concise and easily understood format." *Queue*, vol. 21, no. 5, pp. 66–86, 2023.

[95] Brocoders, "Functional vs. non-functional requirements: The full guide, definitions technical examples," 2022. [Online]. Available: https://medium.com/brocoders-team/functional-vs-non-functional-requirements-the-full-guide-definitions-technical-examples-a830b0092

[96] A. M. Reiter, C. Sargent, and G. D. Roach, "Concordance of chronotype categorisations based on dim light melatonin onset, the morningness-eveningness questionnaire, and the munich chronotype questionnaire," *Clocks & sleep*, vol. 3, no. 2, pp. 342–350, 2021.

[97] Ankit Tiwari, "Riverpod: The future of state management in flutter," June 2023. [Online]. Available: https://medium.com/@im_AnkitTiwari/riverpod-the-future-of-state-management-in-flutter-98e43003a930

[98] L. Thorn, F. Hucklebridge, A. Esgate, P. Evans, and A. Clow, "The effect of dawn simulation on the cortisol response to awakening in healthy participants," *Psychoneuroendocrinology*, vol. 29, no. 7, pp. 925–930, 2004.

[99] D. F. Kripke, J. A. Elliott, S. D. Youngstedt, and K. M. Rex, "Circadian phase response curves to light in older and young women and men," *Journal of Circadian Rhythms*, vol. 5, no. 1, pp. 1–13, 2007.

[100] T. Kantermann, H. Sung, and H. J. Burgess, "Comparing the morningness-eveningness questionnaire and munich chronotype questionnaire to the dim light melatonin onset," *Journal of biological rhythms*, vol. 30, no. 5, pp. 449–453, 2015.

[101] D. J. Kennaway, "The dim light melatonin onset across ages, methodologies, and sex and its relationship with morningness/eveningness," *Sleep*, vol. 46, no. 5, p. zsad033, 2023.

[102] V. Natale, M. J. Esposito, M. Martoni, and M. Fabbri, “Validity of the reduced version of the morningness-eveningness questionnaire,” *Sleep and biological rhythms*, vol. 4, pp. 72–74, 2006.

[103] C. Randler, “German version of the reduced morningness–eveningness questionnaire (rmeq),” *Biological Rhythm Research*, vol. 44, no. 5, pp. 730–736, 2013.

[104] M. Terman and J. S. Terman, “Light therapy,” *Principles and practice of sleep medicine*, vol. 4, pp. 1424–1442, 2005.

[105] J. S. Terman, M. Terman, E.-S. Lo, and T. B. Cooper, “Circadian time of morning light administration and therapeutic response in winter depression,” *Archives of general psychiatry*, vol. 58, no. 1, pp. 69–75, 2001.

[106] C. A. Czeisler, G. S. Richardson, R. M. Coleman, J. C. Zimmerman, M. C. Moore-Ede, W. C. Dement, and E. D. Weitzman, “Chronotherapy: resetting the circadian clocks of patients with delayed sleep phase insomnia,” *Sleep*, vol. 4, no. 1, pp. 1–21, 1981.

[107] D. M. Berson, F. A. Dunn, and M. Takao, “Phototransduction by retinal ganglion cells that set the circadian clock,” *Science*, vol. 295, no. 5557, pp. 1070–1073, 2002.

[108] S. Higuchi, Y. Motohashi, K. Ishibashi, and T. Maeda, “Influence of eye colors of caucasians and asians on suppression of melatonin secretion by light,” *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, vol. 292, no. 6, pp. R2352–R2356, 2007.

Appendix

A. Personas

Personas

Name	Angelika Meier
Age	35
Occupation	Manager
Motivation	She needs to get up early in the morning and be motivated and not tired the whole day
Bio	Angelika was always very busy at work and in life. Nevertheless, she tries to live a healthy well-balanced life and work out regularly.
Frustration	As she has to get up early in the morning she is always tired and her energy level is decreasing continuously. She has more difficulty standing up in the morning and needs to push the snooze button multiple times.
Chronotype	moderate morning type / moderate evening type
Lifestyle	long office hours, less time for hobbies and friends
Usage Pattern	Angelika wants to fight her morning tiredness, she is, therefore, willing to try a wake-up light system to get out of bed more easily.

Name	John Meier
Age	25
Occupation	Student
Motivation	John always goes to bed pretty late and doesn't get out of bed in the morning. Especially when he has a course in the morning it's very hard for him to get up and focus.
Bio	John studies medicine, he knows how important sleep and a regulated lifestyle are. Nevertheless, he does not manage to get to bed before 2 am.
Frustration	As he has to get up early in the morning and to focus during the lecture he is frustrated as it's hard to focus on a lecture when you are tired. He often comes too late, and cannot properly follow the professor.
Chronotype	evening type
Lifestyle	Long hours of studying, sports and also social meetings in the evening are part of his daily life.
Usage Pattern	John has heard that light in the morning can help him to get up more easily. He has a good understanding of technology but, no idea how to set his new light alarm clock to fit his needs.

Name	Barbara Pflanz
Age	30
Occupation	Teacher
Motivation	Barbara is a teacher and just finished her studies. To get to school on time she has to get up pretty early which is hard for her.
Bio	As Barbara just finished her studies, she has a hard time adapting to the early wake-up time. She needs to take the car to work and is worried, that she will get into a sudden sleep accident.
Frustration	Barbara bought herself a light alarm clock, based on a recommendation, to help her to get up and be more alert in the morning. Now she is frustrated because she does not know how to set the timing right, as she only has a minimal effect from the lamp.
Chronotype	moderate evening type
Lifestyle	Off to school pretty early, and after school sitting at her desk until evening.
Usage Pattern	Barbara already has a light alarm clock because of a recommendation, she just needs to find out which setting fits her, as until now she just has moderate results and still is not too alert in the morning.

B. IT-1 - Interview Transcript

Interview - Transcript

Note: Participant names have been anonymized.

Interviewer: Here comes my first question:

Questions 1 & 2: Can the MEQ be summarized and the scores handed down? If so, are there any questions that absolutely must be included?

Participant: Oh yes, actually there is already a shortened version of the MEQ that you can use. So, as the preference of the research perspective is always better to use a questionnaire that is validated. There have been questionnaires with a validated shortened MEQ, I think there is also one in German, but I am not sure. From the perspective of the app, much of the variance in the MEQ is on the last question. So if you just ask the last question you get most of the answers. So I would just give the last question and you get what you are looking for. The only thing about the last question is, and I could be mistaken, that there were 5 choices with 'neither' in the middle.

Interviewer: Actually, there were 4.

Participant: So you could not choose a neither.

Interviewer: Exactly. That was from the D-MEQ. But would you add the 5th choice?

Participant: Well, give me one second, I will give you the reference. So I can give you this. This is the questionnaire with the reduced scale. So I would either use this one or just ask the last question. This questionnaire is based on the original by Hörne-Östburg. I don't know how to pronounce it, it was probably wrong. But this reference is the reduced version of that.

Interviewer: Ok, thank you! So with your answer, you already answered the second question. So we will continue with the third one:

Question 3: Were there any ambiguities or follow-up questions to the MEQ questions?

Participant: No, we didn't have many problems with it. It is a pretty straightforward thing. I have to say many of the questions the ambiguity is that people are unsure when they are forced into a choice like 'oh I could be this or that', but if you are doing that it is typically that you are looking for the extremes, but people in extremes don't have this ambiguity. You are looking for extreme morning types and extreme evening types and most people are in the middle and that's where you get ambiguities, and that is ok because that just means that they float between a slight morning type to a slight evening type, but they are definitely not going from an extreme morning type to an extreme evening type. So short answer: yes, there is ambiguity in the sense that people often don't like these answers because it is not clear to them, but they still have to put them down so it usually doesn't matter too much.

Interviewer: Ok great, thanks! So to further recommend personalized setings I decided to also ask for some more personal parameters like age, biological gender, eye color, and subjective light sensitivity by night. So here my question would be:

Question 4: Does it make sense to measure age, biological gender, eye color, and subjective light sensitivity regarding sleep as parameters?

Participant: So for subjective light sensitivity definitely, that's clear. Age is also super important especially - I mean we don't know where the borders are - but if you are old - whatever that means - you are more sensitive to light and if you are young you are less sensitive to light. Well if you are very young you could sleep through bright sunlight without waking up. So age definitely matters. Biological sex, I mean we always ask stuff like that. I don't know if it matters, we haven't seen it but maybe, and it is just such an easy question to ask, that sure. Eye color: again there have been some reports, I don't know how I would change the app based on it, but it is worth collecting just in case you do find something. I mean you could also ask about skin pigmentation, but that's a very sensitive issue to ask about and given the low yield I probably wouldn't. But again it all makes sense because it is a quick question. You know, regarding the biological sex we don't know whether the menstrual phase matters.

Interviewer: Yes, that would be a very interesting point.

Participant: I mean we don't know if certain points during the menstrual phase can lead to a change or not. But I don't think you are going to get down that road.

Interviewer: No probably not. I just read your paper about sex differences in melatonin onset and there you found out that women have a later melatonin onset than men and also fall asleep later. So it could have an influence too.

Participant: Ah yes. So again it might, but we don't know. But it is easy to add in and when we studied women, so when I studied them it was always at the same time of the menstrual cycle, in the Menzies phase because that's the easiest trackable one. So we always had them come in in the first days of Menzies so could track them in the same phase. So we don't know.A

Interviewer: Ok, so that brings me to the follow-up question. I think you already answered some of it as you said age and subjective light sensitivity definitely matter. So:

Question 5: How much weighting regarding the influence on awakening would the parameters get?

Participant: I would definitely weigh the subjective light sensitivity highly and then the age. The other ones I don't know if I would include at this point. But that being said I would get feedback from test users I would totally use it in a machine learning model to see if you added things if they had... So basically to see if you can change the weighting function on these input parameters based on feedback. So that would kind of optimize the app in terms of automatically assigning amounts of light, but other than that, the other ones I wouldn't include first, because I don't even know what kind of starting weight to put there.

Interviewer: Ok. So for the next question

Question 6: How would you handle the intensity of the flashes for people with higher subjective light sensitivity?

Participant: And that brings me to the next question. Well, people that are very sensitive to light are not gonna like it.

Interviewer: Well, that's what I thought and also found out so far.

Participant: Yeah. So that's where when they are very sensitive, they are not gonna like it. So in older individuals, we found that the sunrise, not flashes but the sunrise, and that was when we were using a Philips lamp, messed up their sleep. So they were woken up early. As soon as the lamp went on they woke up. So it was not like a gradual awakening like 'oh I woke up and now I am happy', no it just messed up their sleep. So the question is, what is the light intensity you are going to use for flashes when you see it from the pillow level?

Interviewer: So right now we are using about 250 lux because if you take factor 10 away from it because of the closed eyes we get around the 50% you found out in dose-response. But we found out that many people wake up from this, especially during the first couple of nights. So I didn't really find a lot of data about when you provide them with 1 lux flashes how would such people respond to that?

Participant: So one thing is, you would have to dim, but if you drop it to 100 lux maybe. We just finished a lab study where we were given this, but at the beginning of the night, which is a big difference because you are under a lot of sleep pressure and there we had 1 person wake up out of 10.

Interviewer: At night 1?

Participant: Yes.

Interviewer: That's pretty good! That were people from age 13 to 35?

Participant: Yeah. And then at the younger, we have much lower rates of awakening, but they are very sleep-deprived. So again, yeah the higher light sensitivity I don't know if it's gonna be effective or useful to them because they gonna be disrupted from it no matter what you use what they perceive it is gonna be a problem.

Interviewer: You mentioned that even people who woke up the first night got used to it after a while.

Participant: Yes, but those weren't people with light sensitivity. Those were just regular people, that couldn't be distracted. But again people with high light sensitivity they gonna be very sensitive.

Interviewer: Do you see a correlation between very light-sensitive people and chronotype?

Participant: We don't have it but that's because we don't study them. So if you are very sensitive to light you will not gonna take part in a study. So we don't know.

Interviewer: Thank you. Ok, so for the other influential factors that might affect light sensitivity I have done some research and

Question 7: Additional influential factors for light sleep or light sensitivity I encountered are:
- Alcohol
- Work, e.g. shift work...
- Medication, e.g., melatonin or anti-depressants...
- Diseases, e.g., eye disease, depression...
- Sleep disorders
- Sleeping position or a sleep mask

Participant: Well yeah, I mean definitely a sleep mask, there it is the whole point is to block out light. That would definitely be a contraindication. The sleeping position would be important. Medication is very complicated. There are medications that increase light sensitivity but that's gonna be... First, we don't know if they increase circadian light sensitivity, but usually, when we have people on this kind of medication we don't include them in studies, because, again, they make things complicated.

Shift work .. yeah shift work is complicated because their sleep might be disrupted depending on it, and it's the same thing with jet lag because the circadian phase they are sleeping in might be abnormal.

Alcohol .. Yeah, these are all great questions, they are all very complicated. Contraindication of application I think really you got if you wear a sleep mask or so, I would say this is not for you. You know, or especially if you wear a sleep mask to prevent light from coming in because you are sensitive, you know that's the double wearing. So I think that one is definitely a contraindication. For the other ones, I don't think they are contraindications: I mean they could totally influence it, but I think that influence is going to be too complex to predict. So for example, if you look at alcohol, yes, if you drink alcohol it usually makes it easier to fall asleep but then the dehydration which is associated with the alcohol often wakes you up during the night and then increases the need to use the toilet, you know. Or you might have drunk quite enough and then you sleep through nothing, so it's complicated.

The same thing with shift work, you might have worked a shift and now you are super tired and you can sleep through anything. Or might have just worked shifts and now you are in a drunk circadian phase and you gonna wake up at 3 o'clock in the morning.

So these are all correct, they are just very difficult to account for. You know. Eye diseases: again I don't know anyone that would be a contraindication, definitely not. I mean a standard kind of ocular optometric disease. If you are looking at it - the most common would be cataracts or glaucoma. I don't think these would really have a big impact on this particular... A cataract might. A cataract would be probably bad, you would wanna increase the intensity, but you know. I guess the question is what are you looking at - 18 to 100 years old in terms of the target population or is it more specific?

Interviewer: So the goal is to help everybody, so yes the age goes from younger to old people. But older people are definitely more difficult and probably require more of a phase-delay.

Participant: Yeah, it's definitely complicated. This is good. Yeah because basically, yeah you would want these to say should we increase or decrease our light? You know if someone has cataracts, gonna be the most common. You can have other people with different sorts of blindness but it's gonna be much rarer, but cataract or not, you know in an older population. There might be a way of basically asking if there is anything that might be able to ask a question that is one of these general questions: Is there anything that is preventing from, you know, light getting into your eyes, for example, cataract, glaucoma or other eye diseases. And if they say yes, increase the intensity, if they say no don't do anything. Again you can give a consumer 100 questions in the questionnaire but that is obviously not helpful. Well, it would be very helpful, but not visible. So try to just think of the most likely kind of things that can influence this. And definitely, the sleep mask and the sleeping position would influence it. So that's going to be a high yield. Sleep disorders again would be interesting but that's gonna be a complicated answer. So basically what would you do with that answer that's complicated again with sleep disorders it would be a much more involved setup of questions to really get something that can be automated. Eye disease I think you can put in a question. Depression is also complicated as are other psychiatric diseases. Yeah Medication I don't think will be that important, I mean even if you are taking a sleep med I don't think that would be that important. And then again the work and alcohol would be too complicated I think. Does that kind of make sense?

Interviewer: Yes, totally! Thank, you that helped a lot. So then we can go on to the last question:

Question 8: To what extent can an existing light, for example by not darkening the bedroom sufficiently at night, change the subjective light sensitivity?

Participant: Yeah, it should have an effect. We haven't tested it yet but there is a strong theory that if you are sleeping with your lights on you gonna need more light because your rods and cones not gonna be sensitized.

Interviewer: Ok, so we should probably include that also in the questionnaire.

Participant: Yeah.

Interviewer: So that was the last question. Thank you so much for this interview and for sharing your insights!

C. IT-2 - Questionnaire Usability Test

Usability Test

Vor dem Test:

1. Wie motiviert bist du, einen smarten Lichtwecker zu kaufen?
   - ☐ 0 - Gar nicht motiviert
   - ☐ 1
   - ☐ 2
   - ☐ 3 - Sehr motiviert

2. Was erwartest du dir von der App? Welche Informationen sollen vermittelt werden?

3. Wie schätzst du deinen Umgang mit Technik ein?
   - ☐ 0 - Sehr schlecht
   - ☐ 1 - Schlecht
   - ☐ 2 - Durchschnittlich
   - ☐ 3 - Gut
   - ☐ 4 - Sehr gut

4. Hast du schon etwas vom zirkadianen Rhythmus gehört?
   - ☐ Ja
   - ☐ Nein

Nach dem Test:

5. Waren die Fragen des Fragebogen verständlich?
   - ☐ 0 - Sehr verständlich
   - ☐ 1
   - ☐ 2
   - ☐ 3 - Gar nicht verständlich

6. Waren es zu viele Fragen / der Fragebogen zu lange?
   - ☐ 0 - Ja, es waren zu viele Fragen
   - ☐ 1
   - ☐ 2 - Nein, es hätten mehr sein können

7. Verstehen Sie, warum dir diese Fragen gestellt wurden?
- ☐ Ja
- ☐ Nein

8. Wie ansprechend empfindest du die Benutzeroberfläche (optisch)?
- ☐ 0 - Sehr ansprechend
- ☐ 1
- ☐ 2
- ☐ 3 -Gar nicht ansprechend

9. War die Benutzeroberfläche intuitiv und verständlich in der Navigation?
- ☐ 0 - Ja, ich habe mich ohne Probleme zurechtgefunden
- ☐ 1
- ☐ 2 - Nein, ich habe mich schwergetan

10. Falls du in der Navigation auf Probleme gestoßen sind, was war das Problem?

11. Was würde dir helfen, dich noch besser in der App zurecht zufinden?

12. Hast du bemerkt, dass es eine Möglichkeit gibt, den Informationsteil zu überspringen / nicht zu überspringen? Warum hast du dich für die jeweilige Option entschieden?

13. Bevorzugt du Video, Text oder Text mit Animation als Informationsquelle?
- ☐ Video
- ☐ Text
- ☐ Text mit Animation

14. Was ist ein zirkadianer Rhythmus?

15. Von welchen Faktoren wird der zirkadiane Rhythmus beeinflusst?

16. Wie motiviert bist du, einen smarten Lichtwecker zu kaufen?
- ☐ 0 - Gar nicht motiviert
- ☐ 1
- ☐ 2
- ☐ 3 - Sehr motiviert

Offene Kritik:
- (Freiraum für offene Kommentare oder Kritik)

D. IT-4 - Questionnaire User Test

User Test: Fragebogen

1. Wie stark ist dein Zimmer abgedunkelt?
   - ☐ 0 - Gar nicht abgedunkelt
   - ☐ 1
   - ☐ 2
   - ☐ 3
   - ☐ 4 - Komplett abgedunkelt

2. Hast du dich gut in der App zurechtgefunden?
   - ☐ Ja
   - ☐ Nein

3. Hat sich dein Aufwachverhalten verändert, seit du die App verwendest? Wenn ja, inwiefern?
   - ☐ Ja (bitte erläutere kurz)
   - ☐ Nein

4. Hattest du das Gefühl, ausgeschlafener aufzuwachen?
   - ☐ Ja
   - ☐ Nein

5. Musstest du die Lichtintensität niedriger einstellen, da du durch die Helligkeit vorzeitig erwacht bist?
   - ☐ Ja
   - ☐ Nein

6. Wie wahrscheinlich ist es, dass du einen smarten Lichtwecker kaufen und personalisiert einstellen wirst?
   - ☐ 1 - Sehr wahrscheinlich
   - ☐ 2
   - ☐ 3
   - ☐ 4
   - ☐ 5 - Überhaupt nicht wahrscheinlich

7. Hast du den Eindruck, die Personalisierung hat dir geholfen, die richtigen Einstellungen zu treffen? Wenn ja, inwiefern?
   - ☐ Ja (bitte erläutere kurz)
   - ☐ Nein

8. Hast du das Gefühl, die Einstellungen waren effektiv, und du konntest deinen zirkadianen Rhythmus in die gewünschte Richtung verschieben?

- ☐ Ja
- ☐ Nein

Offene Kritik:

- (Freiraum für offene Kommentare oder Kritik)