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Developing understandable and actionable sleep data visualizations

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Abstract

Good sleep quality is an important attribute to great physical and mental health. However, majority of research suggests that people do not follow the suggested sleep duration and consequently suffer from chronic sleep disorders. In order to help people understand their sleep and the reasons for bad sleep, sleep data visualizations have been developed, however the goal was to find how to develop them in an understandable and actionable way. The sleep data visualizations have been tested and after that put in an interactive interface prototype. The prototype has been tested with six participants. The prototype has been found to be easily understandable by the participants, as well as actionable.

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1 Introduction

1.1 BACKGROUND

Good sleep quality is a key part to a great physical and mental health, and overall wellbeing. However, the general population has not given enough attention to the importance of a good quality sleep as much as to other healthy behaviors, like nutrition or physical activity. The recommended duration of sleep for adults is 7-8 hours, however 40% of Americans are reported to sleep less than 7 hours a day [1]. Additionally, it is estimated that 50 to 70 million Americans suffer from chronic disorder of sleep and wakefulness [2]. Sleep deprivation and insufficient sleep leads to dangerous consequences many people may not be aware of. A few of the consequences include poor memorizing and changes in thinking which lead to wrong decision making. Sleep deficiency relates to weakened immune system and changes in hormonal secretion, as well as the risk of obesity, diabetes and cardiovascular diseases increase [3].

Most people nowadays have easy access to sleep-tracking technologies. Most smartphones support sleep-tracking applications, and many people also make use of fitness trackers. Ideally with the help of sleep-tracking, people are able to monitor their sleep quality and consequently make better choices towards getting a better night's sleep. However, sleep is a very complex behavior, which is influenced by many factors, and applications might not give sufficient support to make sense of the data, and not account for the personal and outside factors that may influence sleep quality. Research shows that current available technology of sleep tracking is very broad, however the focus mostly lies on monitoring. A study done by Liang & Ploderer [4] suggests that individuals monitoring their sleep with tracking devices like *FitBit* or *Apple Watch* reported increased awareness of sleep habits, however none of them improved their sleep quality. The study participants faced three challenges in improving their sleep: not knowing what normal sleep should be, not knowing the reasons for lack of sleep and not knowing how to act.

1.2 GOAL AND RESEARCH QUESTIONS

The aim of this research is to investigate ways to present the sleep-tracked data in a way that is educational to the user, as well as the user is able to recognize the relationships

between multiple outside factors and sleep, consequently being able to take action into bettering their sleep quality.

The main research question and sub-questions are:

- How to present sleep monitored information in a way that is understandable and actionable?
  - What kind of sleep data should be collected and presented?
  - What other data can be combined with sleep data?
  - What is the current state of the art of sleep tracking visualizations?

2 State of The Art

2.1 BACKGROUND RESEARCH ON SLEEP

The science behind sleep

Sleep is highly important for overall health, therefore it is important for people to get high quality sleep. Highly important aspect of sleep is the circadian rhythm, which is an internal 24-hour clock within the brain. It controls all aspects of the body, including the time a person wants to go to sleep or wake up. Sunlight and darkness heavily influence the circadian rhythm. Daylight keeps individuals awake and alert, and darkness does the opposite. Despite that every human being has this 24-hour pattern, the actual alertness and awakeness depends on an individual. People who have peak wakefulness early in the day and get sleepy early at night are 'morning people', and consist of around 40% of the population. The opposite, 'evening people', who wake up late and go to sleep late, make up approximately 30% of the population. The other 30% fall in between these two types. A chronotype (individual's circadian typology) depends on genetics [5].

Along the 24 circadian rhythm, there is another factor determining wake and sleep, which is sleep pressure. A chemical adenosine keeps increasing in concentration every waking minute. The longer one is asleep, the more adenosine is accumulated. When adenosine concentrations peak, the urge to sleep becomes irresistible, which happens after 12-16 hours of being awake for most people.

The Sleep Cycle

During the night, the brain goes through different patterns of activity, which includes a cycle of NREM (Non-REM sleep) and REM (Rapid Eye Movement) cycle. Each cycle lasts 90 minutes.

Stage 1: Within minutes of falling asleep, the brain produces alpha and theta waves, as well as the eye movements slow down. A person in this stage is in light sleep, somewhat alert and easily awakened.

Stage 2: Fairly light sleep, increase in brain wave frequency, which then slows down. This is the best time to wake up during a power nap.

Stage 3 and 4: The stages of deep sleep, the brain produces slower delta waves. This is the most difficult time to wake up. Body repairs muscles, tissues, and stimulates growth and development.

REM sleep: Most dreaming occurs during this stage, eyes move in different directions. REM sleep helps with learning and memory function. The brain processes information from the day before to be stored in the long-term memory. [6]

The ratio of REM and NREM sleep during the night changes. First half of the night the sleep is mostly NREM sleep, with little REM sleep. In the second half of the night, REM sleep is longer than NREM sleep [5].

How much sleep is enough?

According to National Sleep Foundation [7],good sleep quality indicators at most ages are: shorter sleep latencies (time it takes to transition from wake to sleep), fewer awakenings, and reduced wake after sleep onset (time spent awake after sleep has been initiated and before final awakening). Higher sleep efficiency (ratio of total sleep time to time in bed) similarly leads to higher sleep quality, and lower sleep efficiency leads to poor sleep. Furthermore, less naps throughout the day lead to better sleep quality, while more naps lead to the opposite. The recommended sleep time for younger adults (18-25 years old) and adults (26-64 years old) is 7-9 hours, while teenagers (14-17 years old) are recommended to sleep 8-10 hours.

A rule of thumb proposed by Walker [5] is to answer the following two questions.

After waking up in the morning, could you fall back asleep at ten or eleven a.m.?

If the answer is 'yes', most likely the person is not getting enough sleep quantity or quality.

Can you function properly without caffeine before noon?

If the answer is 'no', then the person is most likely in a state of chronic sleep deprivation.

Factors influencing sleep

Sleep is multidimensional and is influenced by multiple contextual factors [8]. As mentioned previously, melatonin is released in the body with the lack of light. With the development of electric light, the natural order of sleep has been disrupted. Electric light might forward the internal body clock by 2 or 3 hours on average, meaning that the use of even a bedside lamp can disrupt the circadian rhythm. A hint of dim light (8-10 lux) is reported to delay melatonin release. More severe effects come from blue light-emitting LEDs, which has twice the harmful impact on nighttime melatonin suppression. Blue light comes from TV's, laptop screens, smartphones, which are devices that most people use close before bedtime. Use of these devices not only makes falling asleep more difficult, it also influences the amount of REM sleep, feeling of restfulness, and having a lag of release of melatonin the next day. Solution for this problem is to create dim light in rooms where the evening is spent. Additionally, use devices that support 'night mode', which uses more yellow tones on the display, rather than blue [5].

Another huge factor that influences sleep is alcohol. Alcohol sedates a person, however it does not induce natural sleep. The electrical brainwaves during the alcohol induced sleep is similar to light form of anesthesia. This kind of sleep is not restorative, as well as blocks the brain's ability to generate REM sleep.

Caffeine is the most widely consumed psychostimulant in the world [9]. Caffeine latches onto adenosine receptors, which masks the feeling of sleepiness. Simply put, caffeine tricks the body into feeling alert and awake. Caffeine levels in the body peak around 30 minutes after consumption. However, caffeine has an average half-life of 5-7 hours, meaning that if caffeine is consumed close before bedtime, the brain will continue battling against caffeine during the night's sleep. With caffeine being in the body, it does not stop the production of adenosine, which continues to build up. Once the liver is done removing caffeine from the system, and adenosine has built up from before, a phenomenon called 'caffeine crash' happens, when the effects of all the built-up adenosine appear.

According to the Sleep Foundation [10], exercise promotes a good quality sleep and alertness during the day. The sleep quality is impacted by the rise of the body temperature during the exercise. Later in the day, when the body temperature drops back to normal, it triggers drowsiness and the need to go to sleep. The National Institutes of Health [11] recommend around 150 minutes of exercise a week - that is 30 minutes day, 5 times a week,

however it is not recommended to work out a few hours before sleep. According to Gemaldo, M.D., medical director of John Hopkins Center for Sleep, moderate aerobic exercise increases the amount of deep sleep that the person gets [12].

There are many other factors influencing sleep, which are listed in Table 1. To add, Liu et.al [13] discovered that sleep-tracking applications fail to connect contextual factors with sleep data, therefore users cannot find out what outside factors are influencing their sleep. It is worth mentioning that even though users are notified that their sleep is bad, the data is of no use to them, because they do not know what factors influence the bad sleep. This suggests that great visualizations should include contextual factors.

Coffee	Alcohol	Hormone cycle
Mood	Stress	Ambient Temperature
Tiredness	Digital devices	Ambient Humidity
Light	Nap	Exercise Time
Societal Activities	Body temperature	Dinner time

Table 1: Potential sleep impacting factors. [7]

2.2 STATE OF THE ART ON SLEEP-TRACKING

The gold standard of measuring sleep in clinical conditions is polysomnography, which includes various physical measurements all night, e.g. eye movements, muscle and brain activity and multiple others. Another simpler approach is Actigraphy, however both of these approaches are not suitable for daily use because of the expensive equipment and additionally they require medical professionals [13]. Nowadays there are various sleep-tracking devices available for the consumer market. According to Kelly et al. [14], there are five major categories of sleep tracking devices that each use different ways of measuring sleep. Sleep monitoring based on brain activity signals uses electroencephalogram (EEG) on a headgear. This technology is used in products such as *iBrain* and *Zeo.* Sleep monitoring based on autonomic signals measure signals like respiratory and cardiac physiology. *Heally Recording System* and *M1 (SleepImage)* incorporate this type of sleep tracking. Sleep-monitoring devices based on movement are the most user-friendly and seem to be the most accessible for individuals. It is

possible to measure sleep through a mobile application, such as *Sleep Cycle Alarm*, which uses the built-in accelerometer of the iPhone for movement monitoring. A different way is through a wearable, like a wrist watch. Well-known devices of this category include *FitBit* and *Apple Watch.* Bed-based sleep monitors are devices that are put on or under the mattress, either using a pressure sensor or piezoelectric sensor. Both record multiple metrics, like heart rate, snoring, respiration rate and others. Other potential sleep-monitoring devices outside these categories include wearables like shirts or vests [14].

Newer innovations in sleep-tracking include smart rings, such as *Oura Ring.* It is claimed to be the most accurate sleep-tracker, providing sleep efficiency, sleep stages and other things. It tracks heart rate, body temperature, and is synced to a smartphone [15].

2.2.1 At-Home Sleep-Tracking Technology

Individuals wanting to track their sleep can easily achieve that with their smartphones or a fitness tracker device like *FitBit.* Each device is different and may differ in measurements of sleep. With smartphones, it is possible to track body movement and sound. With fitness devices it is possible to track more data, like heart rate and pulse oximetry. Following list mentions some of the currently available devices to track sleep with:

- FitBit (wrist watch)
- Apple Watch (wrist watch)
- Garmin (wrist watch)
- BeautyRest (under mattress device)
- Emfit QS (under mattress device)
- Oura Ring (smart ring)
- Any smartphone

2.2.2 Sleep-Tracking Data Visualizations

Sleep-tracking applications use raw collected data, which later is processed for use in the visualizations. An example of raw collected data could be heart rate, accelerometry, and it is then processed to visualize the sleep stages. Table 2 shows various devices or applications and their data and visualizations.

Device / Application	Raw data collected	Processed Data	Visualizations
Fitbit	-Heart rate -Accelerometry -Sleep duration -Time fallen asleep/time woken up	-Sleep stages -Duration of sleep, -time woken up and fallen asleep	-Sleep stages (percentages and duration of each sleep stage) -Sleep Score - Seven-day average, showing duration of sleep each day
Garmin	-Accelerometry -Pulse oximetry -Heart rate -Time fallen asleep/time woken up -Sleep duration	-Sleep stages -Movement	-Seven-day averages of sleep duration (also time went to bed/woken up) -Sleep stages and duration of each sleep stage -Levels of movement during the night
Sleep Cycle Alarm Clock (iOS)	-Time fallen asleep/time woken up -Accelerometry -Sleep duration -Sound -Geographical location -moon phase -weather -Heart rate -Steps	-Sleep stages -Regularity -Snoring -Time taken to fall asleep -Sleep quality -Affected by location -Affected by the moon -affected by weather	-Sleep stages throughout the night -Statistics throughout the week for: ● Sleep quality ● Regularity ● Went to bed ● Woke up ● Time in bed etc.
Sleep++ (iOS)	-Accelerometry -Heart rate -Time fallen asleep/time woken up -Sleep duration	-Restful sleep(min) -Restless (min) -Awake(min) -Best sleep (what time)	-A bar showing two colors. One shows what time there was good sleep, the other shows restless sleep.
Sleep Watch by BodyMatter	-Accelerometry -Heart rate -Time fallen asleep/time woken up -Sleep duration	-Sleep pattern (light/disrupted sleep or restful) -Sleep score -Regularity of sleep	-Sleep trends (monthly, weekly) -Sleep pattern throughout the night
Pillow	-Accelerometry -Heart rate -Time fallen asleep/time woken up -Sleep duration -Sound	-Sleep stages and heart rate during the stages -Time in bed -Time Asleep -Sleep quality	-Sleep stages and heart rate during the stages

Table 2: Sleep-tracking devices or applications and their data

Each of the applications have different ways of visualizing the same data. Table 3 shows the various visualizations for sleep duration and sleep stages throughout different sleep tracking applications.

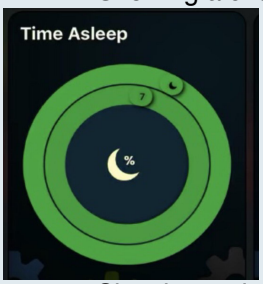
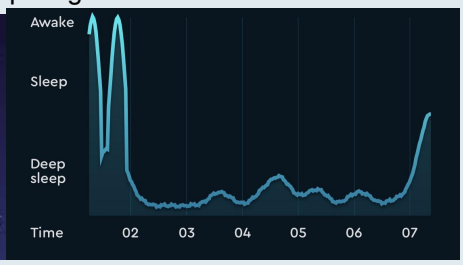
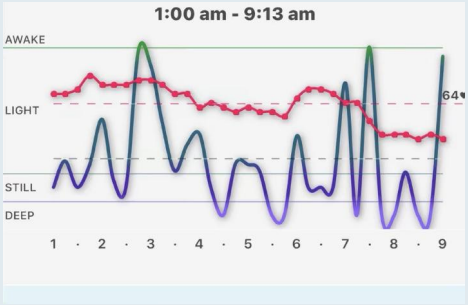
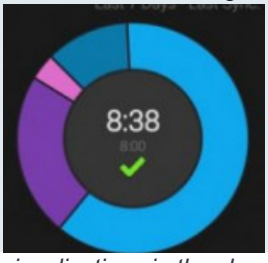
Processed Data	Visualization types
Sleep duration	- Showing a circle (if the goal is reached, it is full, otherwise it is not)  - Showing a circle with sleep stages dividing the circle  - Only showing the duration with numbers
Sleep stages	_ Graph with time on X axis and sleep stage on Y axis   -Additionally, heart rate added  -As a circle, dividing it into the duration of sleep stages 

Table 3: Different types of visualizations in the sleep-tracking applications

2.3 CONCLUSION

The research on the state-of-the-art leads to new insights that will help with developing new sleep visualizations.

First, it is important to take into consideration that there are ‘morning people and ‘evening people’, which means that recommendations and normality of the sleep differ per person. Secondly, coffee is a huge part of most peoples’ lives, and it is a big factor in sleep disturbances. Since caffeine has a half-life, it means that it could be incorporated into visualizations. It can be used as a pop-up recommendation (e.g. ‘We’ve noticed you had sleep disturbances last night. Did you take any coffee past 3 PM?’ if yes, then give a suggestion not to drink coffee after certain time), or a whole visualization dedicated to caffeine use. To add, other factors could be used in a same way (exercise, device usage etc.).

Seeing that the first half of the night the sleep is mostly NREM sleep, with little REM sleep and in the second half of the night, REM sleep is longer than NREM sleep, means it can be used for visualizations. As Walker [5] noted, missing out on morning’s sleep will shorten the REM sleep, and missing out on the first few hours of sleep will shorten the NREM sleep. Analyzing the sleep cycles, such relationship can be seen, and a recommendation can be given to the user to improve their sleep, as well as improve the health literacy of people using the visualizations.

To know whether people are getting enough sleep, the rule of thumb proposed by Walker [5] can be used to assess the users. This can be incorporated in a way that the users are quizzer once in a while to see if they are reaching their best sleep.

After assessing the existing sleep-tracking applications, it shows that most of them have similar structure, and similar visualizations. Most of the applications show the data, however rarely they give more insights to improve the sleep of the users. The findings were similar to Liang & Ploderer [4], where the users are simply shown data, however they might not be able to take action into bettering the sleep. Majority of applications use the same data and processed data, therefore there is not a big variety between sleep-tracking visualizations, which means that these visualizations work well and should also be included in the following stages of design process. However, only one of the applications included contextual factors (*Sleep Cycle Alarm Clock*), but even those factors (moon phase, and weather) have very little to zero scientific research behind it.

From state-of the art analysis it can be concluded that current sleep-tracking applications lack visualizations on contextual factors, therefore in the next step (ideation phase) some of the contextual factors will be included in the visualizations (coffee, device usage, exercise) to make them actionable. Additionally, most visualizations seem to cater to people with the same health literacy or technology literacy level. Since one of the goals is to make visualizations understandable, in the ideation phase visualizations with different levels of difficulty will be made and then tested.

3 Methods and Techniques

3.1 THE CREATIVE TECHNOLOGY DESIGN PROCESS

A design method developed by Mader [16] was incorporated in the educational process of bachelor study Creative Technology that serves as a guideline for student projects. The design process consists of four phases: Ideation, Specification, Realization and Evaluation. These four phases are going to be used as a guide for the report. Figure 1 shows the four phases.

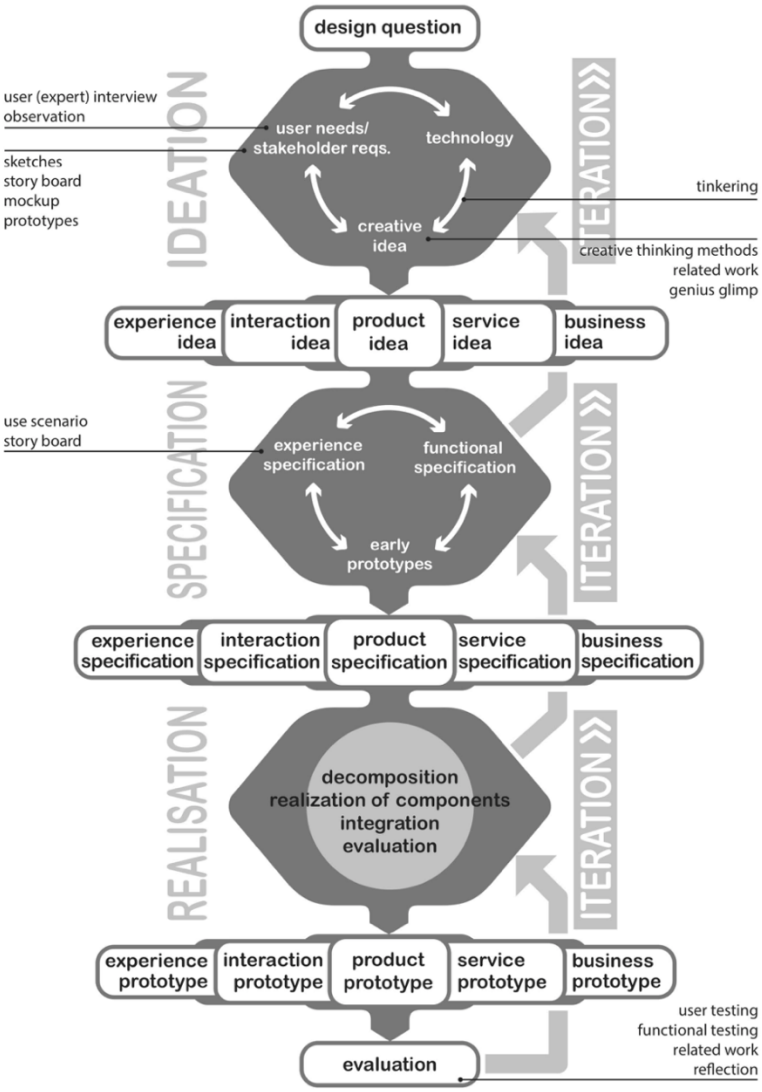


Figure 1: The Creative Technology Design Process diagram

Ideation

In the Ideation phase ideas are being developed and generated. Multiple techniques that help with idea generation are used like brainstorming, user scenarios, story boards and sketches. In this stage user needs and stakeholder requirements are specified. The result of this phase should be an elaborated project idea with problem requirements. Experience, interaction, business model and service are also included as a final result.

Specification

Specification phase introduces prototypes of the initial idea. This is an iterative process, prototypes are improved or discarded with the feedback of users. During this stage, prototype is used in a potential user scenario. Analysis methods like FICS (functions, interactions, contexts and services) may be used in this stage.

Realization

The ideas in this stage are realized in its final form, done by advanced prototyping. Evaluation part of this phase has to validate whether the product meets its specifications.

Evaluation

During this stage, user testing and functional testing of the product is done. With the usability tests it can be seen whether the original requirements of the product are met. Based on results, the product can be further improved.

The three phases follow a *Divergence* and *Convergence* approach. At the beginning of the phase, the design space is opened up and defined (divergence). At the end of the phase convergence is applied by reducing the design space in order to come to the final solution. Reductions are based on the requirements and available knowledge.

3.2 PACT AND USER SCENARIOS

PACT, which stands for ‘People, Action, Context and Technology’ is a framework developed by Benyon [17] that helps with the process of thinking about a design situation and is

used to analyze with whom, what and where a user interacts with a user interface. With the help of storytelling, users and their needs can be described, as well as their interaction with the technology. The 'People' part of this framework focuses on describing the users as personas, and as potential users of the product. In the user scenarios activities are done by the personas by using the product. The context provides the environment in which the activities are performed and the technology that is used to perform the activities. After doing PACT analysis, user scenarios are going to be created.

3.3 USER REQUIREMENTS

Before generating ideas, it is useful to know the requirements for the visualizations. The user requirements are based on FICS, which stands for "Functions and events, Interactions and usability issues, Content and structure, Style and aesthetics". Requirements are conventionally divided into two types: functional and non-functional. Functional requirements are what system must do and non-functional requirements are a quality that the system must have [17]. Additionally, MoSCoW (Must, Should, Could and Won't) analysis will be used in order to prioritize the requirements.

3.4 BRAINSTORMING

Brainstorming is an idea generating method, usually to solve a design problem. With brainstorming all ideas that come to mind are put on the table that also further can help develop other new ideas. Brainstorming can be done in groups or individually. There are various methods and approaches to brainstorming, however a few of them were used for this project: mind mapping and sketching. During brainstorm, many of the ideas will be diverged and then converged, as shown in Figure 2. Many of these ideas can be left out, and some of them

improved or combined with others, which together come to a final idea.

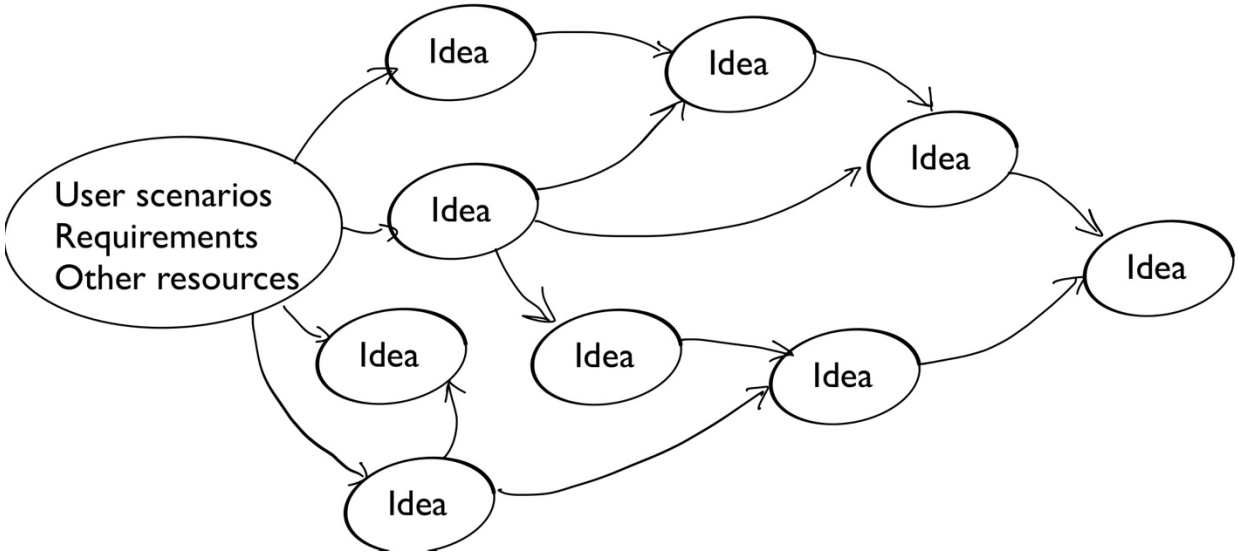


Figure 2: The brainstorming method

3.5 ITERATIONS OF THE VISUALIZATIONS

The visualizations will be developed in iterative steps with user testing carried along the steps. After each user test, the visualizations will be improved based upon the feedback of the users. First user test will be an online questionnaire, the second user test will be a usability test. After two of the user tests, the final version of the visualizations will be made. Figure 3 displays the process of the iterations.

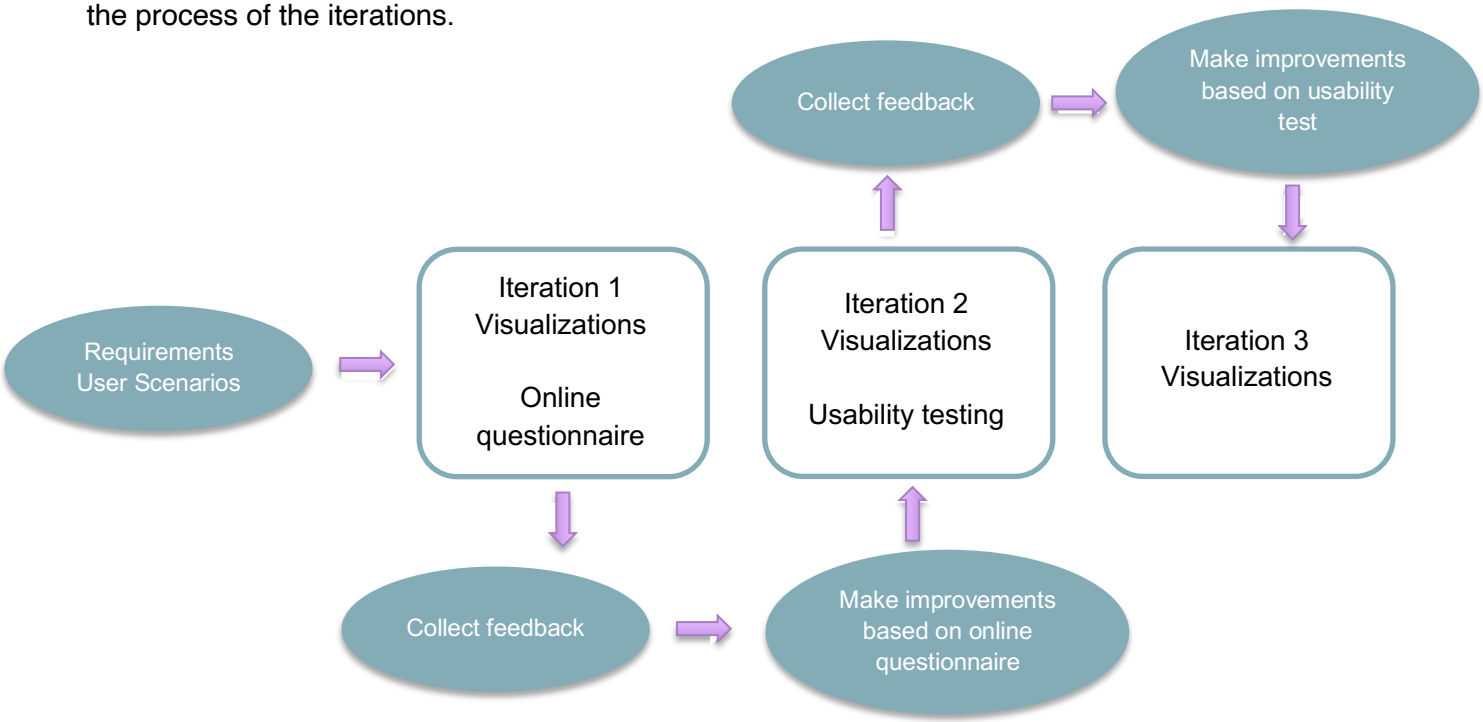


Figure 3: The Method of Iterative Design

3.6 QUESTIONNAIRE

The ideation phase is a great time to get user feedback and input, which can be done through a questionnaire. By getting the user's feedback at the beginning of developing a product, many unnecessary features might be found from the user perspective that might not be found by the designers. Additionally, user input might provide new solutions that were not thought of before. A set of questions will be given to the participants of the questionnaire. It can include both open-ended (require more thought than a one-word answer) and closed-ended questions (choosing between given answers).

3.7 USABILITY TESTING

For the second user test, a usability test will be conducted. Usability, in interaction design, is defined as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [17].

Usability tests are generally conducted by presenting the users with a prototype, while asking a participant to perform specific tasks with the given user interface. While the participant completes each task, the researcher observes the behavior of the participant and listens for feedback. The goal of usability testing is to identify flaws of the interface, usability problems and the user satisfaction of the product [19]. For this thesis, an interactive prototype of sleep-data visualizations in a mobile application will be tested in the usability testing.

There are three usability testing types [20]:

- Moderated vs. unmoderated
- Remote vs. in person
- Explorative vs. assessment vs. comparative

For this project a moderated, remote and assessment user testing will be done. Due to the lockdown imposed by the COVID-19 outbreak in the Spring and Summer 2020, an in-person testing, which would be preferred, is not possible.

After performing the tasks of the usability testing, the participants will be asked a few questions in a small interview. There are three different techniques that can be used to conduct interviews. They are: structured, semi-structured and unstructured interviews [18]. In a structured interview, there are already previously prepared set of questions, which are not changed during the process of interviewing. Semi-structured interviews include predetermined open-ended questions, however, also include questions which can emerge from the dialogue

between the interviewer and interviewee. Unstructured interviews happen through a discussion on the relevant topic. Questions emerge over time during the interview.

The interviews for usability testing are conducted using a semi-structured approach.

4 Ideation

4.1 PACT ANALYSIS

In this section PACT analysis will be done by elaborating on 'People, Activities, Context and Technology'. The goal at the end of this project is to develop an interactive sleep-data visualization interface, and with that in mind the following analysis is made.

People

The users of the sleep-tracking interface are people who want to improve their sleep quality or be more conscious about their sleeping habits. The interface should be easily understandable to people with different backgrounds, education level and age. The interface is be made so that people with different interests and goals can use it. The interface provides very simple and understandable visualizations for people that do not want to have too much in depth knowledge of their sleep, and more complex visualizations can be accessed by people who have more interest in their sleep and science behind sleep.

Activities

The activities that people can do with the interface is to look at their sleep visualizations, starting from simpler ones to more complex. Users can add self-monitored information, like the amount of coffee consumed that day or exercise time. The interface can also provide insights into the user's sleep and give tips on improving certain areas of sleep, for example the regularity of sleep or when certain thing should be used less (devices, for example). The application ideally is used once a day, to review the sleep, compare it to other days and see if there are ways to improve sleep if the user is not getting high quality sleep.

Context

The interface of the sleep-data visualizations is digital, on a smartphone. It is important to have it in mind that there are certain limitations and constraints due to the size of most

smartphone screens. The interface includes a lot of different information, however it needs to be displayed in a small space, therefore the visualizations and additional information has to be space-efficient and not cluttered in order for the user to be satisfied with the interface. Furthermore, most likely the users are going to use the application before or after the sleep when the user wants to review to sleep or input data, therefore it should also support dark-mode for better sleep quality.

Technology

The main technology is a sleep-data visualization interface, available on a smartphone or a tablet. Additionally, the users can have a dedicated device to monitor their sleep (e.g., a wristwatch), however the data is shown on the interface.

4.2 USER SCENARIOS

After doing PACT analysis, user scenarios can further be developed.

4.2.1 User Scenario 1

Julia, a 19 year old student in her first year of university, is struggling with keeping up with her university work. She does not understand why she has so little energy in her daily life. She is very active in sports, doing football and basketball as hobbies. She lives off coffee and energy drinks to keep up with her energy levels. Because she feels tired all the time, she cannot focus on the important tasks, however she is very into video games and likes to stay up late in front of the computer screen. Julia really wants to improve her sleep, and after downloading a sleep-tracker, after some time of using the sleep-tracker she noticed that she stayed up too late and on the days that she could not fall asleep, she drank coffee 2 hours before bed.

4.2.2 User Scenario 2

Anna is a 25 year old software developer and is determined to live the healthiest life she can. She is very organized and wants everything to be in a perfect order. She likes data and likes to monitor all kinds of data with her smartwatch to keep up the best health possible. This way she feels the most in control of her life and health. She is very interested in all the little details about sleep – the amount of sleep stages, the factors that influence. She recently read an article that deep sleep is very important and therefore wants to keep an eye on it and also look at factors that influence it. With this sleep-data application she is excited to track all the

sleep stages, as well as combined with other tracking applications, she noticed that the most deep-sleep she gets is when she works out in the mornings and stops drinking coffee before 3 pm.

4.2.3 User Scenario 3

Erik is a 70 year old living in the country side. He spends his days working in his little garden where he grows various vegetables and fruits. He likes to hunt and fish when he is not in his garden. For his 70th birthday his grandchildren offered him a smartphone together with a activity tracker device. He has no previous knowledge of how to use technology, however with the help of his grandchildren he is eager to learn. He discovered that with the activity tracker he can see how many steps he takes a day and now tries to be more active to keep being healthy at his age. He also discovered that he can look at his sleep and wants to learn more about it. Erik had troubles with sleep, and after starting to use a sleep-tracker, he noticed that he had very irregular sleep, so now he tries to go to sleep at the same time every day.

4.3 BRAINSTORMING

4.3.1 Choosing Categories

The brainstorming process for visualizations is first done by creating mind maps. Firstly, the personas are put in the middle of the mind map, and the features that they would most likely use are written down by quick brainstorming. The mind maps are seen in Figure 4,Figure 5,Figure 6. After mind-mapping, the general categories are chosen for brainstorming sleep visualizations.

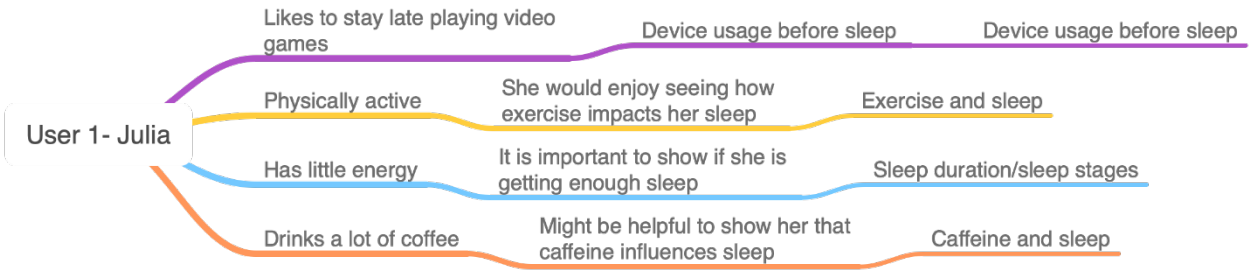


Figure 4: Julia Mind Map

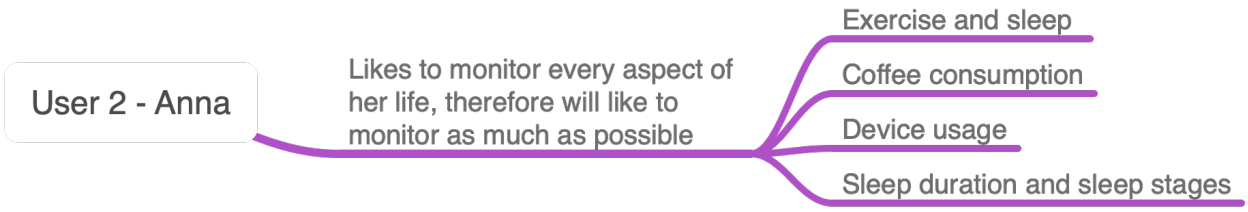


Figure 5: Anna Mind Map

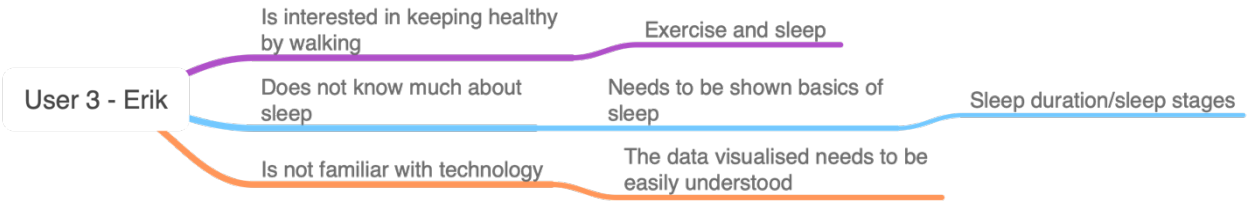


Figure 6: Erik Mind Map

After mind-mapping, it can be seen that all of the personas share some of the features that they would use in a sleep-tracking application. Firstly, all personas share 'sleep duration and sleep stages', which are also present in the previously reviewed sleep-tracking applications. Sleep duration and sleep stages are one of the main features in many sleep-tracking applications, therefore it will be used for the visualizations. Additionally, Anna and Julia are both active, which means that they would benefit from having exercise in a sleep-tracking application and seeing how it affects sleep. Similarly, both of them use devices and consume coffee, both of which influence sleep. For that reason, both device usage and coffee consumption are going to be included in the visualizations.

To summarize, the following categories were chosen for visualization:

- Sleep duration
- Sleep stages
- Coffee consumption
- Device usage
- Exercise

Some of the categories (at least one of the contextual factors and one for sleep data) will have an additional set of visualizations that focuses on trends. The trends will be based on sleep data that lasts some period of time (for example, weekly or monthly average). After choosing the categories, the next step is to brainstorm and sketch the visualizations for each category. This brainstorming is based on the method described in section 3.4.

4.4 USER REQUIREMENTS

A requirement is *"…something the product must do or a quality that the product must have*" [21]. As previously mentioned, user requirements are done with the help of FICS analysis and using a MoSCoW prioritization. The visualizations developed for the online questionnaire have no interactability, therefore the requirements are split in two parts: design and content requirements for online questionnaire visualizations and, additionally, interaction and usability requirements for the final prototype.

The design and content requirements are the following:

Must have:

1. The visualizations must include basic sleep data – sleep duration and sleep stages.
2. The visualizations must include other outside factors that influence sleep, like coffee.
3. The visualizations must clearly display all of the data – both in content (the needed data should be displayed or clearly read off a graph or visualization) and in design (large enough font, enough contrast between the elements and different colors).

Should have:

1. The visualizations should include labels and legends.
2. The visualizations should be simplistic and not overwhelm the user with information .
3. The visualizations that convey information by color should also convey the same information in text.

Could have:

1. The visualizations could be made in dark mode.

The interactability and usability requirements are the following:

Must have:

1. Simplistic and easy interaction
2. Clearly show buttons and areas that can be pressed on and interacted with
3. Multiple windows for different visualization categories

Should have:

1. The interaction should be intuitive (meaning, arrows pointing to the left means going to the previous window, etc.)

Before sketching out ideas, some questions about the interface and how to convey the information are analyzed to help with the process of brainstorming. Table 4 shows all the categories of visualizations and the priority of elements that can be used for the visualizations.

	Sleep duration	Sleep stages	Coffee consumption	Device usage	Exercise
Must have	-Sleep duration -Time gone to sleep/woken up	-Sleep stages (deep sleep, light sleep, awake and REM)	-Amount of coffee consumed in a day -Show that after certain time coffee shouldn't be consumed	-The last time the devices were used before sleep	- Exercise time -Deep sleep time
Should have	-Should show the start and the end of the sleep	-Amount of each sleep stage	-Putting it together with sleep duration	- Add sleep duration or sleep stages	-Comparison of previous days
Could have	-REM/NREM sleep amount -Other contextual factors(coffee, device usage, exercise) -Sleep stages	-Other contextual factors	-Add sleep stages	- What devices were used	

Table 4: Prioritization of Elements in Visualizations

Table 5 shows a few questions that are analyzed for each of the category to facilitate the brainstorming and make idea generation and sketching easier.

	Sleep duration	Sleep stages	Coffee consumption	Device usage	Exercise
What do I want to convey with this visualization?	-Sleep time to know whether the user is getting enough sleep	-Sleep stages to convey what the quality of sleep is (amount of deep sleep etc.)	-How the amount or the time of coffee consumed affects sleep quality	-How the practice of using devices before bed affects sleep quality	-How the practice of exercising affects sleep quality
How to make it actionable?	-Depending on the rule of thumb, the visualization shows up as green/red to show whether the user is	-By putting it together with other contextual factors -Adding what typical amount of each stage is	-By putting it together with sleep duration and/or sleep stages	-By putting it together with sleep duration and/or sleep stages	-By putting it together with sleep duration and/or sleep stages

	getting enough sleep that day -Incorporate contextual factors into the sleep duration	normal for the person			

Table 5: Additional questions for brainstorming

4.5 VISUALIZATION IDEA GENERATION

Many other previously reviewed and new sleep-tracking applications have been used as inspiration for the visualizations. Many of the sleep-tracking applications share similar features, and the way the data is displayed.

4.6 SLEEP DURATION

As mentioned in Table 4, the visualization of sleep duration must have the sleep duration length displayed, as well as the time gone to sleep and woken up. As also mentioned in the state of the art section of this thesis, some of the applications displayed the sleep duration circularly. That was the inspiration for one of the developed visualizations – to make one of the sleep duration visualizations in a 12-hour clock format. It visualizes the length of the sleep along the clock shape, which can be read off the visualization, however an additional sleep duration length is put in an hour and minute format in the middle of the clock for an instant data visualization. Furthermore, time fallen asleep and woken up is also displayed on the clock.

Additionally, some of the applications also visualized the sleep duration in a bar, therefore another visualization was inspired by that, since it is simplistic and minimalistic. In this visualization sleep duration, as well as the time fallen asleep and woken up are displayed in text. The sketches for sleep duration can be seen in Figure 7.

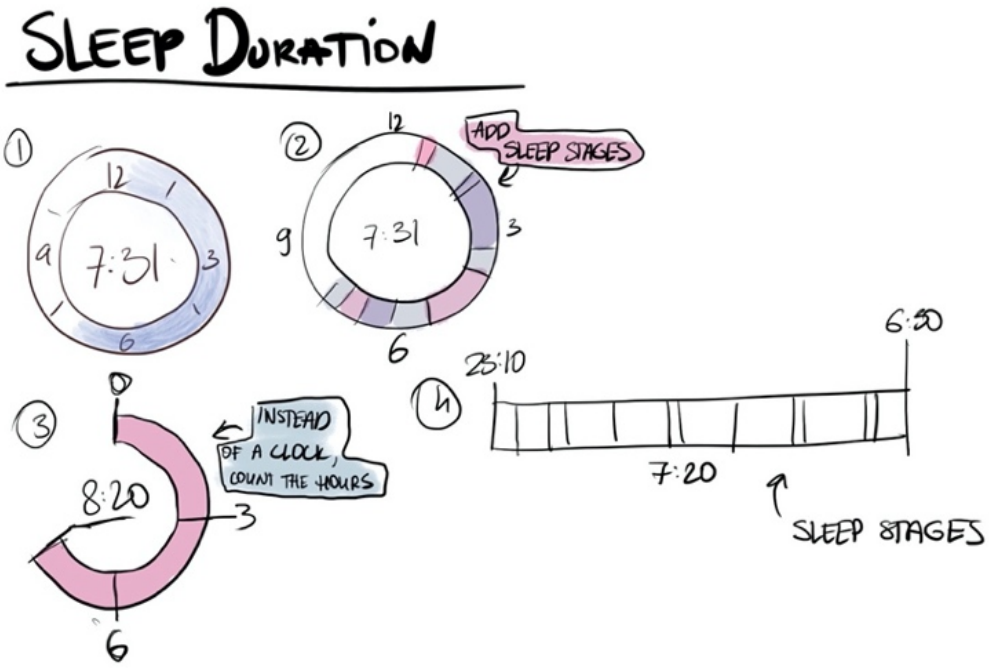


Figure 7: Sleep Duration sketches

Regarding the trends of the visualizations, they were made in a similar way to the sleep duration visualizations. To keep the same design theme, the circular and linear is visualizations are also made. In order to visualize trends of linear bars, multiple bar chart visualizations are sketched. However, in order to show the changes between multiple days, the average sleep duration for the last five days is indicated as a dotted line through the bars. Five days are chosen instead of seven days in order to not make the visualization too cluttered. Additionally, arrows can be added in order to show if the duration has improved or not in relation to the average. Equivalently, in order to show improvement in the circular visualization, the average sleep duration is noted, and, if the sleep duration has improved that night, an additional part of the clock is visualized with the number of hours or minutes that were slept more, or less than the average. Alternatively, a clock shape format with other contextual factors added into it that tracks the changes of sleep duration and factors with an arrow (if it has gone up, then arrow is pointing up, and if it has fallen down - then arrow is pointing down). As shown in Table 4, sleep duration could have other contextual factors present in the visualization. Figure 8 displays the sketches of the visualizations.

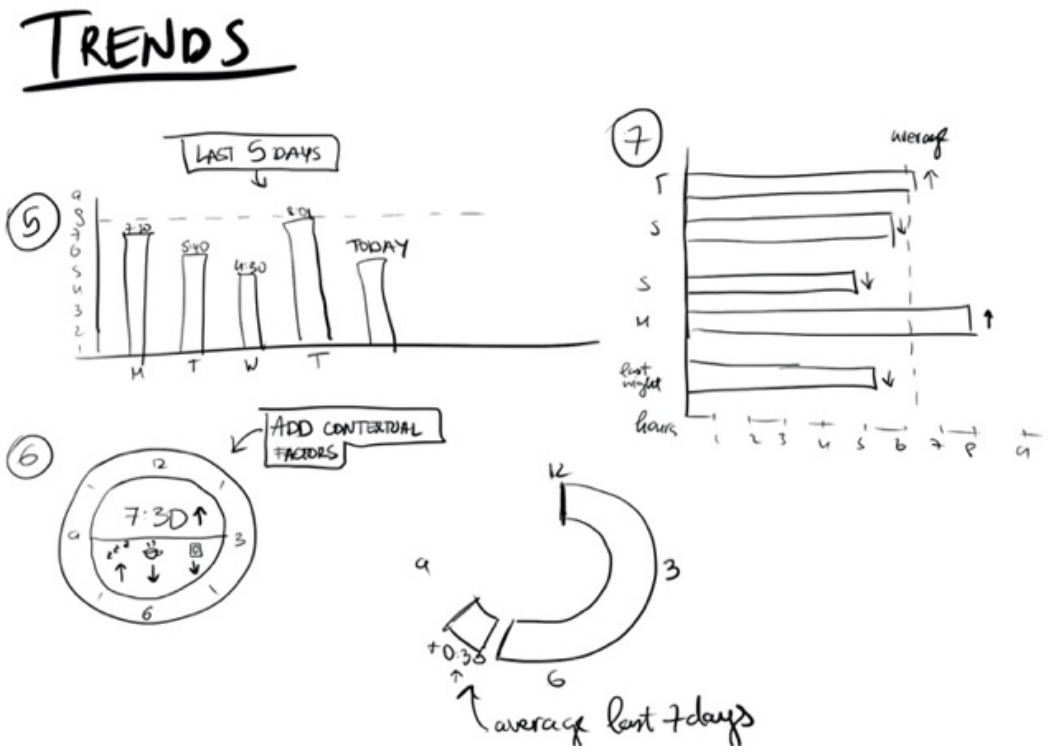


Figure 8: Sleep Duration Trends Sketches

4.7 SLEEP STAGES

As a ‘must’, according to Table 4, is to include the different sleep stages in the visualization. There sleep stages are categorized in four parts: deep sleep, light sleep, awake and REM sleep (only three are seen in the sketches, however in the final visualizations four are present).

For the sleep stages, two different visualizations are made. The second visualization (seen in Figure 9) is based on a visualization that is most popular among other sleep tracking applications. It shows the varying sleep stages during the night. The other visualization was made more simplistic – just providing the amount of each sleep stage in percentages from the whole night. Figure 9 shows the sketches of the sleep stages.

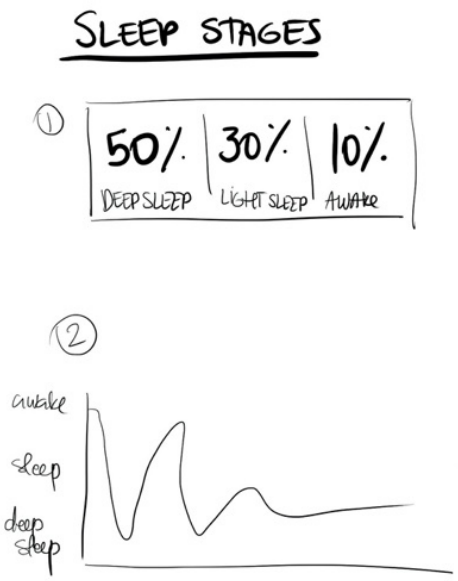


Figure 9: Sleep stages sketches.

As for the trends of sleep stages, one of the visualizations from sleep stages is also taken, however there are added arrows that show how last night's sleep compares to the 7-day average. Similarly, a circular visualization is made that shows the percentages of each sleep stage and how it compares to the average. Lastly, a bar chart is made in a similar manner, only showing the changes to the average by percentages. The sketches for these can be seen in Figure 10.

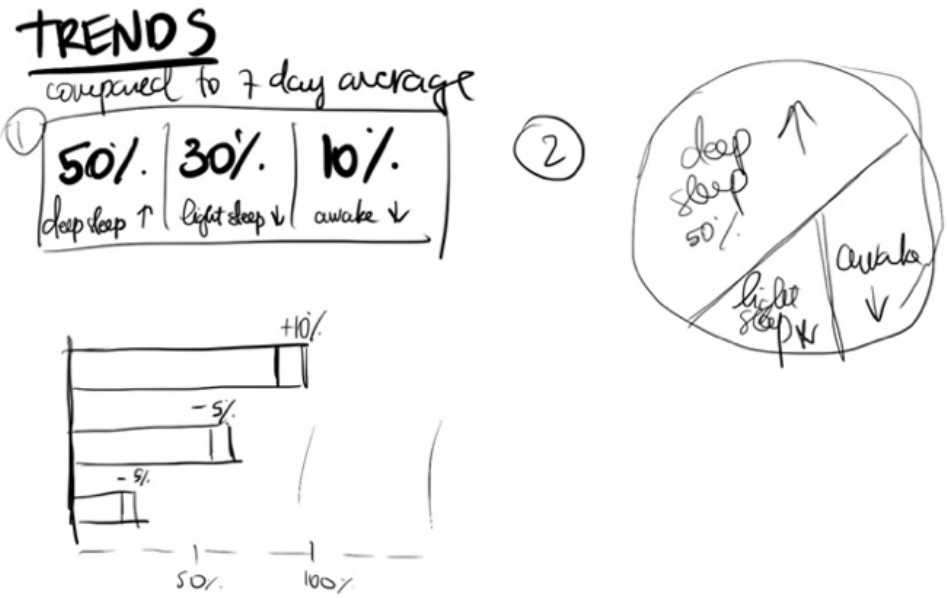


Figure 10: Sleep stages trends sketches

4.8 COFFEE CONSUMPTION

For coffee consumption, two different visualizations are made. To keep the theme of circular visualizations, one of them is made in a clock format, where the last time the coffee is consumed is visualized. Additionally, the clock shape has a gradient color in it, giving the visualization of caffeine amount present in the body decreasing with time. For the other visualization, in order to give the user a timeline of their day and coffee consumption, a timeline was made visualizing the coffee consumed, as well as how long it is still in the body. The inspiration for this visualization was to visualize the user's day and show after what time coffee should not be consumed anymore. Two lines were added that signify the timeframe when the user should not drink anymore coffee. The visualizations are shown in Figure 11.

Figure 11: Coffee Consumption sketches

4.9 EXERCISE

For exercise, it was decided to show the relationship between exercise and deep sleep, since exercise has shown to improve deep sleep [12]. To visualize the two different types of data, one visualization is made in a bar chart, showing the amount of deep sleep and exercise

in hours, and the other visualization is made in a circular graph to keep with the theme of circular visualizations. The visualizations can be seen in Figure 12.

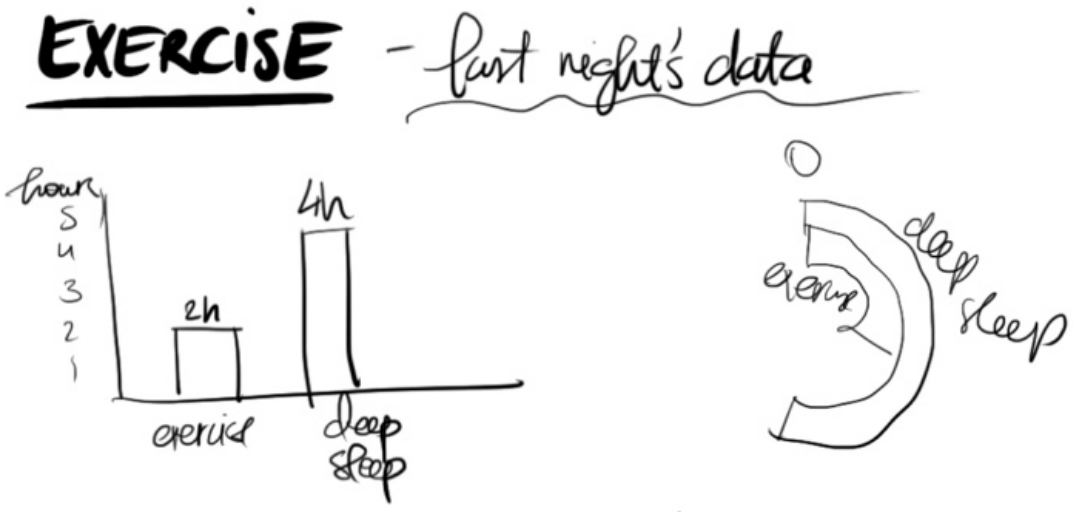


Figure 12: Exercise time sketches

4.10 DEVICE USAGE

For the device usage before sleep, similar visualizations to coffee consumption are made. One is made in a circular graph, showing the used devices before sleep, as well as the sleep. Two lines going over around 2 hours before sleep are put in to visualize the time the user should not use any devices. The other one is made the same way the coffee consumption visualization is made. The device visualization sketches can be seen in Figure 13.

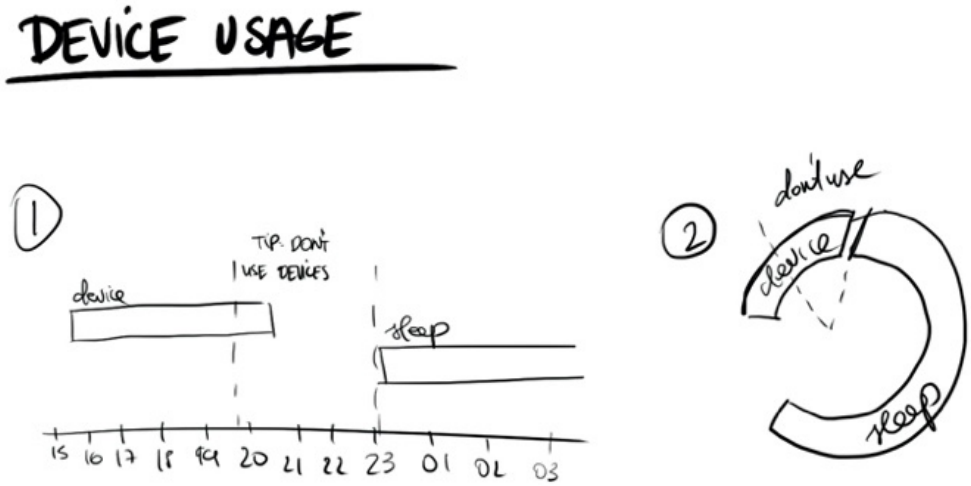


Figure 13: Device Usage Sketches

4.11 COLOUR SCHEME

Figure 14 displays the chosen color scheme for the visualizations. According to Marcus [22], a maximum of 5 +/- 2 colours should be used in a design interface, as well as use familiar and consistent colour codings. In the prototype, in order to depict ‘bad’ and ‘good’ values, two different colors are going to be used. Marcus [22] identifies colour connotations: in western culture red is associated with danger, green with ‘okay’, and blue with water, and sky.

Blue colors for the visualizations were chosen for the display of bars and charts – the neutral part of the visualizations that only show data. Marcus mentioned that red is associated danger, and green with ‘okay’, therefore for the visualizations of trends, green and red are going to be used. Red is going to be used for the trends that have worsened (for example, certain sleep stages have decreased in length) and green for trends that have improved.

Additionally, the visualizations will be made in a ‘dark mode’, that is, on top of a dark background. In 2020, app designers are focusing on dark mode [23]. Furthermore, dark mode is in line with a sleep-tracking application, as one of the factors that influence sleep is blue-light device usage before bed. This way, if the user is using the application before bed, it does not contribute to decreased sleep quality. The colour sdheme can be seen in Figure 14.

Figure 14: Colour scheme for visualizations

5 Specification

This specification chapter will focus on user testing of the first prototypes of the visualizations. An online questionnaire will be made to evaluate the understandability and actionability of the visualizations. After analyzing the results of the questionnaire, an application interface will be made based on the results and feedback of the questionnaire.

5.1 FIRST ITERATION SLEEP DATA VISUALIZATIONS

Two versions of visualizations per category were digitalized. The visualizations in every category provide the same exact information, however the visualizations differ in looks. Additionally, sleep duration, sleep stages and exercise categories have additional visualizations for trends over time. The following images display the visualizations made for the questionnaire. The data for the visualizations is fictitious. The following images (Figure 15 until Figure 22) display the first iteration of the visualizations per each category.

Sleep duration

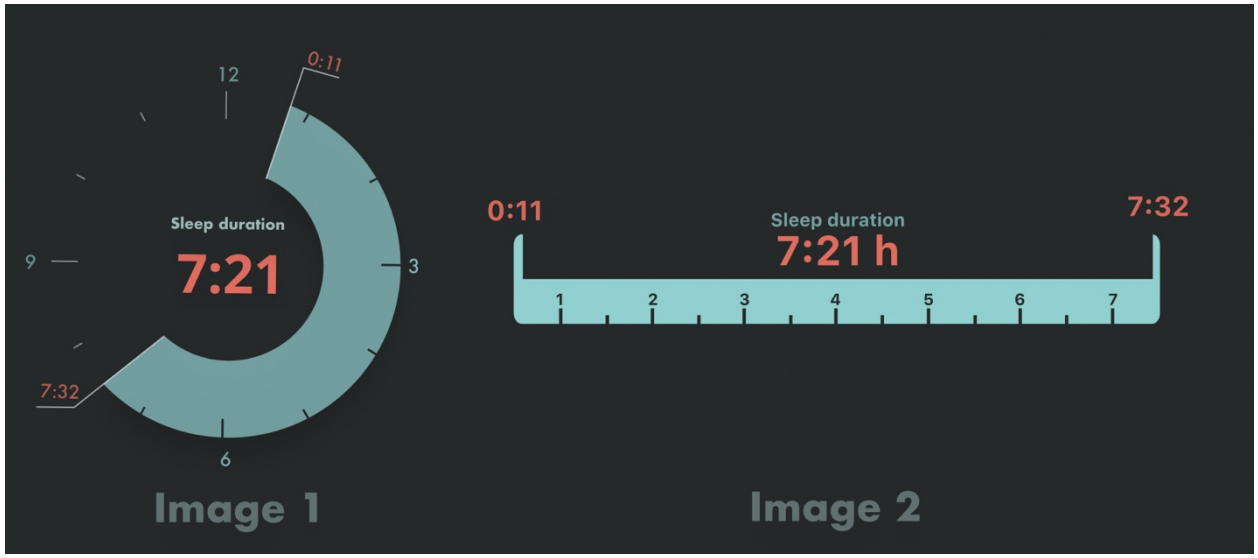


Figure 15: Sleep duration version 1 visualizations

Sleep duration trend

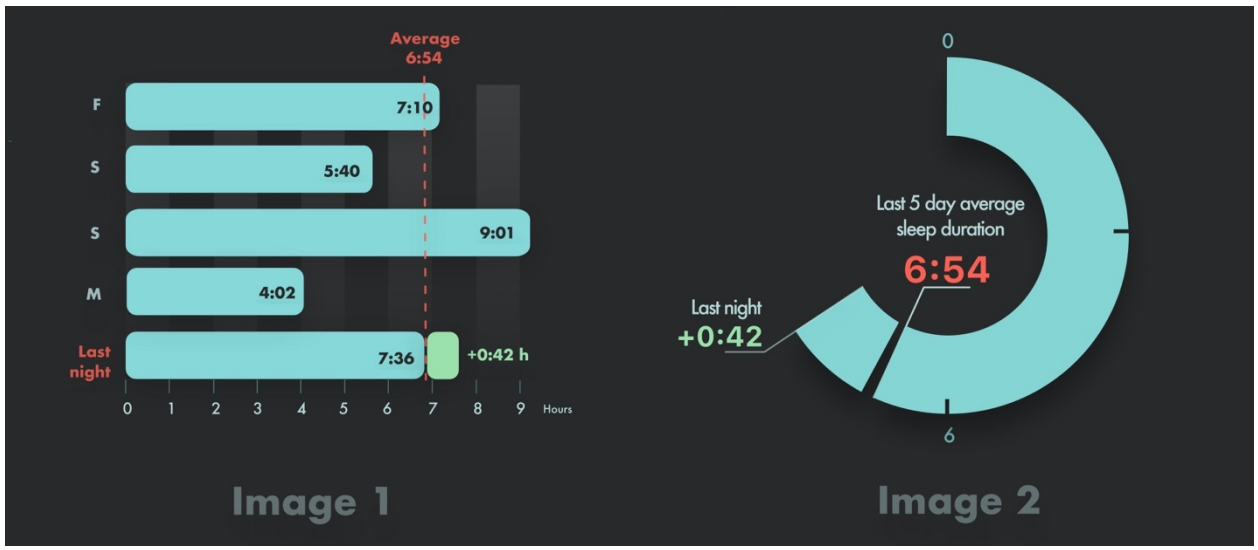


Figure 16: Sleep duration trends version 1 visualizations

Sleep stages

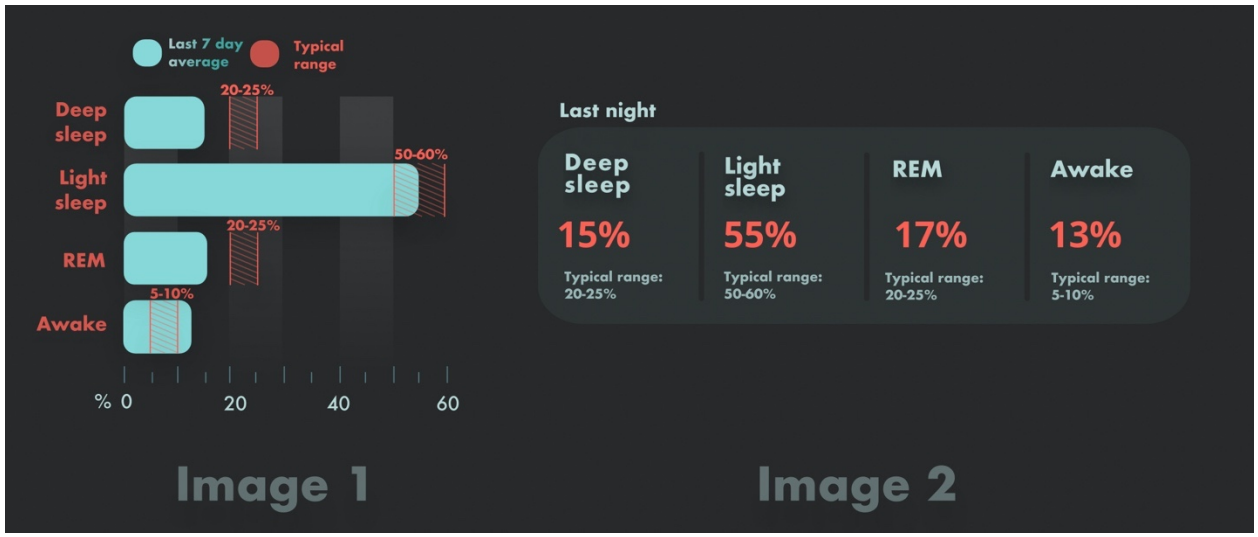


Figure 17: Sleep stages version 1 visualizations

Sleep stages trends

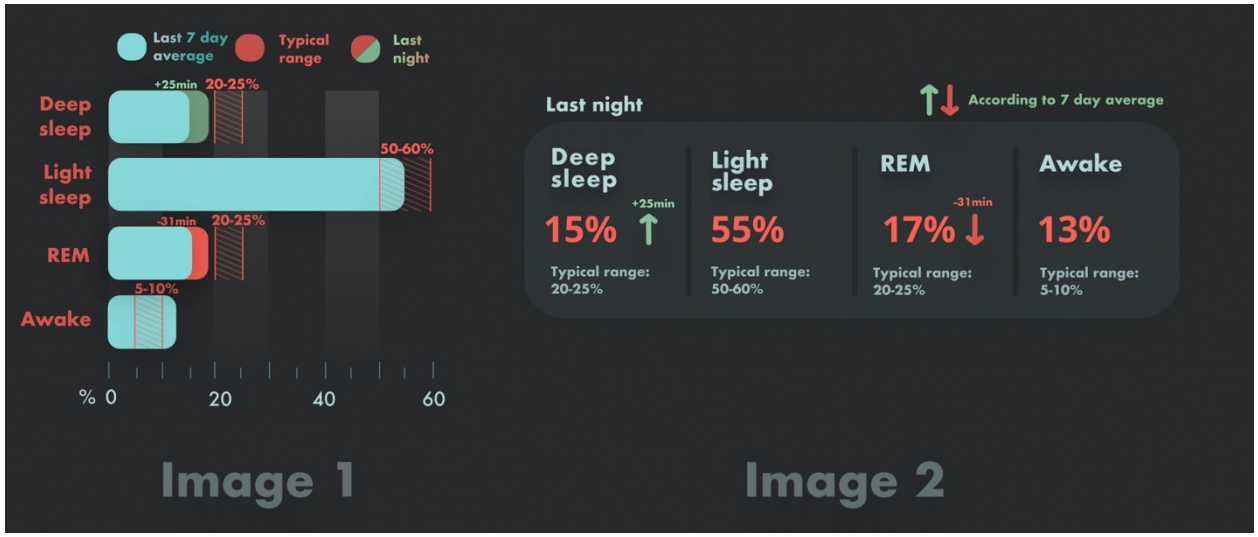


Figure 18: Sleep stages trends version 1 visualizations

Exercise

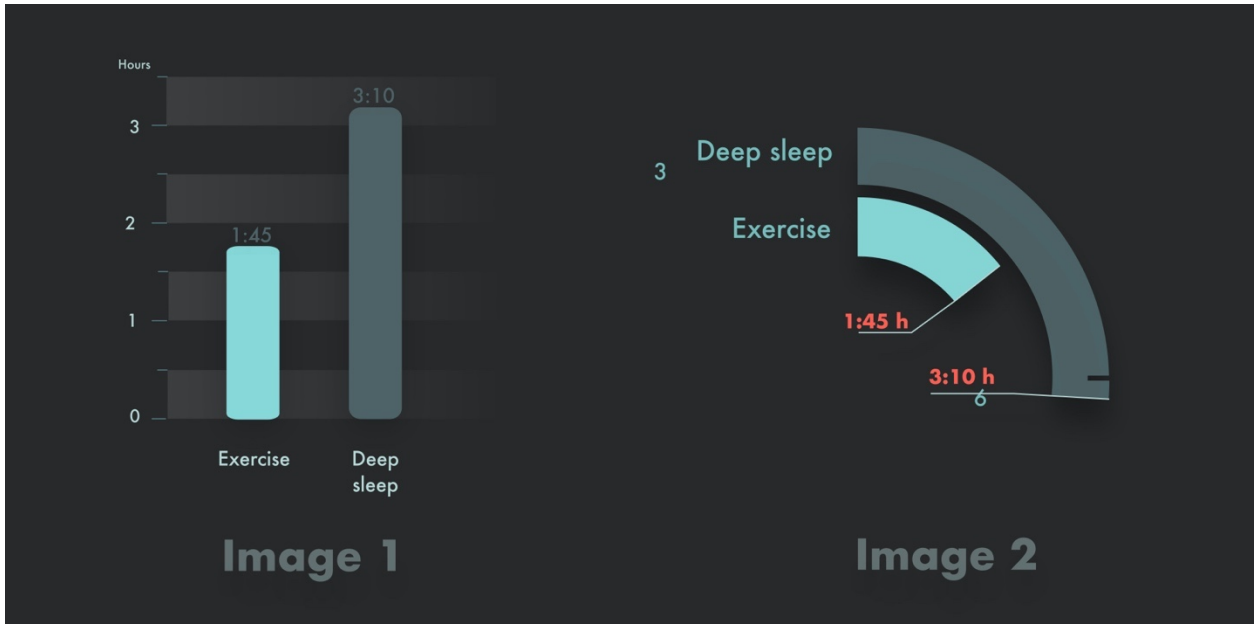


Figure 19: Exercise version 1 visualizations

Exercise trends

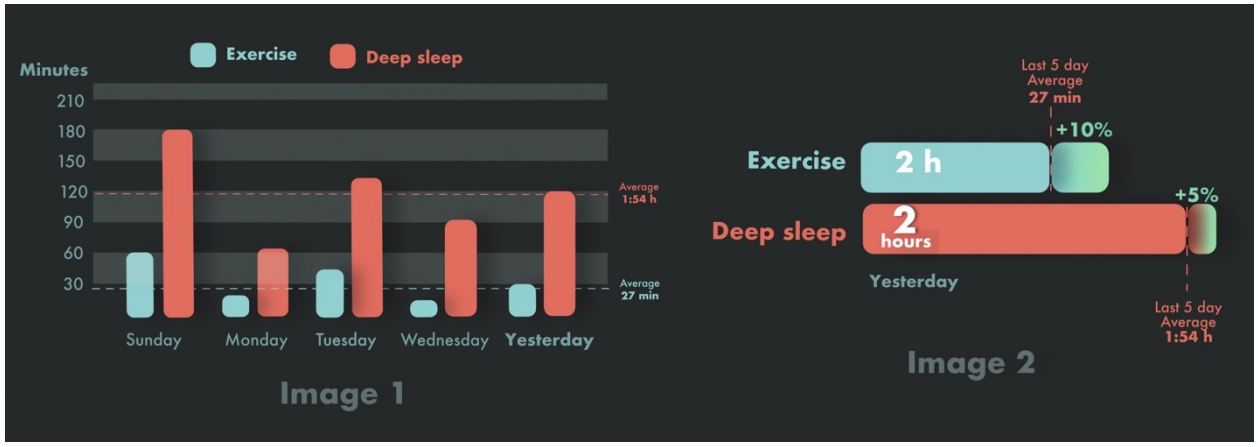


Figure 20: Exercise trends version 1 visualizations

Device usage

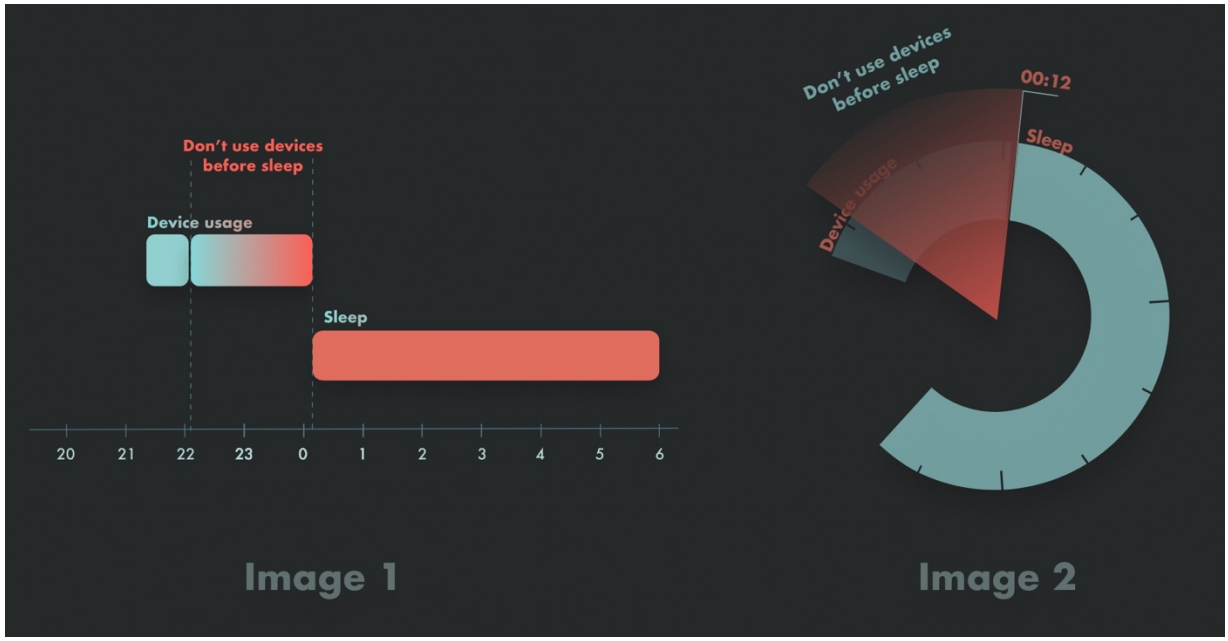


Figure 21: Device usage version 1 visualizations

Coffee consumption

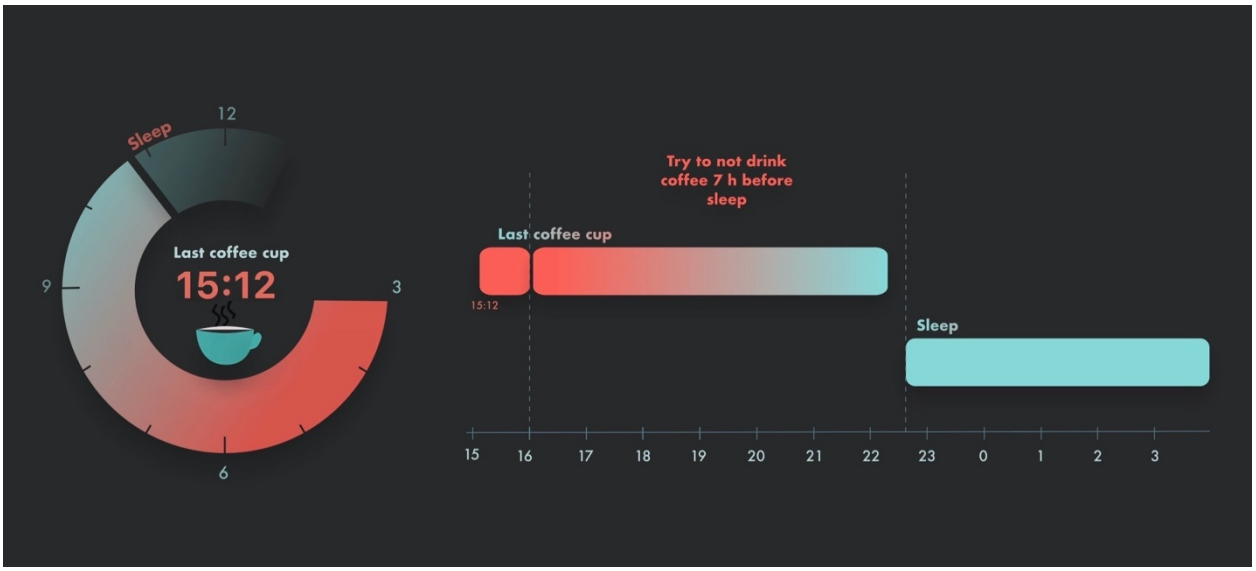


Figure 22: Coffee consumption version 1 visualizations

5.2 ONLINE QUESTIONNAIRE

The online questionnaire consisted of two parts: questions about the visualizations and demographic questions. The first part of questionnaire included multiple questions per each category of visualizations. For every visualization, a set of unique questions regarding the understandability of each visualization is asked, for example ‘What was the user’s sleep duration? and ‘What is the typical range of deep sleep?’. Afterwards, the same two questions are asked for each category: ‘Which one of the images (1 or 2) do you think is more understandable?” and “ Which one of the two images do you find more aesthetically pleasing?” After each of these questions, an optional field is followed where the participant can further explain the choice of their answers. Additionally, a few of the visualizations had actionability questions, that is, based only on the visualizations, they are asked what the owner of the sleep should do to improve sleep quality. That way it can be seen whether they recognize what they had to improve just by seeing the visualizations.

The goal of this questionnaire is to find out which visualizations people understand better, which they find more aesthetically pleasing and how actionable the visualizations are. The online questionnaire was published online on June 11th , 2020 and was online until June 18th, 2020. The questionnaire was distributed with the help of social media (Facebook friends and university groups, Instagram), as well as through family acquaintances. See Appendix 1 for the full questionnaire.

5.3 QUESTIONNAIRE EVALUATION

5.3.1 Demographic Question Analysis

Although the demographic part was the second part of the questionnaire, in order to give an overall image of the respondents, it is put before in this section, before the part 1 of the questionnaire results are shown.

Majority (61%) of the respondents were 18-24 years old, 18% were 25-34 years old, 12% were 35-44 years old, 8% were 55-65 years old and 1% was 65 -74 years old.

4% of the respondents had a PhD or higher education, 22% had a master's degree, majority (46%) had bachelor's degree, 27% had high school diploma and 1% had a trade school diploma.

87% of the respondents said that they do think about sleep, and 13% do not. 53% have used a sleep tracking application before, while 47% have not.

Out of the 53% of the respondents that have used sleep tracking applications before, majority (45%) did it to gather data, 33% to improve the sleep quality, 8% did it to find reasons for poor sleep.

Regarding the devices and applications used to track sleep, there was not a single one preferred among the respondents. Respondents mostly used Fitbit, Apple Watch, Sleep Cycle Alarm, and many others. Most of the respondents (55%) said that the sleep tracking helped them to be more aware of their sleep habits. 13% of the respondents said it did not help in any way.

5.3.2 Part 1 Question Results

In total, there were 74 respondents for the questionnaire. As previously mentioned, the questionnaire had a set of questions that were the same for every category (sleep duration, etc.) and a set of unique questions.

Table 6 shows the percentages of people answering the general questions of each category.

	Which one of the images do you think is more understandable?			Which of the two images do you find more aesthetically pleasing?		
	Image 1	Image 2	None	Image 1	Image 2	None
Sleep duration (Figure 15)	53%	47%	-	78%	20%	2%
Sleep duration trend (Figure 16)	82%	18%	-	55%	45%	-
Sleep stages (Figure 17)	15%	84%	1%	32%	64%	2%
Sleep stages trend (Figure 18)	15%	81%	4%	24%	72%	4%
Exercise (Figure 19)	57%	38%	5%	37%	62%	1%
Exercise trend (Figure 20)	57%	36%	7%	49%	51%	-
Device usage (Figure 21)	73%	23%	4%	60%	39%	1%
Coffee consumption (Figure 22)	55%	39%	5%	69%	30%	1%

Table 6: Analysis of default questions

What can be seen from the Table 6 is that there is not a big difference of preferences of understandability for sleep duration, exercise, exercise trend and coffee consumption visualizations. However, there is a distinguishable preference in terms of understandability for sleep stage and sleep stage trend, device usage and sleep duration trend visualizations. Although some of the visualizations were clearly preferred in terms of understandability, there was not a significant preference in aesthetics for sleep duration trends and device usage. For sleep stages and sleep stage trends the visualizations that were preferred for understandability were also preferred for aesthetics.

Not all, but a few of the categories (sleep duration trends, sleep stages, device usage, exercise trends and coffee consumption) also included questions about actionability. Table 7 shows the percentages of each answer per question.

	Based only on the images above, what would you recommend the owner of this sleep data to do?							
	Sleep more	Sleep less	Stabilize the sleep rhythm	Do not use devices before sleep	Do not use coffee before sleep	Keep exercising daily	No recommendations	Other
Sleep duration trends	22%		51%	8%	10%	7%	2%	• Cannot tell • Set a regulated time where you turn off screens so your melatonin levels grow which will create a natural rhythm
Sleep stages	13%	1%	18%	21%	21%	11%	12%	• No idea • Based on the presented info, only recommendation is to find out why owner is not having 'enough'deep sleep and 'too much' time awake • I don't know – not familiar with REM • To create a deeper REM sleep, try carbachol as improvement on REM if this keeps happening
Device usage	12%		3%	77%	1%	2%	1%	• Sleep later • Go earlier to bed • Melatonin medication
Exercise	9%		8%	1%	1%	52%	25%	• Have no recommendation based on given information. Is 3:10h enough sleep or not? • Not sure
Exercise trends	10%		11%	2%	2%	61%	9%	• Exercise at least 30 minutes a day • I am not aware of a relation between exercising and deep sleep • Exercise longer • Try to exercise for at least half an hour a day. The amount of deep sleep is significantly less when the workout

								was shorter than half an hour. • Exercise more
Coffee consumption	7%		2%	1%	57%	3%	26%	• Drink coffee at least 7 h prior to bed • Do not drink coffee after 12 pm • Decaf coffee/no caffeine also tea has caffeine

Table 7: Actionability questions of the questionnaire

For each of the category of visualizations, there was a certain 'action' that was meant to be taken from the user's point of view in order to improve their sleep, and in Table 7 it can be seen whether the participants understood it or not. For sleep duration trends, the action was 'stabilize the sleep rhythm', since the visualization displayed an irregular sleep schedule and majority (51%) indeed chose the correct one, and second most chosen one was to sleep more (22%).

For sleep stages, there was not one correct answer, however the sleep stages are mostly influenced by the factors like exercise, coffee consumption and devices, and the most answers were indeed to not use devices before bed (21%), and do not use coffee before sleep (21%).

Regarding device usage, the action was to not use devices before bed, and 77% of the participants chose the correct action.

For both exercise and exercise trends, 51% and 61% respectively, chose the correct action – keep exercising daily. However, 25% did not have any suggestions to improve the sleep for exercise.

For coffee consumption, it had the highest percentage of 'no recommendations' out of all the categories. However, 57% did choose the right action, which is to not use coffee before sleep.

5.3.3 Part 1 Open and Unique Question Analysis

The next section reports on the results of the open questions of every category. The open questions for every category were the same – "Why is the image you chose more understandable?", "Which one do you find more aesthetically pleasing?". The questions are further extensions to the previous questions of choosing which visualizations the participants prefer in terms of understandability and aesthetics. The detailed analysis of these questions can be found in Appendix 2.

5.4 TAKEAWAY FROM THE ONLINE SURVEY

Sleep duration

Regarding the understandability of the visualizations, both of them were perceived equally understandable, however Image 1 was preferred in terms of aesthetics. People seem to perceive time in different ways, some find it easier when it is visualized in a clock manner, some find it easier when it is linear.

The suggested improvements for Image 1 could be to change it to a 24-hour clock, as some people sleep more than 12 hours. Additionally, increase the font size and add a goal setting. For Image 2, the rest of the hours can be added, and a legend for the 'ruler' could make it easier to understand. However, in realization part the bar visualization will be used, due to issues in visualizing the circular design pattern with more than 12-hour sleep.

Sleep duration trends

For these visualizations, Image 1 was preferred compared to Image 2, however in terms of aesthetics, both are similarly preferred. Regarding actionability, 51% of the respondents would stabilize the sleep rhythm, and 22% would sleep more, which means that the respondents could tell what they would need to improve by looking at the visualization.

Image 1 was mostly preferred because of a whole week overview. A more detailed look of other days in the week is preferred over just an average number. Most improvements that can be made for Image 1 is to add times of waking up, falling asleep, not use different bars for minutes slept over average. Remove the vertical bars in the background, as well as add suggestions. Regarding Image 2, it was suggested to add previous times of sleep duration, just like in Image 1. In the realization part, Image 1 will be used.

Sleep stages

81% preferred Image 2 in regards of understandability, as well as 64% preferred it aesthetically. Regarding actionability, the answers were divided. That can be a sign on not knowing specifically how to improve certain sleep stages, which requires previous knowledge. Ultimately, Image 1 was way too visually stimulating and confusing to the responders, therefore it is best not to use Image 1 for the next phase prototype. It was suggested to therefore to change the colors in Image 2 to see what lies within the typical range, as well as have 2

different visualizations – one for quick view, the other for a detailed view. For realization, Image 2 will be selected.

Sleep stages trends

Similarly to the sleep stage visualizations, majority (84%) preferred Image 2 in terms of understandability, as well as aesthetically (72%). Same conclusion can be drawn as for sleep stages – Image 1 is too cluttered, which makes the understandability more difficult, however Image 1 will be chosen for realization, in order to have a bit more detailed image for sleep stage trends, however it will be improved in order for it not to be too cluttered.

Device usage

For device usage visualizations, 73% preferred Image 1, and 23% preferred Image 2 in terms of understandability, and 60% preferred Image 1, 39% preferred Image 2 aesthetically. For device usage, Image 1 is the preferred visualization. In terms of actionability, 77% of respondents knew to use less devices before bed. Image 2 was confusing to respondents, however it might work better for people who naturally think of time in a circular manner.

The improvement suggestions for Image 1 is to indicate what different colors mean in the graph, and more clearly indicate when the devices are not used. For the realization part, Image 1 will be chosen.

Exercise

In terms of understandability, 57% chose Image 1, and 38% chose Image 2, however the opposite is found for aesthetics. 37% chose Image 1, and 62% chose Image 2. Image 1 was preferred more for understandability, because a linear graph is easier to understand. However, a big concern for these visualizations is that it does not clearly show that there is a relationship between exercise and deep sleep. Putting deep sleep and exercise together in a visualization does not automatically show a relationship to the users. For this reason in the next prototype, a completely different visualization will be made, with the intent of the user seeing for themselves if there is any relationship between exercise and deep sleep.

Exercise trends

For these visualizations, Image 1 was preferred (57%) over Image 2 (36%), however aesthetically both images are preferred almost equally (49% and 51%, respectively).

Actionability wise, 61% of respondents knew to exercise daily from the visualization. People who chose Image 1 liked that it displayed multiple data from previous days, which Image 2 was lacking.

Similarly to exercise visualizations, they lack to show the correlation between deep sleep and exercise and therefore a new visualization will be made for realization.

Coffee consumption

55% of respondents preferred Image 1 in regards of understandability, and 39% preferred Image 2. Similarly, Image 1 was found more aesthetically pleasing (69%) than Image 2 (30%). Actionability wise, 57% of respondents knew to limit coffee intake before bed from the visualization. Again, clock-shaped visualizations seem to be easier to grasp, and aesthetically it is also more preferred. However, to keep up with the same theme as for device usage, Image 2 will be selected in order to keep the consistency of visualizations.

Overall, based on the online questionnaire, most of the participants seemed to prefer visualizations that are more familiar to them, particularly that they may have seen in other applications, since 53% of the respondents have used sleep-tracking applications beforehand. Some of the visualizations that were not preferred may have been too unfamiliar, and not easy to understand at first. Another thing that was observed in the results of the questionnaire is that participants preferred visualizations that showed the data to the user instantly, instead of having to read and decipher it themselves.

6 Realization

This chapter describes the final phase of the project, where the final prototype is developed and the usability testing follows.

6.1 SECOND ITERATION SLEEP DATA VISUALIZATIONS

The final product of this phase is an interactive interface of a sleep-tracking application. Based on the online questionnaire, one of each visualizations in a category are taken based on the feedback, improved or disposed of. The changes were incorporated based on the number of participants that suggested the change. If majority of the participants suggested a change, then it was taken into consideration. However, if there were suggestions that seemed beneficial to

add as an improvement, even though only a few of the participants suggested it, it was still taken into consideration.

6.1.1 Colour Scheme

One of the main remarks during the questionnaire was to change the colors. Instead of making it a dark theme, the new visualizations are going to be light themed. The color scheme for these visualizations are chosen similarly as described in section 4.11

For ‘bad’ values in the interface, red colour is going to be used, and for ‘good’ values, blue colour will be used. Although green is usually used more as a ‘good’ value indicator, blue will be used instead for aesthetic purposes. Additionally, it is not advisable to use green and red together in a visualization for accessibility, since approximately 300 million of the world population are color blind [24]. Marcus also notes that grey colour is used for neutrality, therefore grey will be used to depict the days when the users skipped the rule of thumb questions, later explained in section 6.2.2. Figure 23 displays the new colours for the new prototype.

Figure 23: Prototype colour scheme

6.1.2 Inspiration for the Interface

Before developing the final visualizations for the interface, some inspiration was drawn from other applications in terms of design and style.

One of the 2020 trends in application interface design is rounded and organic shapes, making user experience easier to interact with [23]. This was incorporated in the visualizations. Figure 24 shows some of the application designs that were used as inspiration.

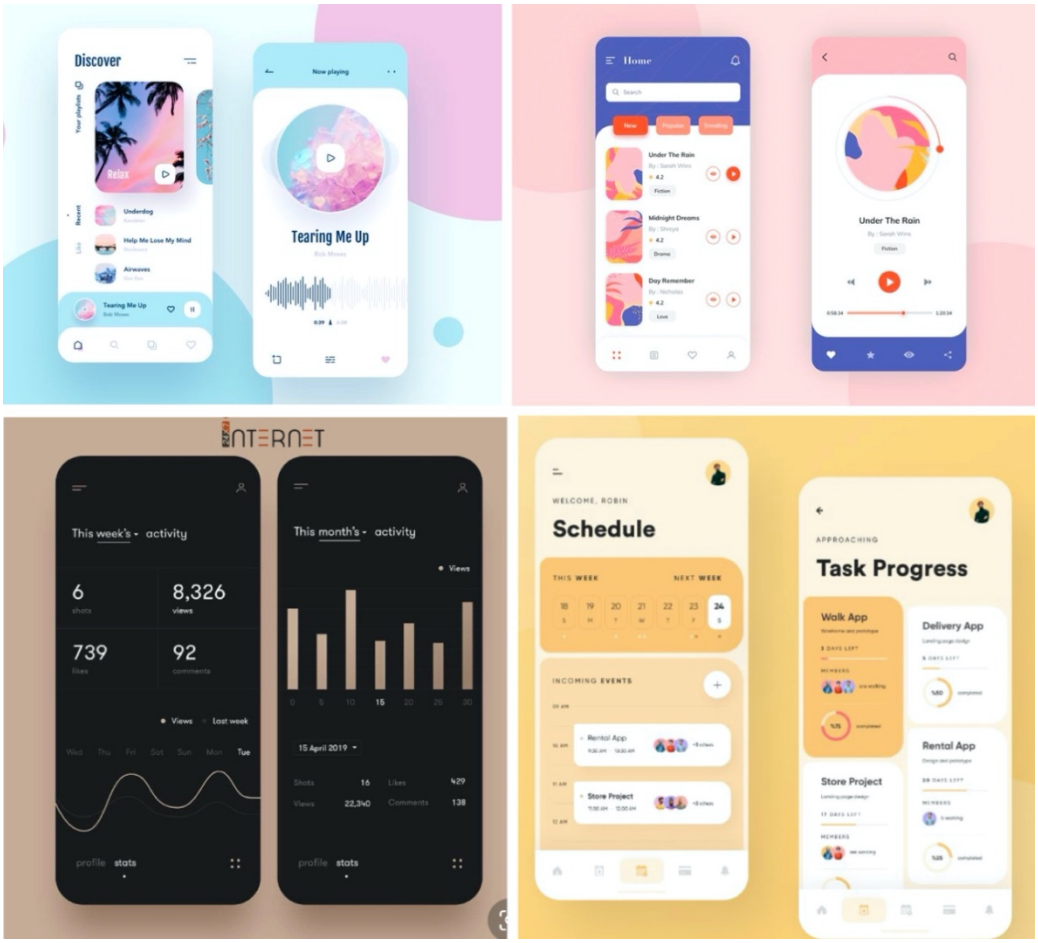


Figure 24: Application Interface Inspiration [25], [26], [27], [28]

6.1.3 Sleep Duration

For sleep duration, Image 2 was chosen (Figure 15). There was not much preference between two of the images, however a problem would arise for Image 1 if a user slept more than 12 h, making it impossible to visualize the same way. No other big changes for Image 1 were made.

For sleep duration trends, Image 1 was chosen (mostly preferred by people). The changes that were made are:

- Changing from 5 days to 7 days, to visualize a week (suggested by X participants in the online survey)

- Instead of having hours slept on X-axis, it is the time of the day on X-axis. That way it gives it also an easier way to compare the regularity of sleep.
- Different colors, depending on the rule of thumb (described in section 6.2.2)
- ‘Last 5 day average sleep duration’ is replaced by text underneath the graph
- Green bar showing the surplus/red bar showing deficiency of sleep compared to last 5 day average is removed. Feedback showed that people were confused about this and could not understand it correctly.

The version 2 of this visualization is seen in Figure 25, and the version 2 of trends is seen in Figure 26.

Figure 25: Sleep duration version 2

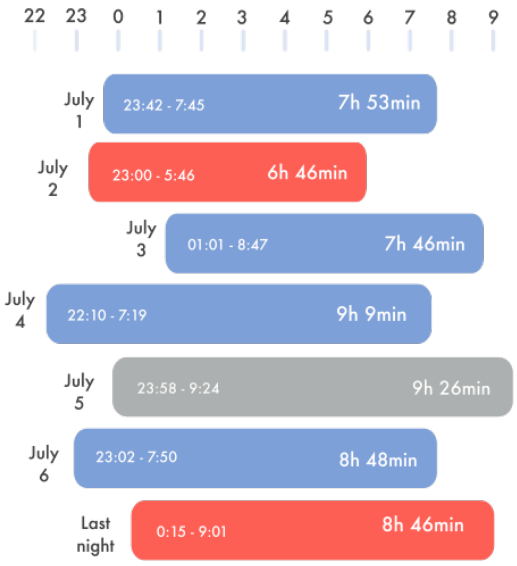


Figure 26: Sleep duration trends version 2

The colors of the bars seen in Figure 27 depend on the self-evaluation further down explained in section 5.2.2.

6.1.4 Sleep Stages

For sleep stages Image 2 (Figure 17) was chosen, since majority of respondents preferred it. There were not many changes made, mostly removing typical range, because that is going to be included in the trends.

Many suggestions were to combine the two visualizations, therefore instead of combining them, I chose to use the percentages for a quick overview of the night's sleep, but a more detailed graph (Image 1) in sleep trends. The changes for the Image 1 sleep trends are following:

- Remove the bars for last night. Many participants found it confusing.
- Remove X-axis percentages and instead write the percentages down on the bars.

The version 2 of this visualization is seen in Figure 27, and the version 2 for the trends is seen in Figure 28.

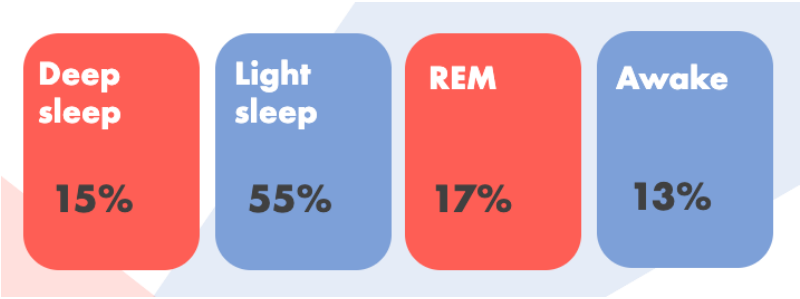


Figure 27: Sleep stages version 2

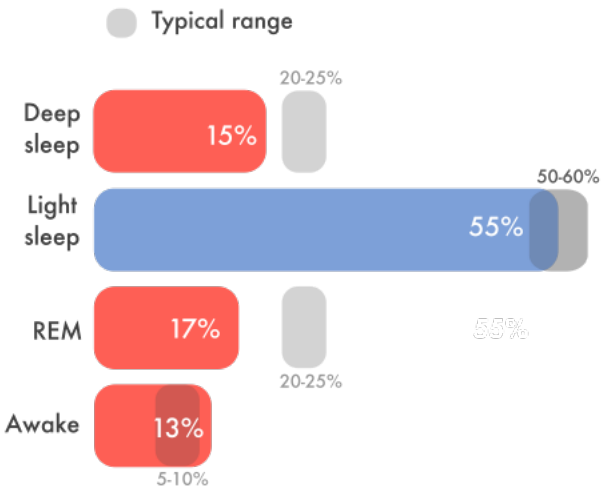


Figure 28: Sleep stage trends version 2

6.1.5 Coffee Consumption

For coffee consumption, Image 2 (Figure 22) was chosen, although majority preferred Image 1. Since majority for device usage preferred Image 1, to keep it a consistent interface, Image 2 was selected for coffee consumption. The changes that were made are the following:

- For a better user experience, the whole day (since waking up and going to bed) is shown in a timeline. There each coffee cup is also shown with an indicator, as well as it shows how many cups the person drank.
- Removed the gradient in 'danger zone' of coffee consumption, because people were confused

The version 2 of this visualization is seen in Figure 29.

Figure 29: Coffee consumption version 2

6.1.6 Device Usage

For device usage, Image 1(Figure 21) was chosen, as the majority of respondents in user testing 1 preferred. Similarly to coffee consumption, the whole day is shown in a timeline. The changes made for the visualization are the following:

- Removed the 'command form' of 'do not use devices 2 h before sleep' by the suggestions of respondents
- Removed the gradient

The version 2 of this visualization is seen in Figure 30.

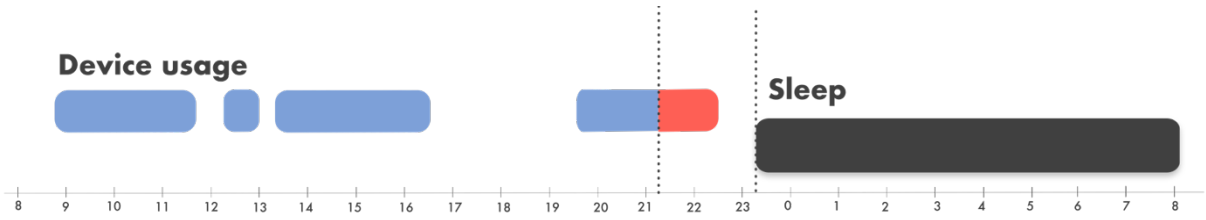


Figure 30: Device usage version 2

6.1.7 Exercise

Many respondents pointed out that no relationship was seen between exercise and deep sleep in the visualizations, for that reason the deep sleep is removed for this visualization. Instead, a bar graph is made, detailing how much exercise the person performed on that day, as well as showing the ideal amount of exercise time (30 min a day) for good sleep quality. Red and blue colors indicate whether the exercise amount is enough or not enough. The visualization is seen in Figure 31.

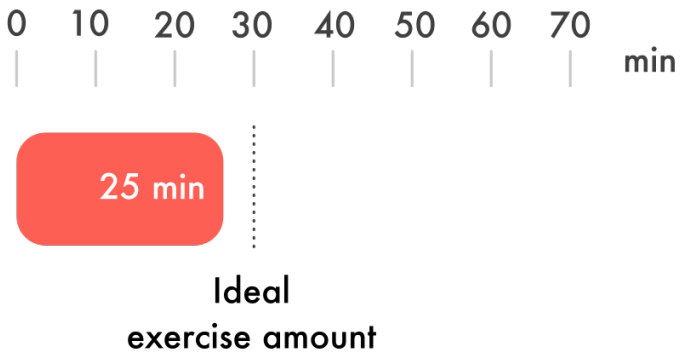


Figure 31: Exercise version 2

However, the exercise trends will include deep sleep. More is detailed in Section 6.1.8.

6.1.8 Weekly Patterns

Many respondents pointed out that no relationship was seen between exercise and deep sleep in the visualizations. For that reason, a tab of 'weekly patterns' is made. There, a weekly overview of all 3 contextual factors (coffee, device usage and exercise) is shown, as well as sleep duration and deep sleep. This way, the user can observe and see the patterns for himself, and see whether there are any relationships between contextual factors and sleep.

Additionally, a 'self-assessment' column is added in order to show how the person felt about the night's sleep that day, according to the two questions asked each day, further explained in the section 6.2.2. If the person felt good, a blue smiley face is shown, if bad – a red 'sad' smiley face. If the questions were skipped that day, no smiley will appear. The visualization can be seen in Figure 32: Weekly pattern.

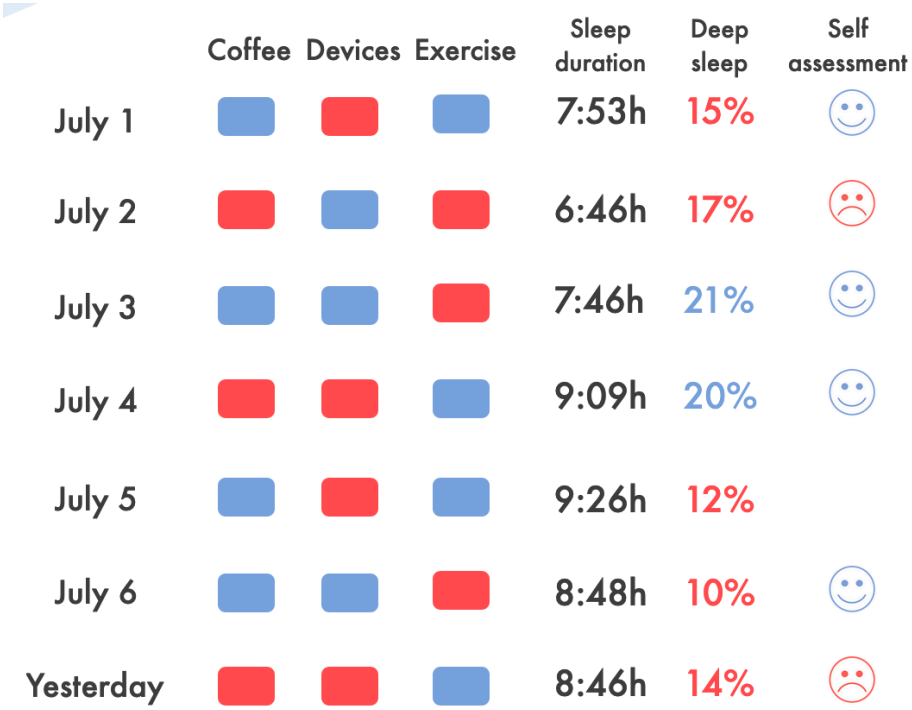


Figure 32: Weekly pattern

6.2 THE USER INTERFACE

To make the interface interactive, many other elements are included together with visualizations. The finished product is a mobile interface prototype, however it is only a design wireframe, not a functional prototype. The wireframe is made with the interface building software *JustInMind*.

6.2.1 Interactivity Between Visualizations

On the main screen, seen in Figure 33, are displayed three different visualizations: sleep duration, sleep stages and other factors. When the user taps on sleep duration, they get sent to a new page containing the weekly sleep duration trend. Similarly, when pressed on sleep stages

and other factors a new screen appears, showing the trends of the week.

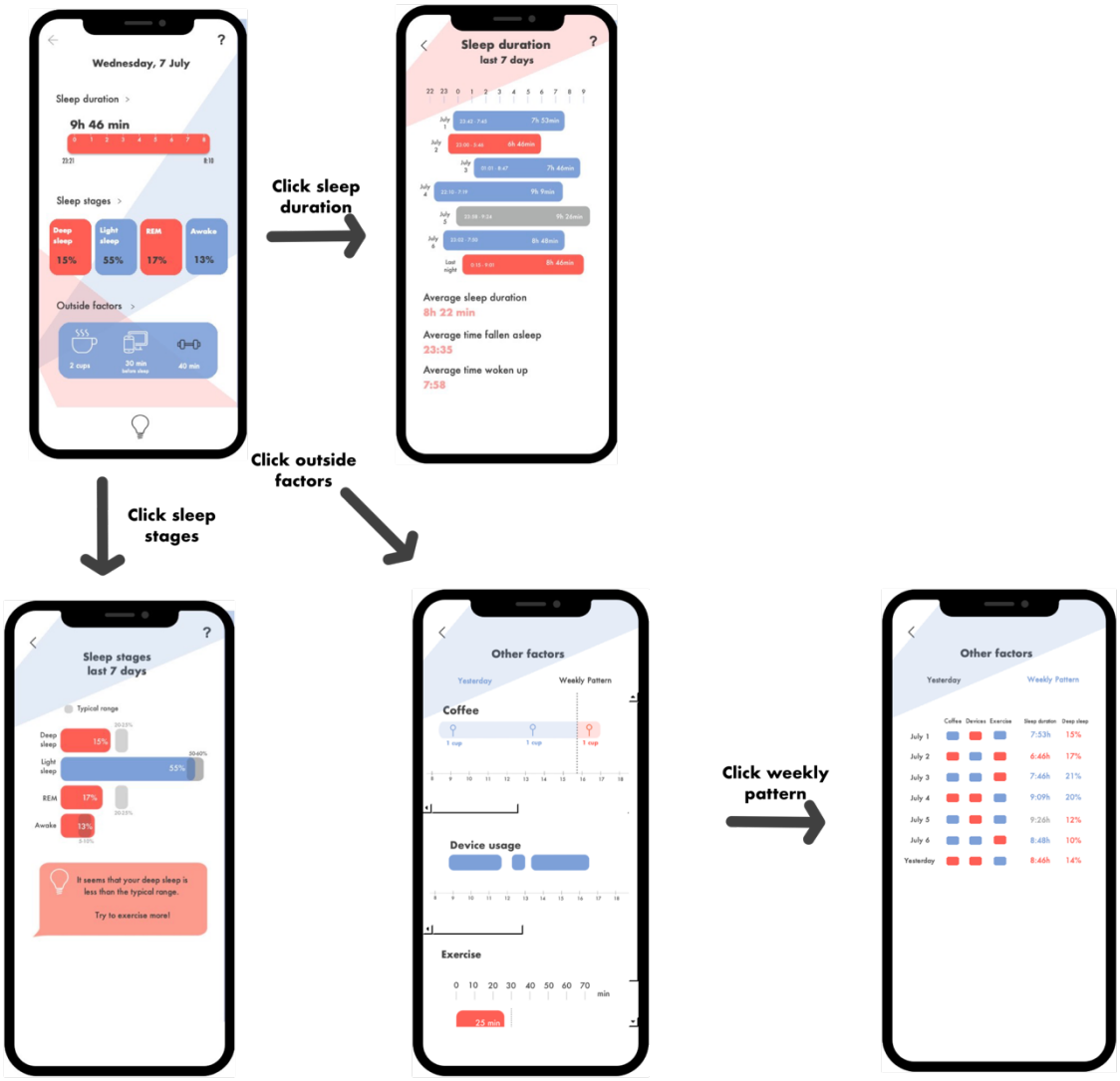


Figure 33: Interactivity map between visualizations

6.2.2 Suggestion and Information Interactivity

One of the features suggested by two participants in the online questionnaire was to include recommendations on top of the visualizations, which could facilitate a person to take more action for their sleep. For example, if the sleep is irregular, the user may or may not recognize it from the visualization. However, with added personalized suggestions, that may help with the understandability and actionability of the visualizations.

There are a few added elements in the interface, and this section goes over all of the added elements.

Rule of thumb

As mentioned previously in the background research, a good way to see if a person is getting enough sleep is the rule of thumb, detailed in section 2.1. Two questions are asked – ‘After waking up in the morning, could you fall back asleep at 10 or eleven a.m.?’. If the answer is ‘yes’, then most likely the person is not getting enough sleep quantity or quality. The second question is: ’Can you function properly without caffeine before noon?’. If the answer is ‘no’, then the person may not be getting enough sleep.

According to the answers the person gives, the sleep duration bar is colored in different colors. If the user selects at least one ‘No’, the bar of the sleep duration changes color to red, if only ‘Yes’ is selected, then it changes to blue, and if ‘skip’ button is used, then the bar is grey.

This rule of thumb is incorporated in the final prototype, which may help with the actionability. The ‘rule of thumb’ can be seen as a self-evaluation tool for the user’s night’s sleep, and, when the person, for example, looks at the ‘weekly pattern visualization’, they can see the smileys and compare how the user felt that day and what factors may have influenced the sleep.

For this reason, the first window when opening the application is the rule of thumb window (after the user has gotten the night’s sleep), as seen in Figure 34.

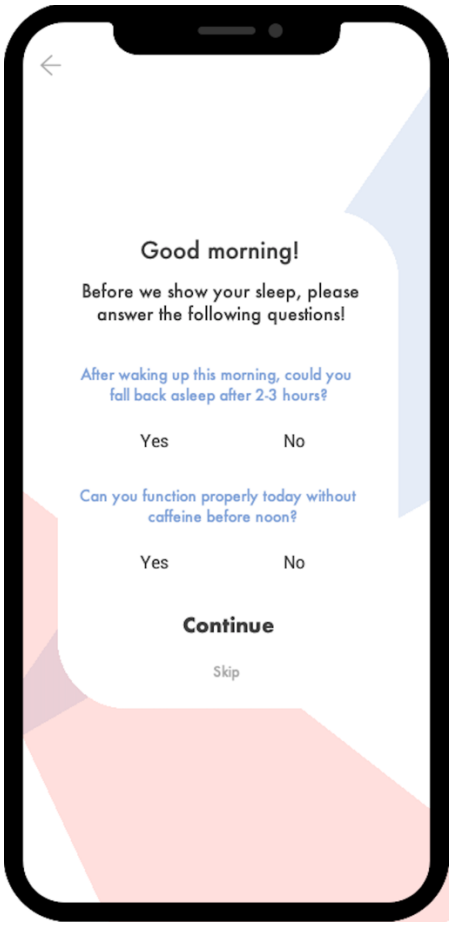


Figure 34: Rule of Thumb window

Additional information tabs

In order to give the user basic knowledge of sleep, as well as how the interface works, additional information tabs are added. If the user wishes, they can learn more about sleep. For each window for sleep duration, sleep stages and other factors there is an added question mark symbol on the top right corner. When the user taps on it, additional information about either sleep or use of the application is shown. These additional tabs can be seen in Figure 35.

1. Main screen

On the main screen the additional tab goes over what the meaning of the colors are. It goes over about how the questions asked in the beginning (Figure 34) influence the colors of bars.

2. Sleep duration

Sleep duration tab goes over the information on regular sleep schedule. On top of that, information regarding missing out on REM and NREM sleep is given.

3. Sleep stages

In this tab information about every sleep stage is given, as well as what benefits to sleep they give.

4. Outside factors

For the outside factors, the tab goes over each of the factors (coffee, devices and exercise), suggesting the daily recommendations and limits.

Figure 35: Additional tabs

Suggestion window

On the bottom of the screen there is a light bulb symbol, which opens a new window of suggestions. The suggestions are personalized and depends on the tracked data. The suggestions are generated based on different factors. For example, if the sleep is not regular or if the user uses too much devices before sleep. The suggestion tab can be seen in Figure 36.

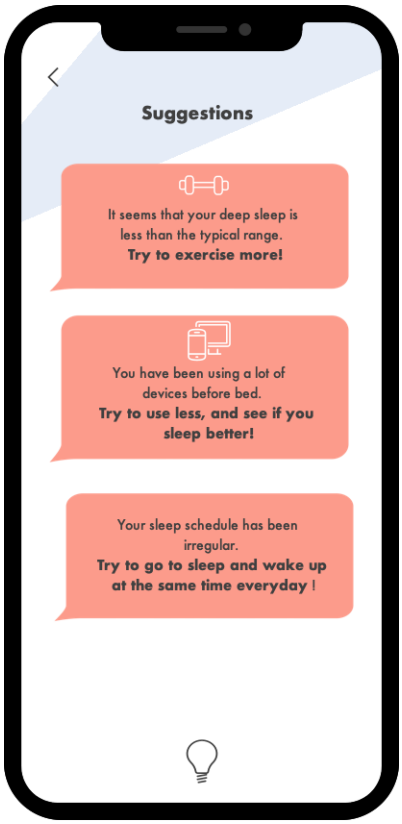


Figure 36: Suggestion tab

7 Evaluation

7.1 USABILITY TESTING

The second user testing is usability testing with the interactive prototype. The goal of this testing is to investigate:

1) if the improved visualizations are understandable
2) if the interface is understandable and easy enough for the user
3) if the added suggestions and information on top of visualizations helps with understanding or if it is only distracting

whether ‘weekly pattern’ would help the user recognize the different factors influencing their sleep

The Protocol for Testing

First, the participant is shown the information brochure, seen in Appendix 3, and an informed consent sheet is also given, and the participant is asked to sign it. The usability test was approved by the ethical committee. After the participant is given all the information about the test, the usability test can start.

The usability testing is conducted remotely, using video chat platforms Skype and Google Meets. The wireframe design platform JustinMind provides an online tool to share the prototypes, making it possible for anyone to try the interface on their computer. The prototype was shared to the users before the test, and the users did the test on their computers. During the test, the screen of the user's prototype and their actions are recorded, as well as their voice for further analysis of both tasks and the interview.

Before the test, the user gets informed that they need to imagine themselves using the application after a night of sleep. Firstly, the user is given a couple of tasks in order to help with goal 2 (find if the interface is understandable and easy enough for the user) of this user testing.

The tasks are the following:

Task 1: Familiarize yourself with the interface

This task did not have a time limit, the users were told to familiarize themselves with the interface until they are ready to continue.

Task 2: You want to find more information on how the application works.

Task 3: Sleep duration – find which days you did not feel like you got enough sleep.

Task 4: Sleep stages - Find out what the average deep sleep amount you have been getting in the last 7 days.

Task 5: Devices - Find out whether you used devices past the recommended time last night.

Task 6: Weekly pattern - Find out which days in the past 7 days you drank coffee past the recommended time.

Task 7: Info tab - You want to know more about the sleep stages. Where would you find the information?

Task 8: Find the suggestion tab

The user completes the task correctly when they achieve the following for every task:

Task 2: Reached the window of the added information tab accessed by the main tab

Task 3: When the user replies: July 2nd, and Last night

Task 4: When the user replies: 55%

Task 5: When the user replies that he used the devices past the recommended time

Task 6: When the user replies: July 2nd, July 4th and Yesterday

Task 7: Reached the window of added information tab accessed by the sleep stage tab

Task 8: Reached the suggestion window (by tapping on the light bulb on the bottom of the screen from any window)

After the tasks are done, a semi-structured interview takes place. There are general questions asked, however, if a discussion arises, different questions might be asked in order to elaborate. The following questions are asked:

1) Do you find the interface easy to navigate?
2) Do you find these visualizations easy to understand? If not, why?
3) Look at the sleep stage 'information tab'. Do you find it helpful that there are added suggestions and information on top of the visualizations or is it only distracting?
4) Look at the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
5) If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
6) Are there any suggestions to improve the interface?

7.2 RESULTS OF USABILITY TESTING

In total, six people participated in the usability testing. The participants were recruited privately. Two participants did not participate in online questionnaire, and four people participated. The following table displays the participants, their age and their educational background.

Participant	Age	Educational background
User 1	21	Business Administration, Bc
User 2	22	Business and Languages, Bc
User 3	23	Sports Management, Bc

User 4	34	Business Administration, Ms
User 5	20	Electrical Engineering, Bc
User 6	22	Medicine

Table 8: Usability test participants and their background

The usability testing consisted of two parts: the task part and the interview part. The task part is analyzed in a way to see how quickly the tasks were done, as well as how many clicks the user did in order to finish the task. The interview part, however, is transcribed and can be seen in Appendix 4.

7.2.1 Task Analysis

	User 1		User 2		User 3		User 4		User 5		User 6	
	Clicks	**Time**	**Clicks**	**Time**	**Clicks**	**Time**	**Clicks**	**Time**	**Clicks**	**Time**	**Clicks**	**Time**
Task 1	12	2 min 13 s	2	30 s	1	6 s	4	42 s	3	24s	3	16s
Task 2	1 (min 1)	5 s	1	2 s	3	3s	1	5 s	1	3s	3	3s
Task 3	1(min 1)	7 s	1	24s	4	1 min 20 s	1	8 s	1	8s	1	12s
Task 4	1 (min 1)	9 s	1	16s	1	10 s	4	1 min, 26 s	1	13s	1	20s
Task 5	2 (min2)	9 s	2	22s	2	30 s	2	31 s	9	*30s*	5	25 s
Task 6	3 (min 2)	10 s	4	26s	5	28 s	9	27 s	2	7s	3	22s
Task 7	3 (min2)	8 s	2	15s	2	15 s	10	32s	6	15s	2	11 s
Task 8	1 (min 1)	2 s	2	16s	8	21 s	1	5s	1	2s	19	57 s

Table 9: Usability testing results

Table 17 shows the time it took for the users to finish the tasks, as well as the number of clicks until they finished the tasks. Task 1, which was to get to know the interface, was done the longest by User 1, as well as the number of clicks that were done, meaning that the user looked around in many of the windows of the interface. User 1 had the fastest task finishing times compared to other users, which may have been caused by the user taking around 2 minutes to familiarize himself with the interface. Other users did not take as much time for task 1, however User 2 finished the tasks in optimal number of clicks, that is, in only one of the tasks the user had 2 more clicks than the minimal clicks needed to finish. User 4 had problems reaching the window of task 7, User 5 had problems reaching window of task 5 and task 7, and similarly User

6 with task 8. Some of these may be attributed to the interface, however during the usability testing some of the users did not properly understand tasks the first time they heard them and had to be reminded again.

7.3 INSIGHTS FROM THE USABILITY TEST

Overall, all people participating in the usability test did not have many issues working through it. The biggest problem with the interface seems to be the learning curve – multiple people had to do a trial and error before getting completely comfortable with the interface, which is an issue of the interface and not the tool that was used for the usability testing. It was very well noticeable with user 1, who was the only one who took some time to get familiar with the interface, going through every tab and reading through. As seen in Table 9, user 1 had the fastest times of completing the tasks, which could be explained by the user taking the time to get familiar with the interface. User 3 mentioned: '*I think it is easy, but if you know. If you did not know, then it is hard. But when you use it regularly, you can see, you already know where to look.'*. User 4 said *'When we just started, you saw that I wasn't really sure what to do, Like, I'm in this stage and you asked a question and I did not know where to click and get the info'*. A recommendation from user 4 is the following: '*it would be nice to have like a general first usage guideline that can pop up everytime, but you can , if you forgot it pops up everytime, but as soon as you click 'don't show it to me again', you can remove it from everytime you start the app. That would be really nice'*.

Overall, the visualizations seem to be easily understandable by all participants. Some recommendations were given to improve some of the visualizations. Some of the recommendations that user 1 mentioned are the following:

1. '. For the sleep duration, as I said, maybe put the dates in front and maybe make this (pointing at the sleep duration weekly) scrollable, because I don't always wake up before 9...'
2. 'it would also be nice if you could maybe click on the different days in the sleep duration to see the information of sleep stages or the overview of the day like here (shows the main screen). Now you have it for the last 7 days, but maybe that you would have it for like every individual day as well'
3. Maybe here (pointing at the other factors tab) it could be that, I mean if I want to know what I did right or wrong, now I have to look it myself. But maybe at the point it

could be like 3 bullet points, like you drank 1 cup of coffee too late or so, however you want to formulate it, and then second bullet point 'You used your device too late' and 'you exercised too little', right? And then you could see three bullet points here.'

User 2 would want a bit of a summary added to how many devices have been used in a day: 'Like, here you can see that it is 40 minutes before sleep (pointing at the outside factors on the main screen), but here(pointing at the devices in the outside factor tab) if you would like to summarize how many hours the device usage is, then at the side a total amount of hours spent on devices would be nice perhaps.'

At least a couple of people mentioned that it would be better to outline the buttons or make it somehow more visible that the text is clickable, and it is a button. User 2 says: '*I would suggest to highlight the text that is clickable and not clickable, so it stands out',* user 4 mentions:

'Just the one that I specified at the beginning to have the sleep duration, sleep stages and outside factors bolder, just to understand that those are 3 different things that you can click on and investigate', user 5 says: '*maybe doing like a light hint of ovalish button, rounded square around certain things will make it more obvious that you can click on another tab. And for example, if you have yesterday selected, you can have an outline, like in blue and then add light red outline for the other know, to know which one you're looking at. And in the app blue is used for good and red for bad, like on and off.'*

One of the goals of this usability testing was to find if the 'weekly pattern' would help with the actionability. All of the participants, when asked question 4, knew to look at the devices, coffee consumption and exercise and compare it to the days the visualization had red or blue smiley faces. All of the participants then noticed relationships, and said that to improve their sleep, they would not drink coffee before sleep, as well as not use devices before bed time.

Additionally, every respondent liked and found it helpful that there are suggestions and also information added on top of the visualizations. User 1 mentions that it is easier to recognize things that are going wrong when there is something that points it out, '*if I would look at this and had like no idea that you need regular sleep, then I would think, okay, this is quite irregular, but who cares? And then here it says that it is irregular, and that makes me think, alright, I should care about it.'* User 4 also mentions: '*, but having an option to educate yourself a little bit on certain stages of sleep or other things, is pretty helpful.'*

To conclude, the prototype was well received by all of the participants, however there were some small issues when using the prototype. The visualizations were easy to understand,

however the added interactions on top of visualizations make it harder for the users to easily use the prototype at first. Therefore, the prototype needs a learning curve in order for it to be used properly and easily. The usability testing also showed that the new ‘weekly pattern’ visualization and suggestions also make people be more aware of their habits and how to change them, therefore making the visualizations actionable.

7.4 THIRD ITERATION SLEEP DATA VISUALIZATIONS

This section goes over all the changes made to the prototype based on the feedback from the usability testing.

Firstly, multiple buttons were improved for the prototype. As a few participants mentioned, the buttons were not visible or bold enough. For that reason, instead of having just a text as a button, an oval rectangle with text inside is used as a button, therefore making it easier to spot. The new buttons are put for the main screen, and outside factor screen, as seen in Figure 37.

Figure 37: New Buttons after usability testing feedback

Secondly, one of the users mentioned that having bullet points as an overview for outside factors would be a nice additional feature, however the main tab is already used as an overview for the day, and clicking further on the factors is supposed to give a more detailed view. Therefore, instead of adding the bullet points, an exclamation point will be added in the main tab when one of the two factors (coffee and devices) is used past the recommended time. This way the user has a quick view to see if coffee or devices were used properly or not, without having to look at a more detailed information. The new improvement can be seen in Figure 38, as well as the added new buttons.

Figure 38: Outside factor improvement after usability test

Thirdly, a small change is made for sleep duration weekly visualization of having the dates aligned in one column, for a better aesthetical design.

Finally, one of the main things that could be added is a walk-through of the application, as many usability test participants had mentioned, however it is outside of the scope of this

thesis, since the walk-through helps with the understanding of the application and the interactivity, rather than the actual visualizations.

Although it is not the main goal of this research, in order to achieve an understanding of visualizations, the users first need an overview of how the visualizations work together with an added interaction. Visualizations on their own are understandable, however once they are put together, the interaction between the visualizations might be confusing for the first time users.

8 Discussion

The aim of this study was to investigate ways to present sleep-tracked data in a way that is educational to the user, as well as the user is able to recognize the relationships between multiple outside factors and sleep, consequently being able to take action into bettering their sleep quality.

The main results of this research are the following: to present sleep information in an understandable and actionable way, many elements of the existing sleep-tracking applications should be used. It was seen in the questionnaire that many participants choose visualizations that are more familiar and therefore easier to understand, rather than ones that may look more interesting and unique, however that could have also been influenced by the fact that 53% of the participants had used a sleep-tracking application before. As well as the visualizations should be as simple and straight-forward as possible, because many people want to take a quick look and get the information instantly, without having to figure out what the visualizations try to convey. Additionally, to make it actionable, multiple factors that influence sleep should be included in the visualizations. For example, ‘weekly pattern’ visualization made participants aware of what things they should change in order to improve their sleep, therefore making the visualization actionable. To add, when the visualizations are put in an interactive interface, to help with the understanding and actionability, suggestions and extra information can be provided. All of the participants during the usability testing noted that they found the suggestions and information very useful, since it makes the user think more about their sleep when the interface says what should be improved. Additionally, extra information is good when the user wants to learn more about the sleep.

One of the sub-research questions was ‘What kind of sleep data should be collected and presented?”. Firstly, after reviewing sleep-tracking applications, all of the applications shared the same type of sleep data: sleep duration, time when the user went to

sleep, and woke up, and sleep stages. These elements are the main features of the sleep-tracking applications, therefore this data should be collected. According to Walker [5], there is a big importance of balance between NREM and REM sleep, which means that it is also important to keep track of sleep stages.

There are many different factors that influence sleep, according to Walker [5]. This helps to answer the second sub-research question 'What other data can be combined with sleep data?'. Various outside factor data can be collected in order to show the users that there are also other factors that they do in their daily life that influence sleep. For example, coffee consumption after certain time will leave a person with deceased sleep quality. There are various factors, as seen in Table 1, however not all of them can be measured. The factors that can be measured and also combined with sleep data are: coffee consumption, exercise amount, device usage before bed and others.

To answer the last sub-research question 'What is the current state of the art of sleep tracking visualizations?', a few of the currently available applications were reviewed. The findings were similar to Liang & Ploderer [4] – users are simply shown the data, however they might not be able to take action into bettering the sleep. Most of the applications show the data, however, rarely give more insights to improve the sleep of the users and provide any contextual factors. However, it was found that the applications share similar structure and similar visualizations in terms of looks, as well as the data shown.

There were certain limitations of the study, one of them being COVID-19 lockdown. Due to the lockdown, it was not possible to conduct the usability tests in person, which unfortunately may have altered the results. Specifically, a mobile interface prototype had to be tested through a computer screen, which removes the realness of testing a mobile prototype on the designated device.

Furthermore, a drawback of the usability testing was that the interface had a learning curve, and therefore could not be properly tested, because the users were still getting to know the interface. Although the visualizations on their own are understandable by the users, the actual interactivity may take a while to learn

Additionally, the prototype was not developed fully accessible. The first iteration of visualizations did not account for color-blindness by using red and green colours together, as well as other possible accessibility issues.

Finally, some of the visualizations for the online questionnaire did not share the same information in the same category, by having small differences. This might have also influenced results of the study. That issue was pointed out by a few participants of the online questionnaire.

One of the strengths of this study was that the appropriate research methods were used. Additionally, two different types of testing were conducted during this research, which provided more realistic results and more feedback to be incorporated for the final prototype.

Another strength of this research is that there are not many studies done on this topic. As such, the amount of literature on this topic is limited, which makes this research more unique and can be used as a starting point for other researchers working on sleep-data visualizations.

To conclude, although there were some limitations, the goal of this research has been reached and the ways to make understandable and actionable visualizations have been found.

9 Conclusion

To conclude, in order to develop understandable and actionable sleep-data visualizations, it should have the following qualities:

- Elements of the existing sleep-tracking visualizations should be used,
- Visualizations should be as simple and straight-forward as possible,
- to make it actionable, multiple factors influencing sleep should be included in the visualizations, just like in ‘weekly pattern’ visualization

Additionally, when the visualizations are put in an interactive interface, suggestions and extra information about sleep elements can be provided.

Furthermore, the usability testing showed that the interactive sleep-data visualization interface had a learning curve, therefore, in order to help with the understandability of the interface, a walk-through video or guide can be added for the first-time users of the interface.

10 Future Work

Firstly, due to the global pandemic of COVID-19, it was not possible to do the usability testing face-to-face and because of that the testing had to be done online. Unfortunately, since the prototype is a mobile interface, it was not possible to test it out on a mobile device, instead it was tested through a computer. For a future work, a face-to-face test would be a better way to test a prototype.

Secondly, more functionality could be tested. For example, adding weekly or monthly visualizations to the prototype and then the actionability of such visualizations can be tested.

Thirdly, the current prototype is only a design prototype, however for a future testing, an AI tool could be incorporated, which would look at the relationships between outside factors (for example, coffee) and other sleep data, like deep sleep or sleep duration. The AI tool could make the visualizations more actionable, because it would see more detailed relationships between many factors.

Lastly, the usability testing could be done with people less knowledgeable with technology. For this usability testing, most participants were aged between 20 and 30 years old. However in the future, people in different age groups could be tested in order to see how understandable the visualizations and the interface is for people in different age groups.

Appendix 1 – Questionnaire

Default Question Block

You are being invited to participate in a research survey by Laura Maškanceva. This questionnaire is a part of my graduation project for Creative Technology at the University of Twente.

Many sleep tracking applications do not provide sufficient support to improve the user's sleep and give insights into why the sleep might be lacking. My graduation project focuses on developing a sleep tracking application interface that might help the user understand how they could improve their sleep. With this study I want to test multiple prototypes in order to find which people find more understandable, actionable and appealing.
The more people that can participate in this study, the more it will help me with this project.

This survey will take you approximately ***15*** minutes to complete.

By participating in this study, you agree that **you are 18 or older to be able to give informed consent.**

Your participation in this study is **entirely voluntary** and you can withdraw at any time. You are free to omit any question.

Your data is processed **completely anonymously.**
Thank you for contributing to my graduation project!

If you have any questions or remarks, you may contact me:

Laura Maskanceva
Creative Technology at the University of Twente
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Contacts of my supervisors:
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Dr. Christiane Grunloh
c.grunloh@rrd.nl

Roessingh Research and Development

If you have any complaints about this research, please contact the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL).
E-mail: ethics-comm-ewi@utwente.nl

Have you read the above information and do you agree with participation?

- ○ Yes, I have read the information and agree to participate
- ○ No

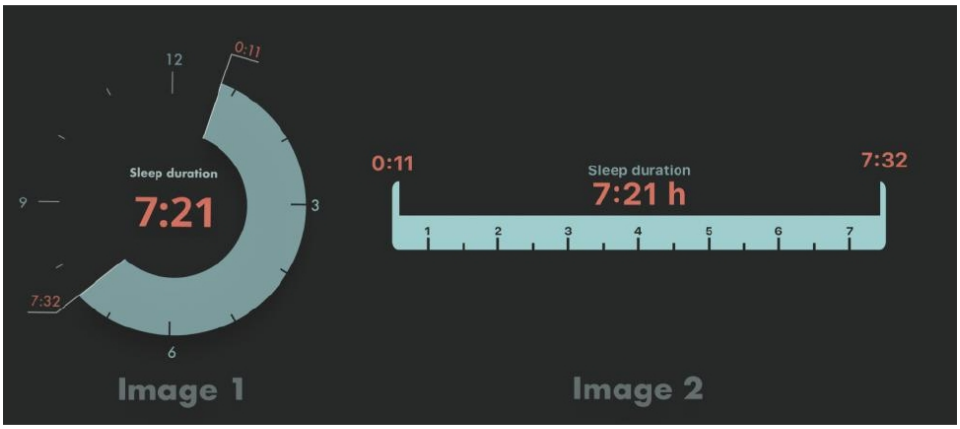
In the following pages you will be shown images of sleep tracked data.

You will be asked questions about how you understand the shown images, as well as you will be asked questions about what actions you would take if you were in the user's place that has the displayed data.

Take some time to observe the images and then proceed to answer the

questions.

Two images that share the same information about a night's sleep are given below. Observe them and answer the questions below.



Answer the following questions based on the images you see above:

1)What was the user's sleep duration?

2)The time the user went to sleep:

3)The time the user woke up:

Which one of the images (1 or 2) do you think is more understandable? (Easier to tell the duration of sleep, etc.)

- ○ Image 1
- ○ Image 2
- ○ None of the above

Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about the trends of night's sleep are given below. Observe them and answer the questions below.

Answer the following question based on the images you see above:

1)What is the average sleep duration in last 5 days?

Did the user sleep more or less last night compared to the last 5 day average?

- ○ More
- ○ Less
- ○ Can't tell

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

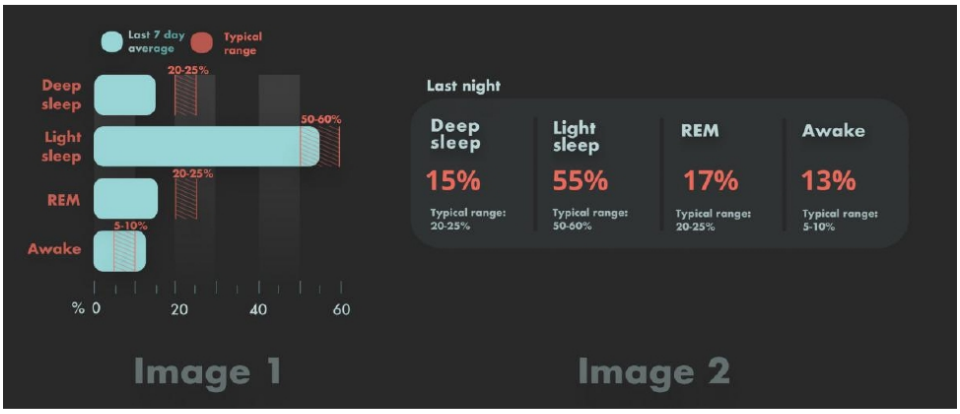
Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about a night's sleep are given below. Observe them and answer the questions below.



Answer the following question based on the images you see above:

1)What is the typical range of deep sleep?

2)How much REM sleep did the user get last night?

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- Image 1
- Image 2
- None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about several night's of sleep are given below. Observe them and answer the questions below.

Answer the following question based on the images you see above:

1)What changed last night in comparison to the average?

2)Did REM sleep increase or decrease, and by how much?

3)What is the typical range for light sleep?

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

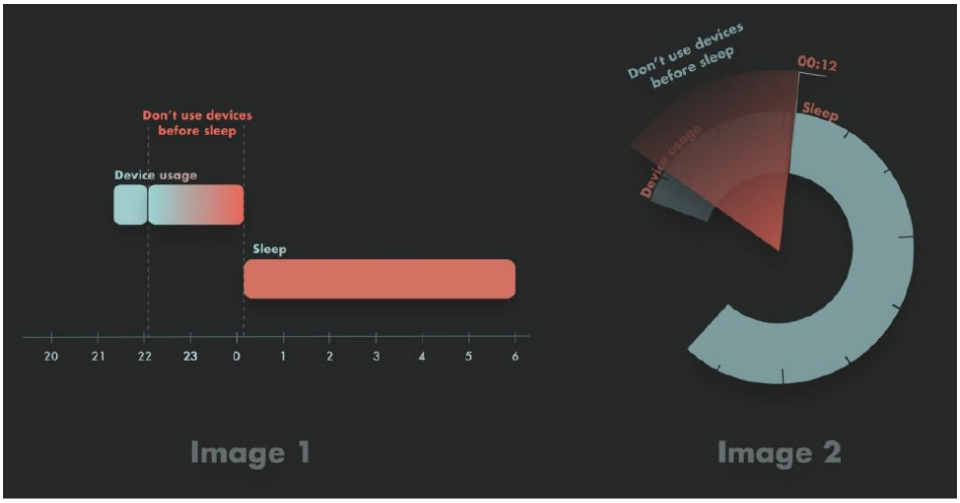
Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- Image 1
- Image 2
- None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about a night's sleep are given below. Observe them and answer the questions below.



Answer the following question based on the images you see above:

What was the user doing before sleep?

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

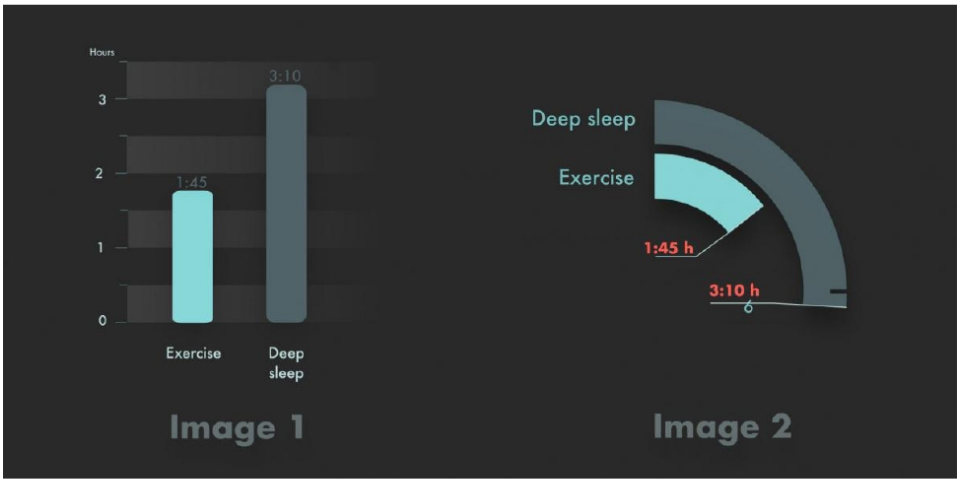
Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about a night's sleep are given below. Observe them and answer the questions below.



Answer the following question based on the images you see above:

What relationship is depicted in the images above?

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

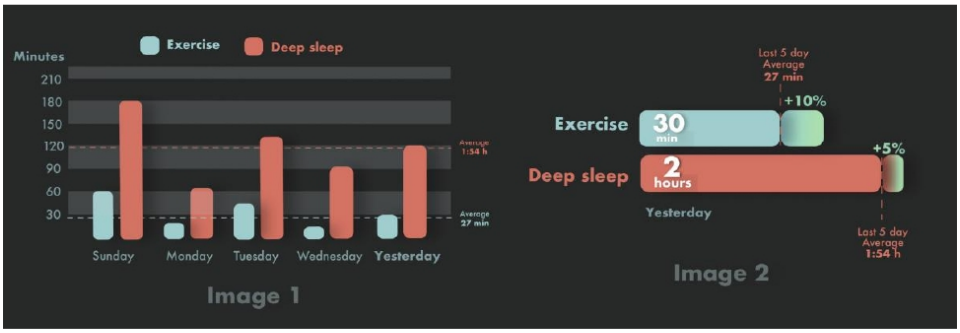
Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Two images that share the same information about several nights of sleep are given below. Observe them and answer the questions below.



Answer the following question based on the images you see above:

1)What is the average exercise time in the last 5 days?

2)What was the amount of exercise yesterday (in min)?

3)By how much more did exercise time increase yesterday compared to the average?

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Why is the image you chose more understandable? (Optional)

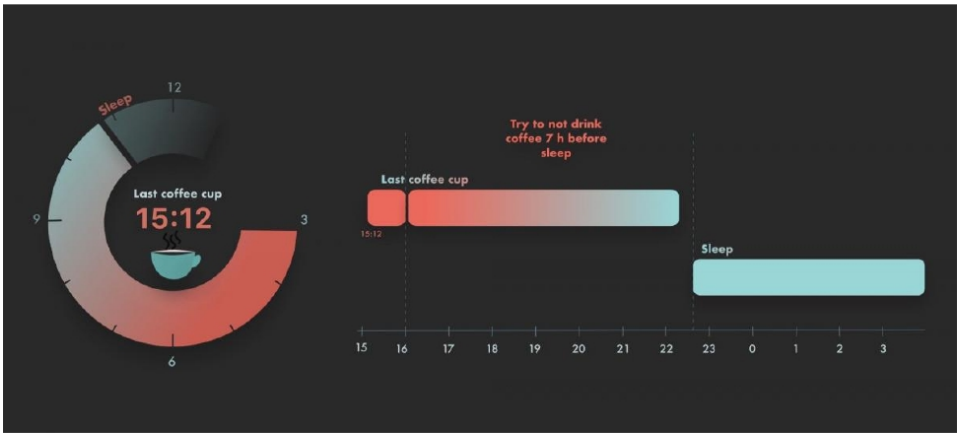
Which of the two images do you find more aesthetically pleasing?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Block 1

Two images that share the same information about a night's sleep are given below. Observe them and answer the questions below.



Answer the following question based on the images you see above:

What time did the user drink his last coffee cup?

Based ONLY on the images above, what would you recommend the owner of this sleep data to do?

- [ ] Sleep more
- [ ] Sleep less
- [ ] Stabilize the sleep rhythm (strive to sleep the same hours every day)
- [ ] Do not use devices before sleep
- [ ] Do not drink coffee before sleep
- [ ] Keep exercising daily
- [ ] No recommendations
- [ ] Other

Which one of the images (1 or 2) do you think is more understandable?

- ○ Image 1
- ○ Image 2
- ○ None of the above

Why is the image you chose more understandable? (Optional)

Which of the two images do you find more aesthetically pleasing?

- Image 1
- Image 2
- None of the above

Do you have any suggestions for the images above? Do you have any recommendations about information that is given in the images? (Optional)

Lastly, some general questions will be asked.

What is your age?

- ○ 18-24 years old
- ○ 25-34 years old
- ○ 35-44 years old
- ○ 45-54 years old
- ○ 55-64 years old
- ○ 65-74 years old
- ○ 75 years or older

What level of education have you acquired?

Do you ever think about your sleep? (The reasons for lack of sleep, how to sleep better etc.)

- ○ Yes
- ○ No

Have you ever used sleep tracking apps before? (With or without sleep tracking devices like FitBit or Apple Watch)

- ○ Yes
- ○ No

What was the motivation to start tracking your sleep?

- [ ] To improve the sleep quality
- [ ] To find the reasons for poor sleep
- [ ] To gather data
- [ ] Other (please specify)

What devices or sleep applications have you used?

- [ ] FitBit
- [ ] Apple Watch
- [ ] Garmin
- [ ] Seep Cycle Alarm Clock
- [ ] Other (please specify)

Has the use of sleep tracking helped you in any way?

- [ ] Improved my sleep quality
- [ ] Found out the reasons for bad sleep
- [ ] Improved the regularity of sleep
- [ ] Made me more aware of my sleep habits
- [ ] Other (please specify)
- [ ] No, the use of sleep tracking has not helped me in any way

Appendix 2 – Detailed Analysis of Questionnaire questions

Sleep duration

The unique questions for these visualizations were to find the sleep duration, the time the user went to sleep and the time the user woke up. For all three questions all respondents responded correctly.

For the question “Why is the image you chose more understandable?”, 53% of respondents preferred Image 1 and 47% preferred Image 2, meaning that respondents did not specifically prefer one visualization over another. From the people who chose Image 1, 26 of them mentioned that it is easier to understand, as it resembles a clock and it is more natural and intuitive when it is visualized in a clock shape. 3 remarks were made about the clock being only 12 hours, and sleep with more than 12 hours would not be possible to visualize, as well as one person thought that the clock resembles a goal (so if the whole ‘circle’ would be full, then the user got enough sleep), which was not the point of the visualization.

2 of respondents specified that they imagine time linearly, therefore Image 2 felt more natural to them. 18 of the people who preferred Image 2 mentioned that it is easier to read, as it goes from left to right and a linear graph is in first glance easier to read than a circular one. 4 people also found the bigger font better in Image 2.

For the question “Which one do you find more aesthetically pleasing?”, 78% preferred Image 1. Table 10shows the suggestions from the respondents for these visualizations.

Image 1	Image 2
- make it a 24h clock instead of a 12h - add a green line in which you see the wished sleep amount -add an indication of when sun rises - make it clear that 0:11 is when the user went to sleep and 7:32 is when the user woke up	-add rest of the hours, just like in image 1 (12h) -add a legend for the ‘ruler’ (confusing whether the numbers are time of the day or time duration)

Table 10: Suggestions from the respondents for sleep duration

Sleep duration trends

The unique question for these visualizations was to find the average sleep duration in last 5 days, which all respondents got correct.

For the question “Why is the image you chose more understandable?”, 82% percent of respondents preferred Image 1, 18% preferred Image 2. 31 respondents specified that they preferred Image 1, because it mentioned that it is better when the whole week is seen, and not only one night and the average , as well as a bar chart is easier and faster to read than the clock, however people who chose Image 2 liked it because of the clock interface.

Table 11 displays the suggestions from the respondents.

Image 1	Image 2
-Add the times of when the user woke up and went to sleep each day. -Not use different bars for minutes slept over average, also not use different colors, just overall color if it was a good or a bad night. -Remove the vertical bars in the background -Add suggestion to the user -More attractive colors -Put 7:36 in a different spot (so it is not interpreted as 7:36 +0:42)	- Add previous times of sleep duration

Table 11: Suggestions from the respondents for sleep duration trends

One person suggested to use both, so Image 2 would be an easy overview, while Image 1 would be more detailed.

Sleep stages

The unique questions for these visualizations were to find the typical range of deep sleep, and REM amount the user got last night, of which 93% and 95% were answered correctly, respectively.

For the question “Why is the image you chose more understandable?”, 15% of people chose Image 1 and 84% preferred Image 2. People who chose Image 1 liked that it

immediately shows how the weekly sleep stage pattern compares to the average, however 76% of those who chose Image 2 felt that Image 1 was way too visually stimulating, has too much information and thus preferred Image 2, because it is clear with no extra information. Table 12 shows the suggestions for improvements to these visualizations from the respondents.

Image 1	Image 2
-Add 'too little', 'just right' or 'too much' instead of the typical range, also change color accordingly -remove vertical bars in the background - skip the red striped range, put a green line below -better colors -Instead of typical values, provide the number of last 7-day average	-use in combination with a relative visualization (a pie chart) to get a quick view, but also a more detailed one. -better colors - If the data of last sleep falls within the typical range, it can be made green, if it falls outside, then colored red

Table 12: Suggestions from the respondents for sleep stages

Sleep stages trends

The unique questions for these visualizations were to find what changed last night in comparison to the average, find whether REM sleep increased or decreased, and what is the typical range for light sleep. 98% of the answers were answered correctly.

For the question "Why is the image you chose more understandable?", 15% of the respondents chose Image 1 and liked that it was visualized in a graph form. 81% preferred Image 2, because similarly to sleep stages in the last visualizations, the respondents found Image 1 way too cluttered, too much information. Image 2 was easier to understand and to compare when there are percentages written out. Table 13 displays the suggestions for the improvements from the respondents.

Image 1	Image 2
-not use red color for typical range and decreasing time. Make the color of percentages white or blue. - Do not combine percentages and minutes	-Percentages with different colors (green, orange, red) may help indicate if part of the sleep is in the good range or not

Table 13: Suggestions from the respondents for sleep stage trends

Similarly to the previous visualizations, it is suggested to combine them.

Device usage

The unique question for these visualizations was to see if the people recognized that the user used devices past the recommended time. All of the respondents answered correctly.

For the question “Why is the image you chose more understandable?”, 73 % of the people chose Image 1 and 23% chose Image 2. Image 1 was preferred over Image 2 because it is clearer and easier to understand. 20% of people who chose Image 1 were confused about Image 2 and how to understand it. However, Image 2 was preferred by people who liked that time is shown in a circular manner. Table 14 displays the suggestions for the improvements from the respondents.

Image 1	Image 2
- clearly indicate what blue and red mean, and the transition between the two - Indicate more clearly when the devices are not used -add advised time to go to bed -more clear colors - Try not to use ‘command form’, but more of an advice -Make it clearer that it is for the user, not a general recommendation	-Smaller overlay and no red on red text

-add negative consequences of using devices before sleep -add clear time when the user went to sleep	

Table 14: Suggestions from the respondents for device usage

Exercise

A unique question for these visualizations was to see if the respondents see any relationships in the visualizations. All of the respondents responded correctly.

For the question “Why is the image you chose more understandable?”, 57% chose Image 1 and 38% preferred Image 2. Image 1 was more preferred over Image 2 because it is a linear graph and is easier on the eye. However, those who preferred Image 2 mentioned that Image 2 clearly shows the relationship between deep sleep and exercise. Table 15 displays the suggestions for the improvements from the respondents.

Image 1	Image 2
-make it clearer that there is a relationship -include an average -make numbers red	-make it clearer that there is a relationship -include an average

Table 15: Suggestions from the respondents for exercise

Exercise trends

The unique questions for these visualizations were to read data off the visualizations, and 95% of people responded correctly.

For the question “Why is the image you chose more understandable?”, 57% of people chose Image 1 and liked that it included multiple data from previous days and found it more understandable and that there is a clear comparison. 36% of respondents preferred Image 2. However, multiple people noted that they did not see any correlation between deep sleep and exercise. Table 16 displays the suggestions for the improvements from the respondents.

Image 1	Image 2
- Add how many hours/min the person exercised - More pronounced lines indicating averages	-make numbers smaller -do not mix minutes and percentages

Table 16: Suggestions from respondents for Device usage trends

Coffee consumption

A unique question for these visualizations was to find what was the last time that the user consumed coffee. All of the answers given were correct.

For the question “Why is the image you chose more understandable?”, 55% people chose Image 1 and preferred it because the advisable time not to drink coffee is more precise, as well as the time is easier to read. 39% of people chose Image 2 preferred the linear interface to visualize time.

Image 1	Image 2
- Clearer indication of what the transition from red to blue means - Have a clearer indicator of when last coffee was consumed. - Make dashed lines clearer - Consistent color scheme - Add a ‘countdown’	- Have a clearer indicator of when last coffee cup was consumed.

Table 17: Suggestions from respondents for coffee consumption

Appendix 3 – Information Brochure and Informed Consent

Informed Consent for standard research

'I hereby declare that I have been informed in a manner which is clear to me about the nature and method of the research as described in the aforementioned information brochure 'Sleep-tracking application interface usability test". My questions have been answered to my satisfaction. I agree of my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason and I am aware that I may withdraw from the experiment at any time. I agree to have my voice recorded. If my research results are to be used in scientific publications or made public in any other manner, then they will be made completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact:

Laura Maskanceva
l.maskanceva@student.utwente.nl

Miriam Cabrita
m.cabrita@rrd.nl

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c.grunloh@rrd.nl

If you have any complaints about this research, please direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

Signed in duplicate:

....

Name subject *Signature*

I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.'

Laura Maskanceva .....

Name researcher *Signature*

Enschede, 9.07.2020.

Information brochure
‘Sleep-tracking Application Interface Usability Test’

Dear reader,

In this letter, we would like to inform you about the usability test you have applied to participate in. The test will take place on 16-07-2020, online with the online communication tool Skype. In the proposed research, entitled “Developing understandable and actionable sleep-tracked visualizations”, a prototype for a sleep-tracking application interface is tested. The usability test is a part of my bachelor graduation project for Creative Technology. The aim of this research is to develop understandable and actionable sleep-tracked visualizations.

During this test, the participating tester is presented with a smartphone application interface through a link that will be given during the research. The prototype will be available in a web form, not in a physical form on a smartphone, therefore it is important that the tester uses the prototype as if they would use a smartphone.

The prototype will show a data from last night’s sleep from a certain person. The tester would have to imagine that it is their data that they got from last night’s sleep, and explore the prototype with that in mind. The tester will be asked to perform a couple tasks on the prototype. After that, a few questions about their opinion on the prototype will be asked.

You can decide to stop at any point in the course of the research without this having any consequences for yourself and without giving any reasons. You will be recorded during the test. Your data will be handled in a confidential manner, the anonymity of your data is guaranteed and will never be disclosed to third parties without your permission.

Yours sincerely,

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Appendix 4 – Usability test interviews

User 1

Interviewer: Do you find the interface easy to navigate?

User: Yes, I do.

Interviewer: Do you find it intuitive?

User: Yes, well, I mean, yeah. It is pretty straightforward, it is pretty easy to use. I don't think people would, like, have problems with using this.

Interviewer: Do you find these visualizations easy to understand? If not, why?

User: Let me see. I think I got pretty much everything. Yeah, I think these are pretty clear. For the sleep duration, as I said, maybe put the dates in front and maybe make this (pointing at the sleep duration weekly) scrollable, because I don't always wake up before 9, so, but yes, this is pretty easy to understand. Let me see other visualizations. Oh, maybe it would also be nice if you could maybe click on the different days in the sleep duration to see the information of sleep stages or the overview of the day like here (shows the main screen). Now you have it for the last 7 days, but maybe that you would have it for like every individual day as well. That might be nice. Yeah, these are pretty clear (pointing at sleep stages). Yeah, also makes sense that you drank a cup too late (pointing at the coffee consumption visualization). Maybe here (pointing at the other factors tab) it could be that, I mean if I want to know what I did right or wrong, now I have to look it myself. But maybe at the point it could be like 3 bullet points, like you drank 1 cup of coffee too late or so, however you want to formulate it and then second bullet point 'You used your device too late' and 'you exercised too little', right? And then you could see three bullet points here.

Interviewer: So, you would not have to scroll through it?

User: Yeah, I mean it is like still interesting to see this, for sure, but maybe just 3 bullet points like makes it maybe a bit quicker or so to see. And then this one (weekly pattern), yeah this all makes sense. Yeah, like maybe in the future it could get more advanced that it would recognize the patterns itself.

Interviewer: Look at the sleep stage 'information tab'. Do you find it helpful that there are added suggestions and information on top of the visualizations or is it only distracting?

User: No, it is very helpful. Especially, like you kinda recognize the stuff yourself as well, but if you have like a little text that says, alright, this is going on, that makes it easier to recognize.

Because people also like, if I would look at this and had like no idea that you need regular sleep, then I would think, okay, this is quite irregular, but who cares? And then here it says that it is irregular, and that makes me think, alright, I should care about it. So yeah, it gives some insight to people I think, for sure.
Interviewer: Go to the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: Well, obviously, don't drink coffee, like 7 hours before you go to bed and then don't devices before bed.
Interviewer: If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
User: In this, I see that 2 or 3 times for the coffee it is like a red face, and probably that has quite some impact, so maybe don't drink coffee that late. And also, this, 6:46 , I guess sleep more, don't take coffee that late and also devices and exercise should be important. But I think the main thing what I would recognize for this is the coffee.
Interviewer: Are there any suggestion to improve the interface or anything you want to add?
User: Yeah, as I said, the bullet points here maybe, and I mentioned some stuff along the way. And the scrollable things here, maybe being able to click on the individual days and click. And it is basically it, I guess.

User 2
Interviewer: Do you find the interface easy to navigate?
User: I think yeah, it is. It is really neat, the design is nice.
Interviewer: Do you find the visualizations easy to understand?
User: Yes.
Interviewer: Would you change or add anything to them?
User: I'm not sure, there was this one thing. Like, here you can see that it is 40 minutes before sleep (pointing at the outside factors on the main screen), but here(pointing at the devices in the outside factor tab) if you would like to summarize how many hours the device usage is, then at the side a total amount of hours spent on devices would be nice perhaps. Otherwise I really like the other visualizations.
Interviewer: Do you find it helpful that there are added suggestions and information on top of the visualizations?

User: It definitely is helpful, especially at first, before you have the intuition of where you're going to click and what you are gonna find there. I was first confused with the self-assessment colors instead of it being in a mathematical way, comparing the lowest sleep amount and the highest. This actually makes a lot more sense.
Interviewer: Look at the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: So, here you can see that when you used coffee past the recommended time, you self-assess badly, so think you should be using less coffee. You should just follow the suggestions, really.
Interviewer: If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
User : Not use devices before bed, especially exercising more as well, sleep longer if possible and don't drink coffee before sleep.
Interviewer: Are there any suggestions to improve the interface?
User: I would suggest to highlight the text that is clickable and not clickable, so it stands out. I really like the minimalistic design in the interface and the colors are also really nice, not too barging in your face and not too contrasted.

User 3
Interviewer: Do you find the interface easy to navigate?
User: Yes, and no. Because some things are easy, but some things you need to learn in the process. If you know the device already, it is easy, but if you learn for the first time, then it is hard.
Interviewer: Do you find the visualizations easy to understand?
User: Yes, I think it is easy enough. Because if you have any questions, there is a question mark, as well as suggestions. I think it shows everything in one way to see your results in one day.
Interviewer: Do you find it helpful that there are added suggestions and information on top of the visualizations?
User: I think it's easy, but if you know. If you did not know, then it is hard. But when you use it regularly, you can see, you already know where to look. It is not something you need to use every day, but it is there, and you can use it when you need it. It is just explaining what can improve your sleep data.

Interviewer: Look at the ‘weekly pattern’. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: Maybe use less, because coffee is something that gives you adrenalin and keeps you awake at night and if you are not using devices it will help you fall asleep quicker. You can see in the data during the sleep, if you’re not using coffee and devices, it will help you fall asleep quicker. For example, 3rd July, you did not use coffee and devices, you had more deep sleep. You should see how to use those things less in your daily life.
Interviewer: If you want there to be more ‘blue smiley faces’, what would you change about your night’s sleep?
User : I don’t know. Not use coffee, if you see this example, there are 2 sad faces, so I think the problem is coffee and devices. So, if you want more blue smiley faces, you don’t use those 2 things, and also exercise more.
Interviewer: Are there any suggestions to improve the interface?
User: I think I really like this interface because it shows exactly what you need and it shows like sleep averages, like deep sleep and other things.

User 4
Interviewer: Do you find the interface easy to navigate?
User: Um, it looks nice, definitely gives a good feel and visual information, easy to read it. Maybe would be more beneficial to just highlight the here sleep duration, make it bolder, maybe underline it, so you understand that these are the things that you can click on. It is easier to see it on the computer, because it says what is clickable, I don’t know if it is going to work on the phone, but other than that it is pretty good.
Interviewer: Do you find the visualizations easy to understand?
User: When I first tried, probably not, but as soon as I click on more on them and do a trial and error clicking, then yes, I can understand it easy.
Interviewer: Do you find it helpful that there are added suggestions and information on top of the visualizations?
User: I would probably like to have it fully on top of the home screen, so if I click here, if it would cover it, it would be fine. It is similar to what you have with suggestions, like it covers the whole screen. So, if you could do something similar to question mark, maybe using the same font, then it follows the consistency. You know what else could be really good? Every time a person, for example, if he downloads the app, like there are some apps, as soon as you register, it gives

you like a clickable video, and shows how the interface works. Like step 1, there is a question mark, you find all the answers in the window you are in. The next step is – you click this, and get suggestions. Then step 3 – these are sleep stages and there you can see this and that. If there is a way you can do it, it will be easier for the user to understand it. Like when we just started, you saw that I wasn't really sure what to do. Like, I'm in this stage and you asked a question and I did not know where to click and get the info. But other than that, it is good, I like it.
Interviewer: Look at the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: I would decrease it or follow the guidelines you specified the window here (shows the other factor coffee consumption visualization) when it shows if you're within this window, you may experience not enough sleep, so it is pretty good, I like it.
Interviewer: If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
User : I would try to increase my deep sleep, that's the key factor that is not letting me choose the happy smiley. I would limit the unsafe the limit of devices before sleep, no coffee 2 h before I go sleep, also no exercise before you go to sleep.
Interviewer: Are there any suggestions to improve the interface?
User: Just the one that I specified at the beginning to have the sleep duration, sleep stages and outside factors bolder, just to understand that those are 3 different things that you can click on and investigate. In terms of when the person firstly launches the app, it would be nice to have like a general first usage guideline that can pop up every time, but you can , if you forgot it pops up every time, but as soon as you click 'don't show it to me again', you can remove it from every time you start the app. That would be really nice.

User 5
Interviewer: Do you find the interface easy to navigate?
User: Yes, mostly. I felt like, for example, if I go and look for the weekly pattern, I did not really feel like it was a button. Especially when I opened it up there was a line under the weekly pattern, and I thought it was a part of another visualization.
Interviewer: Do you find the visualizations easy to understand?
User: I do think they are easy to understand. I don't think there's anything that's not easy to understand. I think it's good.

Interviewer: Do you find it helpful that there are added suggestions and information on top of the visualizations?
User: Well, like you don't have to click the question mark icon if you don't want to and if you see a big amount of text and you don't feel like reading it, then you don't have to, but having an option to educate yourself a little bit on certain stages of sleep or other things, is pretty helpful.
Interviewer: Look at the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: It says under 'you have been using devices before bed, try to use less', so I would use my devices less or not within a couple of hours within sleeping and if I realize if I drink 3 coffee cups a day then I drink a bit less, because that's a lot. I also can see here that yesterday I drank coffee after 17:45 and then I would try not to drink coffee after 14 or 15 anymore.
Interviewer: If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
User : Well I see two smileys that are bad and one I slept under 7 hours, so that's probably not good. Then the other one I saw that I used both too much coffee or too late, and the devices in the evening. And also, you can see that the percentages for deep sleep are therefore pretty low, so I would try and make sure sleep enough and not drink too much coffee. It is pretty obvious that there is a correlation between certain ratio of blue blocks to red blocks and unhappy smileys and also the deep sleep, so that would get me thinking about making sure I get enough proper sleep.
Interviewer: Are there any suggestions to improve the interface?
User: Like I said, maybe doing like a light hint of ovalish button, rounded square around certain things will make it more obvious that you can click on another tab. And for example, if you have yesterday selected, you can have an outline, like in blue and then add light red outline for the other know, to know which one you're looking at. And in the app blue is used for good and red for bad, like on and off. For the rest I think it's pretty good and straightforward.

User 6
Interviewer: Do you find the interface easy to navigate?
User: Actually yes.
Interviewer: Do you find the visualizations easy to understand?
User: Yes.
Interviewer: All of them?

User: I would say so, yes. I think every application needs a bit of like, time to know where things are and I think if this was actually pretty easy to understand, of course, when you are going through it the first time, then you don't see the thing that you're looking for right away. I did not have to look for it that much, so I think it's good.
Interviewer: Do you find it helpful that there are added suggestions and information on top of the visualizations?
User: Yes, definitely.
Interviewer: Look at the 'weekly pattern'. If you want to improve your sleep, what would you do about coffee consumption and device usage?
User: So, they have to be reduced before going to sleep, especially looking at yesterday.
Interviewer: If you want there to be more 'blue smiley faces', what would you change about your night's sleep?
User : Definitely not coffee, and devices before sleep. The sleep duration should be higher and sleep duration should be longer, since sleeping longer will make deep sleep longer as well. Exercising is beneficial, also stress and other factors come into play as well, but I mean they are very unique to each person. So, this is very good.
Interviewer: Are there any suggestions to improve the interface?
User: Actually no, maybe with time you could add different colors that people personally could change. Maybe a guy would want something darker, but other than that I would say it is pretty good.

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