Doplor Sleep

Friendly feedback towards a better hospital soundscape for sleep.

Master Graduation Report
Yiling Liu - 4973917

Chair: Elif Ozcan Vieira
Mentor: Jered Vroon
Client: Daan Kamphuis
(Reinier de Graaf Gasthuis)

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Education

MSc. Integrated Product Design
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Faculty of Industrial Design Engineering

Supervisory team

Project chair
Dr. Elif Ozcan Vieira

Project mentor
Dr. Jered Vroon

Client
Reinier de Graaf Gasthuis
Daan Kamphuis

Author
Yiling Liu
Contact: liuyiling33@hotmail.com

Abstract

Recently in the Netherlands, researchers have found that sleep duration and quality were suboptimal in the hospital. Evidence proved that many modifiable hospital-related factors negatively associate with patients' sleep (JAMA Internal Medicine, 2018). The sound factor is the most significant sleep disturbance in the hospital.

In this graduation project, collaborating with Reiner de Graaf hospital and Critical Alarms lab, an information exchange system was proposed to raise awareness of sound as sleep disturbance. The system captures the sound-producing events and visualizes them with visually attractive graphics. In this system, we use the smartphone as the sound captor. The recorded sounds are processed locally on the phone and converted into information such as sound level and the category it belongs to (alarm, speech, incidental sounds, or snore). Fitbit is implemented in the system to collect sleep information. To both patients and medical staff, The Doplor sleep system presents the influence of sound on sleep in a friendly and comprehensive way. During this project, a functioning prototype was developed. We have tested its functionality and user experience with the potential users.
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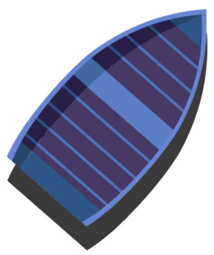
Acknowledgments

To my chair Elif Özcan, my mentor Jered Vroon, and my client Daan Kamphuis, I appreciate and feel lucky to have you coach me for my master graduation project. Thanks for all your encouragement and for always staying positive about my work. They meant a lot to me. I'd like to thank every staff of Reinier de Graaf, who has once supported me. Thank you, Irene Verhoeff, for being interested in my project and offered a lot of help during the COVID period. Lastly, thank you, critical alarms lab, for giving me the chance to work on such great and meaningful projects. I will always remember the days when we work for exhibitions and emotionally support each other during COVID.



Start the journey!

Reading Guide

The reading guide aims to help readers more easily understand the strcture of the report and how the content of each chaper is organized.

Emphasis and Addition

Almost each chapter starts with a brief introduction or background, and ends up with a summary of takeaways and a small reflection (Figure 4) regarding the conducted research or design activities.

Within each chapter, if a design activity resulted in desgin implications orins piration, a purple rectangle (Figure 1) is used to present the main takeaways from this chapter. Next to a yellow rectangle (Figure 2), a side note provides with additional information or explanation when needed.

Key insights in the texts are highlighted as Figure 3.

Takeaways

- Takeaway 1
- Takeaway 2
- Takeaway 3
- ...

Figure 1. Example of a rectangle containig main takeaways from this section.

Side note

The additional information or explanation needed.

Figure 2. Example of a rectangle next to a side note which contains additional information.

If a sentence leads to a key insight, it is highlighted like this.

Figure 3. Example of highlighted texts.

Reflection points

The content of the reflection.

Figure 4. Example of a rectangle containing the reflection of a chapter.

Structure of Report

This report describes a desgin process which is devided into two phases: the research phase and the desgin phase. In total, the report is composed with twelve chapters. Each chapter is structured with, first, an introduction that explains the background and the purpose of current chapter; then, the research or design activity is decribed; lastly, the chapter is concluded with a summary of main takeaways.

An overview of the report structure is presented as below.

Introduction

Chapter 1 - Introduction
This chapter is mainly about how this graduation project was initiated, including the background, previous study, main stakeholders, problem definition, project scope and approach.

Research Phase

Chapter 2 - Context Study
This chapter describes interviews and surveys conducted among nurses and patients to analyze the context.

Chapter 3 - Basics about Sleep
This chapter gathers the sleep knowledge derived from various design research activities, such as expert interviews and literature studies.

Chapter 4 - Current solutions
This chapter presents both current solutions that have already been applied and future recommendations proposed in the literature.

Chapter 5 - Design brief
By synthesizing the takeaways from the research phase, a design vision and goals are derived and presented in this chapter. The design goals are further translated into design requirements.

Chapter 6 - Technology
This chapter describes how technology was selected for developing the concept based on a series of criteria. The aim is to ensure the feasibility.

Design Phase

Chapter 7 - First Concept
As design requirements have been defined and technology has been chosen, This chapter presents the first concept generated.

Chapter 8 - Concept Development
This chapter describes an iterative design process, which consists of two iterations on the product segment of the concept.

Chapter 9 - Final Concept
This chapter elaborates on the final concept and explains how it works.

Chapter 10 - Final Concept Embodiment
This chapter describes the embodiment of the product and gives suggestions on future development.

Chapter 11 - Final Test and Evaluation
This chapter presents the process and results of user evaluation on the product segment of the final concept.

Finalization

Chapter 12 - Conclusion and Discussion
This report ends with a conclusion of the project and the main outcome. It follows a discussion of the project, including the limitations and future opportunities.

Figure 5. The structure of the report.

Table of contents

Chapter 1

Introduction

This chapter is mainly about how this graduation project was initiated, including the background, previous study, main stakeholders, problem definition, project scope and approach.

Introduction

Most of us may have experienced sudden arousals while sleeping in a strange environment, such as a hotel or a place of a friend. Although people are unconscious during sleep, the brain can still receive external stimuli (Black & Matassarin-Jacobs, 1993). People can be aroused or feel hard to fall asleep because of the unfamiliar odor, lighting, bedding textures, and sounds. Researchers term this phenomenon as the "first-night effect". According to them, half of your brain stays alert when sleeping in unfamiliar places (Tamaki & Sasaki, 2016).

Sound is one of the environmental factors that keep stimulating the brain during sleep (Muzet, 2006). Imagine that you are now staying in the hospital due to illness. You are already anxious about your health, while the sounds of medical alarms, operating machines, and nurses talking about negative news from another patient. All these sounds keep reminding you that you are in a dangerous situation. Like many hospitalized patients, you may feel exhausted and unsatisfied with your well-being. According to the study by Burglund et al. (2011), the noise has cardiovascular and physiologic effects that can also affect mental health. Therefore, sleep is seen as important health and well-being variable for humans, especially for patients who are vitally in need of good rest.

1.1 Background

1.1.1 Sleep deprivation in the hospital

According to JAMA medicine (2018), sleep in hospitals is reported to be suboptimal. Patients generally sleep shorter and awake more during sleep in the hospital. The sleep issue described in this article has received considerable attention from Reinier de Graaf hospital.

Based on the result of the study conducted in hospitals in the Netherlands in 2018 (Wesselius et al., 2018), it has been found that the total sleep time of patients in the hospital was 83 minutes shorter than at home. It takes 21 minutes longer for patients to fall asleep in the hospital than at home. When being awake after falling asleep, it takes them 29 minutes longer to fall asleep again, comparing sleep during hospitalization to sleep at home. The sleep efficiency in the hospital is 12% less than the sleep efficiency at home (Table 1). The data were collected using the Consensus Sleep Diary.

Table 1. Comparing sleep at home and at hospital. Data from Wesselius et al. (2018)

Measure	Home	Hospital	Difference(95% CI), min	P Value
Sleep-onset latency	23	44	21	<0.01
Wake after sleep latency	32	61	29	<0.01
Total sleep time	07:27	06:04	-83	<0.01
Sleep efficiency, % (95% CI)	88	76	-12	<0.01

The study also let patients score selected PROMIS (Patient-reported Outcomes Measurement Information System) sleep disturbance items. The result shows that

1. sleep in the hospital is less refreshing compared to sleep at home;

2. patients feel more difficult to fall asleep in the hospital than at home;

3. patients feel lousier when waking up in the hospital than waking up at home.

4. Overall, patients participating in this study reported lower sleep satisfaction and sleep quality in the hospital than at home.

1.1.2 Delirium

Despite the general sleep issues mentioned in the previous section, patients with brain diseases, such as delirium, suffer from a more severe sleep disorder. Hence the sleep of hospitalized patients is highly concerned by the neurology department of Reinier de Graaf hospital.

According to Daan Kamphuis, the doctor of the Neurology department and medical manager of Reinier de Graaf hospital, patients in the brain care unit (BCU) can appear to be delirious. Delirium is an abrupt change in the brain that causes mental confusion and emotional disruption. Delirious patients wake up confused and temporarily forget why they are staying in the hospital. They are likely to feel anxious, worried, and even lose control.

While on the other hand, delirium also causes sleep disorder by disturbing circadian rhythm regulation (or sleep-wake cycle). According to nurses from Reiner de Graaf hospital, delirious patients are sometimes active during the night. They may get out of bed and talk loudly and become sleep-disturbing factors for other patients. Their abnormal behaviors and extreme emotions at night also require more attention and care from the nurses.

Delirium is mainly caused by the coeffect of sleep deprivation, primary neurologic diseases (e.g., stroke attack), and physical or psychological stress. Remarkably, stress caused by the environment (e.g., admission to an intensive care unit) is also considered as one of the main contributing factors to delirium. This is why the neurology department sees it important to diminish environmental factors that are violent for sleep. They are interested in collaborating with designers to achieve this purpose.

1.1.3 Sound issues of hospitals and Critical ALarms lab

A study published by the Journal of Clinical Sleep Medicine analyzed patient-reported in-hospital sleep disruptions and assessed how they associate with objective sleep duration and sleep efficiency (Grossman, 2017). By conducting a subjective survey among patients, a ranking of most reported disruptions was derived. From Figure 6, it can be found that noise (All Sources) ranked the highest among all environmental disturbances. Alarm and staff conversation, as sound-related disruptions, are also shown in this ranking. Therefore, we can conclude that sound is the most significant environmental sleep-disrupting factor according to this ranking.

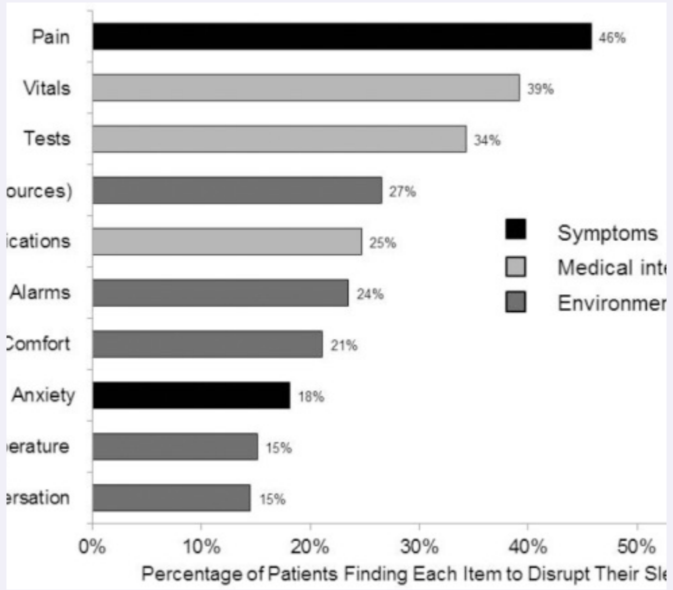


Figure 6. ranking of environmental disturbances.
(Grossman, 2017)

In recent years, Critical alarms lab (CAL) of Delft University of Technology has focused on sound issues in healthcare contexts. Related research has been done by CAL on how to design hospital soundscapes for better sleep experience (Birdja & Özcan, 2019). In the research publication, Birdja and Özcan proposed a strategy to systematically tackle the auditory quality of critical care settings in favor of better patient sleep experience. In their strategy, one proposed research direction is to map the soundscape and use it to create awareness of sound in the hospital. A previous design intervention was created for this research direction. This graduation project is inspired by CAL's strategy and can be seen as a continuation of the Doplor project, but tailored for the sleep environment in general hospital wards.

1.2 Problem definition

1.2.1 Project scope

Reinier de Graaf hospital, as the client of this project, seeks to find design solutions to tackle the environment sleep disruptions in the ward. The critical alarm lab is interested in supporting the student in research and creating design interventions on the hospital's sound issues. A discussion between Reinier de Graaf hospital and Critical alarms lab has helped the student establish the project scope.

As agreed by all stakeholders, the following tasks need to be accomplished in this project:

1. Measure and identify the environmental sleep-disturbing factors currently existing in the ward of Reinier de Graaf hospital. The environmental factors include but are not restricted to sound factors.

2. Focus on sound factors, design tools to raise the awareness of sound, to help both patients and hospital staff be more aware of the sleep disturbances caused by sound-producing events.

1.2.2 Project Approach

The whole project is divided into two phases: the research phase and the design phase. The ViP Vision in Design method (van Dijk & Hekkert, 2011) has inspired the project approach, which is visualized as Figure 7.

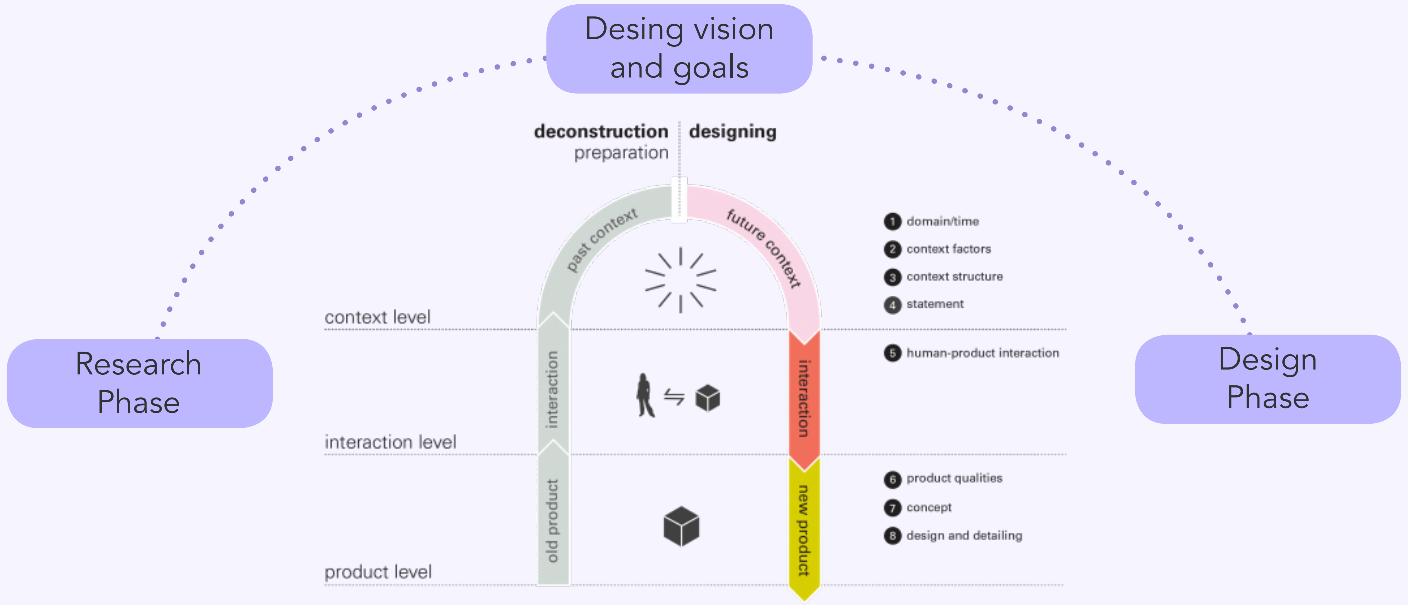


Figure 7. Project approach inspired by the ViP method.
Figure adapted from van Dijk & Hekkert (2011)

- Research Phase

The research phase of the project aims to fill in the knowledge gaps. First, a context study was conducted to understand the current sleep and sound problems and get to know the target user groups (Chapter 2). Next, we tried to gain insights into the formation of sleep and how sleep is influenced by external factors from a biological perspective. Gaining basic knowledge related to sleep is essential for designing scientifically-informed solutions for this project (Chapter 3). As suggested by the ViP design method, some current solutions for sleep problems were analyzed to inspire new designs that suit users' interaction habits and fit the context (Chapter 4). At this stage, the takeaways and findings led to a design vision and design goals, which are translated into detailed requirements and product functions (Chapter 5).

Since the product functions require the implementation of technologies, research on state-of-art technology has been done (Chapter 6).

- Design Phase

The chapters about the design phase describe a user-centered design process. The formulated design goals and selected technology have resulted in an initial concept (Chapter 7). The concept has, then, been through two small iterations. Each iteration was powered by evaluation and feedback from the potential users (Chapter 8). After elaborating on the final concept, how the concept was embodied, and future steps were discussed (Chapter 9, Chapter 10). Lastly, a final user evaluation was conducted, which resulted in future recommendations for this concept (Chapter 11).

Summary

The current chapter introduced the problem and design challenge by synthesizing the interest of different parties. The project scope, main tasks, and project approach are defined. The next chapters will elaborate on the research and design activities conducted according to the project approach.

Main takeaways

1. The change in the sleep environment can cause sleep deprivation. Being hospitalized can cause stress, which is risky for patients with brain issues to turn delirious.

2. In the neurology department, sleep deprivation can cause delirium. Once turned delirious, patients cannot retain a normal sleep cycle, which causes more severe sleep deprivation for themselves, and can disturb the sleep of other patients. This vicious cycle caused by sleep deprivation is highly concerned by the hospital staff of the neurology department.

3.Sound factors are the most dominant environmental sleep-disturbing factors.

Reflection points

Collaborating with Reinier de Graaf and Critical alarms lab is a good practice for balancing two parties' interests and finding common ground. Since the amount of time and effort is limited for a one-person project, I need to consciously set a manageable scope for the project and communicate personal interests to the clients.

Chapter 2

Context Study

This chapter describes interviews and surveys conducted among nurses and patients to analyze the context.

The purpose of the context study is to (1) understand how is sleep experience of patients at Reinier de Graaf hospital compared to sleeping at home; (2) gain a clearer picture of the context, including how patients and hospital staff interaction to find design opportunities that could fit in their daily routine; (3) Understand the wish and needs of the main stakeholders; (4) map the soundscape in the ward.

Context Study

2.1 Background

As mentioned in the previous chapter, good night sleep is critical to patients' recovery and well-being during hospitalization. However, a study of 2005 patients in the Netherlands suggested that patient sleep quantity and quality were significantly influenced by hospitalization compared to sleeping at home (Wesselius et al., 2018). In this project, a survey for patients and interviews with nurses was conducted to examine whether the study of Wesselius is applicable for Reinier de Graatoospital. Trying to understand the sleep experience in the hospital wards from both patients' and nurses' perspectives may lead to new insights.

Understanding sleep experience and problems are the first steps. The second step is to identify the sound sources that are perceived as sleep disturbances by patients and nurses

2.1.1 Sound as a sleep-disturbing factor in the hospital

The study of Wesselius et al. (2018) also identified different sleep-disturbing factors in the hospital. In this study, noises and awakenings by medical staff were identified as the most important factors. The sleep-disturbing factors are correlated to sleep variables such as sleep-onset latency, nocturnal awakenings, and final awakening. (Table 2)

It can be concluded that the hard time of falling asleep and sleep disruptions are largely related to sound factors. The study identified that the most common disturbing factor is noise from other patients. The noise of medical instruments is reported as one of the main causes of not being able to fall asleep. The article also mentioned the noise of hospital staff, although it is not one of the main factors affecting the sleep variables mentioned above. Awakening by hospital staff is not a sound factor but can be detected and quantified using the sounds produced by hospital staff. The measurements can be translated into, e.g., the frequency of awakening.

Table 2: Top 3 sleep-disturbing factors in the hospital (Wesselius et al. ,2018)

Sleep variables	Top 3 sleep-disturbing factors
Sleep-onset latency	1.Noise of other patients 2.Pain 3.Noise of hospital equipment
Nocturnal awakenings	1.Other reasons (e.g. toilet visits) 2.Noise of other patients 3.Awakened by hospital staff
Final awakening	1.Awakened by hospital staff 2.Other reason (e.g. toilet visits) 3.Noise of other patients

A list of sound-related sleep-disturbing factors is identified as below.

- The noise of patient
- The noise of the Hospital Staff
- The noise of Medical Instruments

Another study by Park et al. (2014) determined the noise sources perceived by hospitalized patients in an internal medicine department and provided a more detailed list of sound sources. The list of sources of noise is presented in Table . As shown in Table 3, this study also assessed whether a specific source of sound disturbed patient's sleep.

To examine whether the findings of Park et al. are applicable for Reinier de Graaf hospital, a part of the survey for patients used the list created by Park et al. to examine to which extent each source of noise has disturbed sleeping patients.

2.1.2 Sound levels of hospital wards

Previous research by Fillary et al. (2015) aimed to identify how sound affects patients' sleep in general wards. This research provided insight into the noise level of the wards. It has been found that no published results of hospitals meeting the World Health Organization(WHO) sound level guidelines of a maximum of 40 decibels(dB) in patients' rooms at night. There is even an increase in nighttime noise over the previous 45 years, with average levels increasing from 42 to 60 dB by 2005. As a reference, it has been identified that arousals can occur from noise above 55 dB (Passchier-Vermeer & Passchier, 2000). The research paper also argues that arousal may also be due to the type of noise specifically found in hospitals and not just noise level.

However, the sound level may not be the most important parameter to look at when determining whether the hospital is 'suitable for sleep'. Reducing negative sounds does not necessarily create a positive environment. We need to examine the effect of different sound sources on sleep, not only from the aspect of sound levels but also on the content and interpretation (Mackrill et al., 2013). Considering the sound as 'soundscape' is an approach to assess sound in terms of people's perception.

Table 3: Sound disturbances perceived by hospitalized patients.

eived sources of noise[a]	All	Patients not disturbed sleep[b] (n=14)	Patients disturbed sleep[b] (n=89)
patients' caregivers or visitors	22 (21.4)	1 (7.1)	21 (23.6)
patients' snoring	18 (17.5)	0 (0.0)	18 (20.2)
flushing	16 (15.5)	3 (21.4)	13 (14.6)
vheel sound	14 (13.6)	1 (7.1)	13 (14.6)
hone and TV	13 (12.6)	0 (0.0)	13 (14.6)
onal medical device	11 (10.7)	2 (14.3)	9 (10.1)
edure by medical staffs	10 (9.7)	0 (0.0)	10 (11.2)

s are presented as number (%).
ents could respond to multiple sources.
p disturbance assessed by the Pittsburgh Sleep Quality Index.

Side note - Soundscape

The soundscape is an acoustic version of the landscape. It describes how people perceive the sound. Hence it considers the meaning of the sound. Unlike acoustics, it deals with the transfer of information instead of energy (Truax, 1984).

2.1.3 Mapping the soundscape of hospital wards

Little research has been found that assessed the sound in the general wards by mapping the soundscape. However, an adequate amount of study has been done to map the soundscape of ICU. Due to the similarity between ICU wards and general wards, the research about sounds of ICU can give some idea about how the soundscape of a general ward is like.

A study by Krueger et al. (2007) classified the sources of sound in NICUs as being either operational sounds (generated by the staff or equipment in the NICU) or structural sounds (generated by the building, for example, sounds generated by ventilation, air conditioning systems, and doors). According to Konkani and Oakley (2012), the same classification scheme developed by Krueger et al. can be applied to all hospital noises.

Konkani and Oakley has further specified the sound sources if ICU as 1)conversations between the ICU staff, medical professionals, and visitors; 2)medical equipment alarms; 3) caregiving activities such as hand washing, opening disposable equipment packages, storage drawers; 4) telephones, pagers, and televisions; and 5) closing doors and falling objects. Based on Konkani and Oakley's study, Dilip Birdja (2019) mapped the sound-producing events from the patient perspective to demonstrate the sounds patients are exposed to. (Figure FIXME)

Furthermore, At the intensive care unit of the Jeroen Bosch Hospital in 's-Hertogenbosch, the Netherlands, researchers have collected and analyzed 67 hours of audio recordings. This study showed the distribution of sound-producing events over the critical care sound categories.

- patient involved noise (31%)
- Staff related sounds (57%)
- vocal and staff-related sounds (38%) (i.e., verbal and non-verbal)
-Sounds related to staff activity (19%) (i.e., caregiving activities).
- medical alarms (30%)
- operational sounds of life-supporting devices (13%).

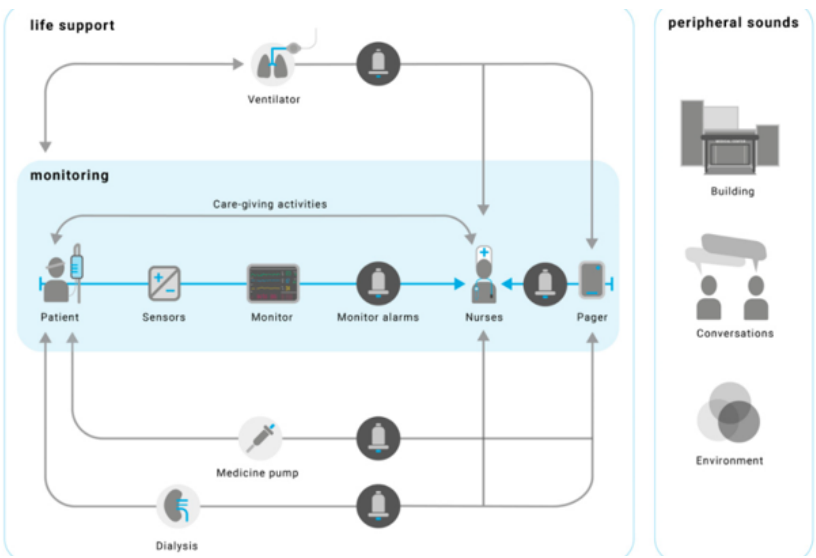


Table 8: Insight into the distribution of the sound producing events over the critical care sound categories. Figure by Birdja (2019) adopted from Bogers (2018).

According to observation at the regular ward of Reinier de Graaf, it is obvious that the proportion of medical alarms is smaller compared to ICU. Patients staying at regular wards may have completely different interpretations of medical alarms since they hear it less often. In order to map the soundscape of general wards, the sound-producing events need to be measured at Reinier de Graaf hospital. Due to the COVID circumstance, entering the hospital becomes difficult. Instead of measuring the sound, we interviewed the nurses remotely to gather information about sound sources in the ward.

2.2 Method

- Survey for Patients

The questionnaire is uploaded to the system of Renier de Graaf Hospital under the help of the staff from the quality and safety department. Patients can get access to the questionnaire and answer it using an iPad provided by the hospital. With the help of a nurse, twelve participants were recruited for this survey and finished the questionnaire. All participants are currently staying in the neurology department.

Figure 9 presents how the questionnaire was composed. The questions regarding sleep were from the Pittsburgh Sleep Quality Index (PSQI). The list of sound sources used in the questionnaire was retrieved from the publication of Park et al., as mentioned earlier. The full questionnaire can be found in Appendix A.

Part 1:
Sleep at home vs. at hospital

Part 2:
Environmetnal sleep-disturbing factors

Part 3:
Disruptions of sound-producing events

Figure 9: questionnaire setup (for patients).

Interview with nurses

Seven interviews were conducted with the nurses from the neurology department of Renier de Graaf hospital. Due to COVID-19, it was not possible to enter the hospital to recruit nurses for the interview. One nurse from the neurology department volunteered to recruit nurses, conduct the interview, and translate the transcriptions into English.

Figure 10 shows how the interview questions were set up. The full interview questions can be found in Appendix B.

Part 1:
Sleep problems at hospital

Part 2:
Solution and iteraction with patietns

Part 3:
Sound disturbances

Figure 10: Interview question setup (for nurses).

2.3 Procedure and Data Analysis

- Survey for Patients

Before starting the survey, the nurse explains to the patient the purpose of this study and gives instructions on how to use the survey system of Renier de Graaf. The patient answers the questions on the iPad belonging to the hospital. The nurse is standing aside to ensure the patient has no difficulties in finishing the questionnaire.

The responses from the twelve participants were converted to .esv files and analyzed in SPSS. For comparing sleep variables at home to the hospital, a paired sample t-test has been used. For the feelings about temperature and lighting in the hospital, a one-sample t-test (to see how the answers are different from 'neutral') was applied, and for the disturbances of different kinds of noise, one-way ANOVA was used.

- Interview with nurses

Based on the question list, the nurse who helps with this study interviewed other nurses in the ward. During the interview, the responses were recorded. After the interview, the recording was transcribed and translated. The translated transcriptions were sent to the researcher for further analysis.

The interview data were analyzed by reading though the transcription and extracting the core ideas and keywords of an answer. The coded words in the answers of all subjects were gathered to help find patterns.

2.4 Findings

- Sleep experience of patients in the hospital compared to home

In the questionnaire for patients, the participants were asked to rate on the items shown in Figure 11 for both the sleep at home and at the hospital. The mean scores were calculated and presented in Figure 11. However, the data analysis result shows only the (subjective feeling of) sleep quality at home is significantly better than sleep in the hospital ($p < 0.05$); and that patients feel significantly more refreshed after waking up at home than waking up in the hospital ($p < 0.05$). The rest of the pairs did not show significant differences.

Besides, subjects were asked to fill in their sleep latency, times of awakes, and sleep duration for both the sleep at the hospital and the sleep at home. Only the sleep duration shows a significant difference ($p < 0.05$). On average, patients slept 31 minutes shorter at the hospital than at home

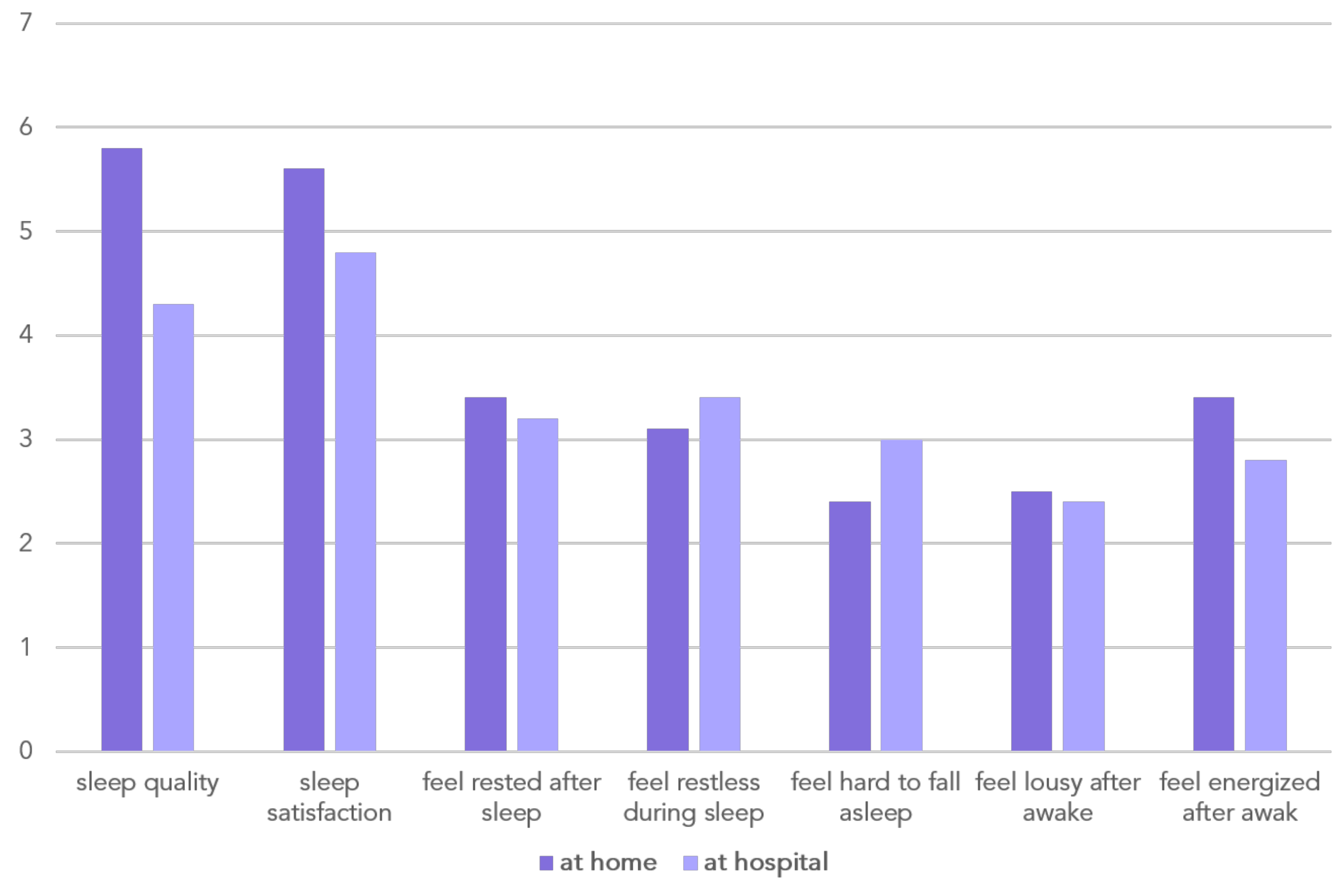


Figure 11: Comparing the sleep at home and the sleep at hospital.

- Environmental sleep disturbances in the hospital.

In the same questionnaire, patients were asked to rate to which level they agree with the statements presented in Figure 12. The mean scores were calculated and visualized. Only the scores for 'feeling too cold to sleep,' 'feeling too dark for sleep,' 'it was quiet,' and 'woke up by noise' were significantly different from 3, which stands for 'neural' ($p < 0.05$). The result suggests that patients feel it neither too cold nor too dark to sleep; they don't agree with that the hospital is quiet, and they agree that noise in the hospital woke them up.

- How different sounds affect sleep in the hospital

In the questionnaire, the patients were asked to rate for 'how frequently they were disturbed by the following sounds' and 'to which level they were disturbed by the following sounds. The list of sound sources is from the research of Park et al. (2014).

The means scores were calculated and presented in Figure 13. However, according to the statistic analysis, the result suggests that there were no significant differences between each sound source. Therefore, we cannot determine which sources of sounds are more disturbing or more often to occur during the night.

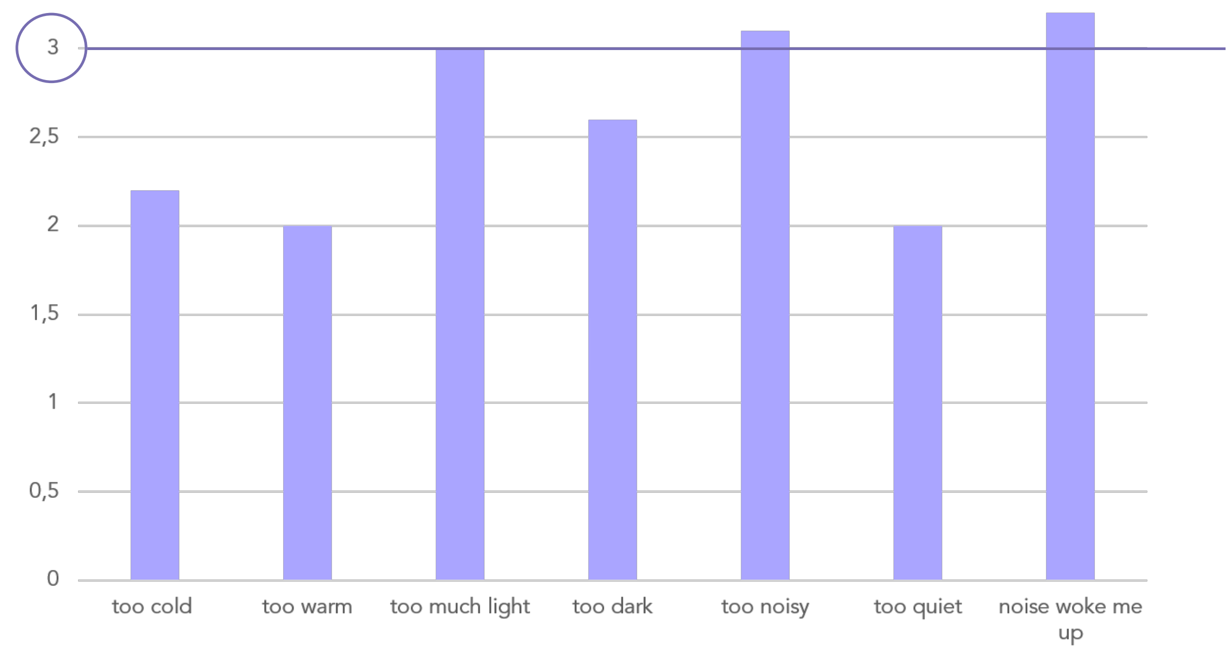


Figure 12: participants rated for their perceiption of environmental sleep disturbances. The scores were compared with 3, which stands for neutral.

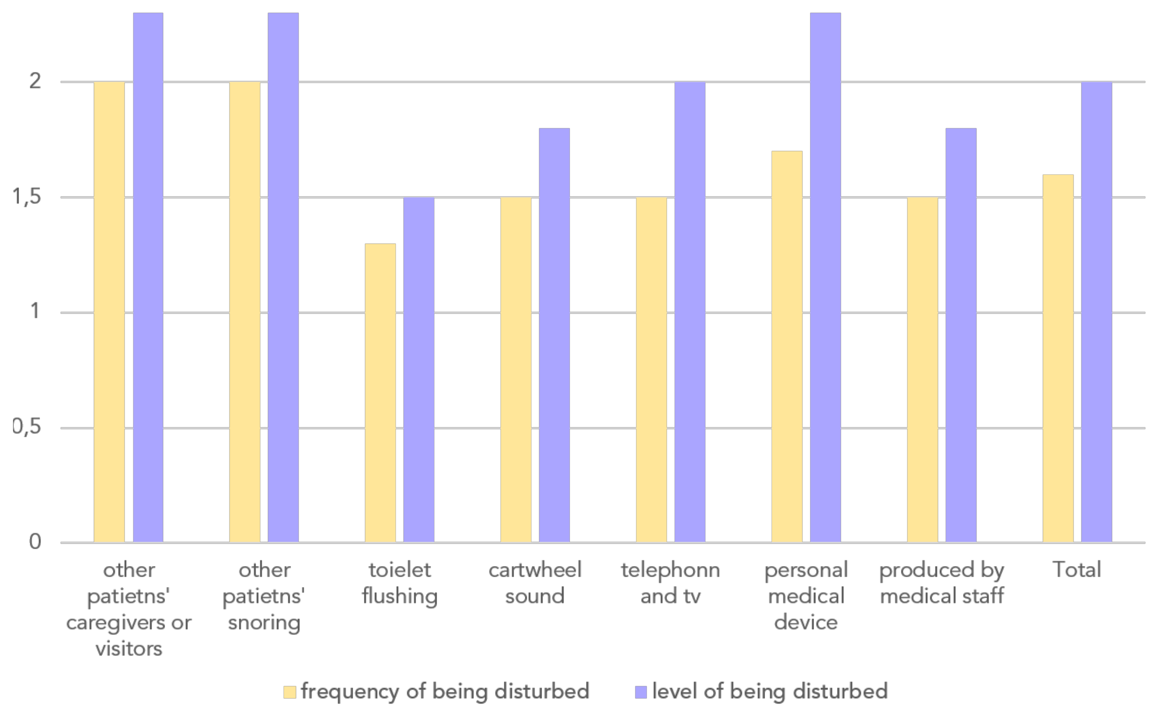


Figure 13: participants rated for their perceiption of noise disturbances in terms of the frequency and level of being disturbed during sleep.

- The context of the hospital ward

From the interview with nurses, the context of the neurology department ward was better pictured.

According to the nurses, the ward is in the shape of a "long corridor" with nine one-person rooms, four rooms with four beds. The ward is so long that the nurses have to walk far to the kitchen, medication room, and wash kitchen. The ward has one entrance door. There are a lot of activities at the ward in both directions.

In the ward, there is a living room, wash kitchen, front desk, nurse room, and a multifunctional room. Behind the front desk, there are two other smaller multifunctional rooms for doctors and nurses. An examination room is located halfway of the corridor. A lot of equipment like wheelchairs, walkers, hoists, etc. are placed in the corridor. The ward contains one front desk and two offices. The stroke unit is a seperate room with seven patients and one one-person room. The patients are monitored 24/7. The monitors often generate alarm sounds.

- Nurses' observation for the sleep problem in the wards

According to most nurses, sleep in the single-patient room is generally fine. In the stroke room, patients are unrested because they have sensors connected to their bodies and need to be checked every two hours. For patients staying in the room with eight patients, they are in lack of rest mainly because of the influence of other patients. For example, some patients talk loudly on the phone.

Delirious patients cannot fall asleep at night and leave the bed. Their behaviors not only keep themselves from sleeping but also can disturb other patients.

- Soundscape mapping

After gathering all the sources of sound mentioned by the nurses, these sounds were grouped, and different sound categories were generated, such as sounds generated by visitors, patients, hospital staff, environmental sounds, and sounds from medical equipment (Figure 14).

The way of categorizing the sounds is based on how the stakeholders involved in the context would react to the sound. For example, the nurse reacts to the sounds generated by visitors differently than the sound produced by his or her colleagues.

However, with the current technology, computers cannot distinguish the identity of the speaker (i.e., this person is a nurse, a patient, or a visitor) without harming the privacy of this person. Human's ability is needed for this. Therefore, if the goal is to design an intervention that can map the soundscape, the sound of the hospital ward can be categorized as Figure 15. This way of categorization is also based on how the listener would respond to it or the underlying meaning of the sound. And the sounds with the same acoustical features that technology cannot easily distinguish are merged as one group (e.g., speech).

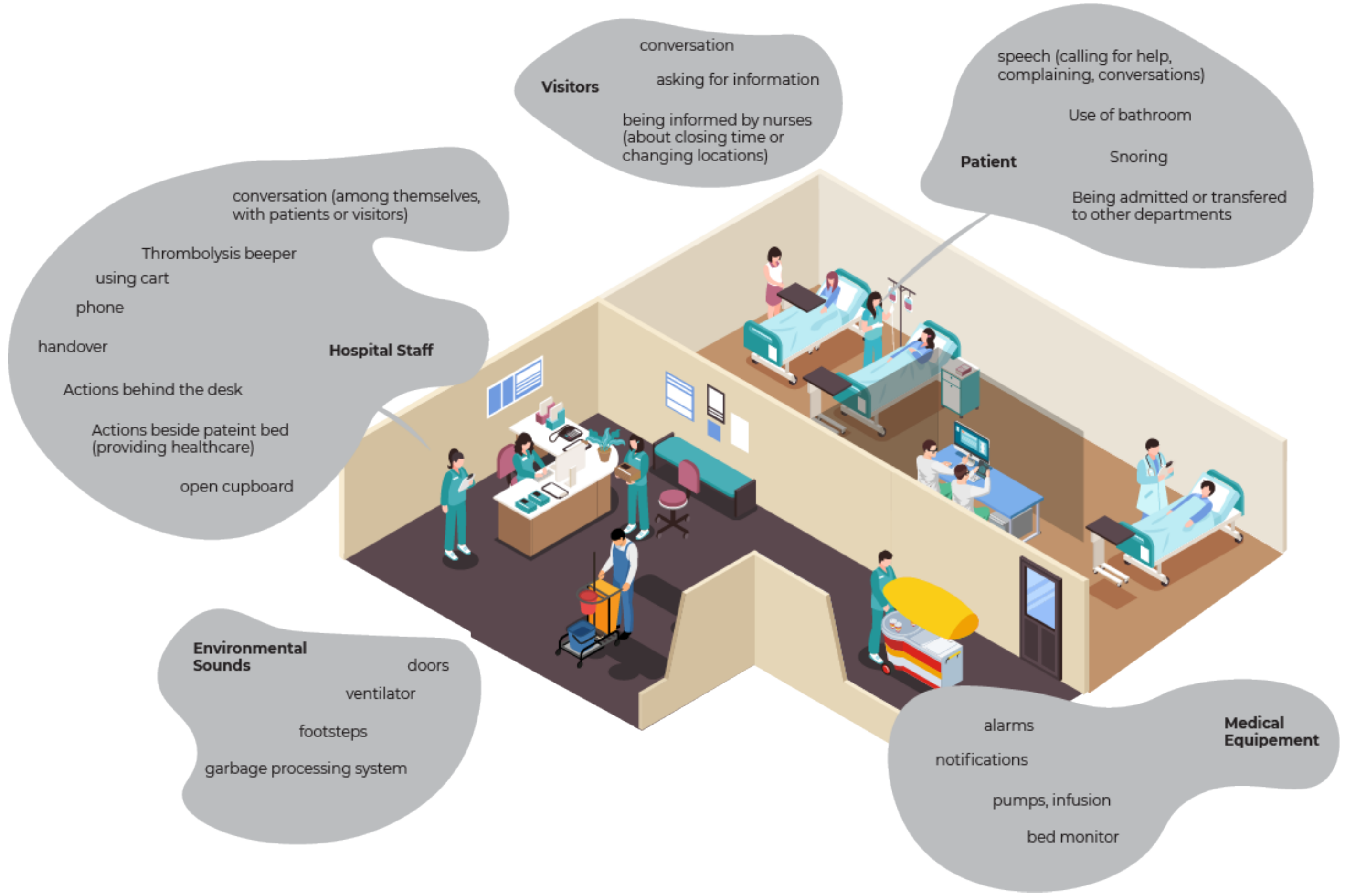


Figure 14: Sound sources in the hospital ward. The illustration of the ward is created based on observation and memory, which cannot represent the actual layout of a hospital ward.

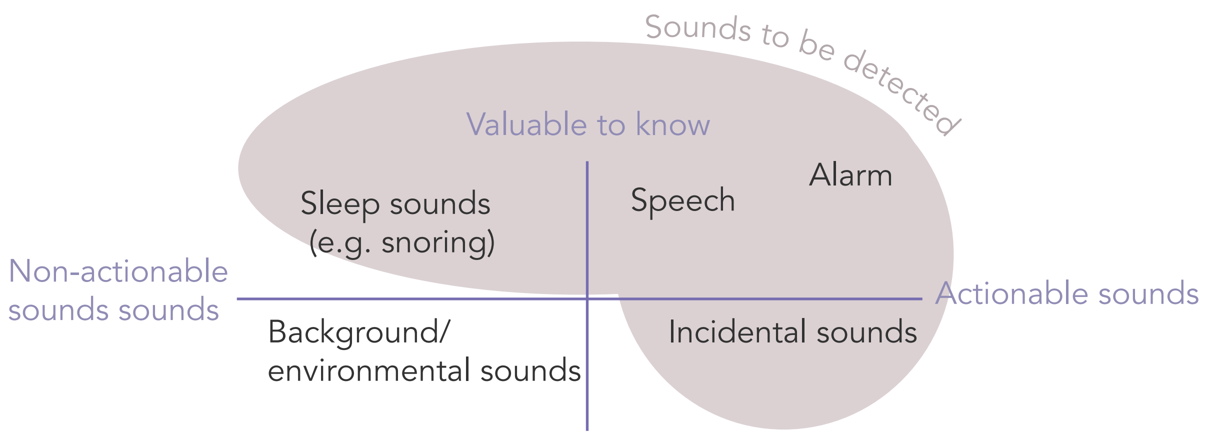


Figure 15: A Quadrant helping to categorize sounds.

As shown in Figure 15, sleep sounds (such as snoring), speech, incidental sounds, and alarm are considered as the target sounds to be detected because it is valuable to know if the sound is present and (or) this sound can be reduced by taking actions.

The sleep sound is valuable to be detected because the nurses can protect sensitive patients by switching the room for him or her. The alarm is actionable because a large percentage of alarms are false alarms; the threshold of the alarming system can be adjusted if the situation allows.

- Nurse-patient interaction

In the questionnaire, one question was how does the nurse tackle the sleep issues of patients and how do nurses interact with patients during this process.

Most nurses try to reassure the patients and listen to their worries when the patients feel confused, scared, or worried. Through the nurses' narratives, we can sense that the nurses often communicate with patients. Patients also show their trust in nurses. Besides providing healthcare, the nurses also need to comfort the emotions of the patients.

Besides reassuring, nurses also give patients earplugs or medicine for sleep when necessary.

Summary

This chapter is mainly about the context study conducted with nurses and patients at Renier de Graaf hospital. Before introducing the survey and interviews, background information was provided to help people understand the purpose of conducting the study and what was the base of the study.

Main takeaways

1. The result of the survey study shows that patients are experiencing shorter sleep duration, lower sleep quality, and lower sleep efficiency in Reinier de Graaf hospital compared to sleeping at home.

2. The current results of the survey study can not reveal the effect of other environmental factors on sleep.

3. In this project, sound in the hospital wards are categories into snoring, speech, incidental sounds, and medical alarms.

4. Nurses sometimes deals with the emotions of patients and listen to the worries of the patients.

Reflection points

Due to the limited smaple size, the survey conducted with patients did not result in new insights as expected. In the future, more pariticipants need to be recruited for this survey.

Chapter 3

Basics about Sleep

This chapter gathers the sleep knowledge derived from various design research activities, such as expert interviews and literature studies.

Basics about Sleep

3.1 Introduction

To understand how sleep is influenced by external factors such as sounds, we need to understand what determines good and bad sleep. From our life experience, we know that sleep applications or sleep monitoring devices such as Fitbit sleep have their own algorithms to calculate sleep quality and sleep efficiency. No matter how the algorithm works, the device or application needs to be able to detect sleep and wake. This chapter focuses on understanding basic knowledge about sleep from a biological perspective. First, we try to understand what are the factors that regulate sleep and wake patterns in humans. This can provide insights into how to achieve a natural, ideal, and undisrupted sleep. Next, we learn about different stages of sleep and how to detect them, so as to determine if a person is asleep and how is the quality of sleep. Finally, the common sleep problems nowadays people have, and the contributing factors are analyzed. Since environmental noise or sounds are the focused factors in this project, an in-depth study has been done on how sounds are affecting people's sleep. Last but not least, this chapter discussed what is needed for good sleep hygiene.

3.2 Inspiration from Sleep Expert

The study into sleep was initiated after a conversation with Muriël van Oers, the Neuroscience & Sleep expert from Somnox, a company developing sleep-assisting products. During the conversation, Muriël van Oers recommended the book Why We Sleep by Mattew Walker for the supplement of my basic knowledge about sleep. Hence most sleep-related information described in this Chapter was derived from the book by Mattew Walker (2017).

Muriël van Oers indicated that the sleep-disturbing factors could occur both before falling asleep and during sleep. If the goal is to design a device that dismisses the sleep-disturbing factors, the designer should clarify whether this product is targeting the period before asleep or during sleep.

When asked to describe the soundscape that is most suitable for sleep, Muriël van Oers suggested that the environment for sleep should better be as quiet as possible.

As for assessing or determining how well a person slept, Muriël van Oers recommended the use of the Pittsburgh Sleep Quality Index (PSQI). The questions from PSQI were thus used as a base for composing our questionnaire for patients from Reinier de Graaf (See the previous Chapter. Full questionnaire can be found in Appendix A). As for the sleep monitoring products, Muriël van Oers suggested the use of a sleep tracking mattress, e.g., Withings Sleep.

3.3 What makes people sleep and wake

Sleep and wake are determined by two factors. Every human being shows a biological circadian rhythm that is approximately one day (24 hours) in length, which is one of the two factors. The second factor is sleep pressure - a chemical called adenosine. It keeps increasing in concentration with every waking minute. The longer you are awake, the more adenosine will accumulate, which leads to more desire to sleep.

As figure 16 shows, the bigger distance between the two curves is, there is more desire to sleep. If the distance is small, that means the person has more desire to wake up. Both sleep and wake driving factors can be influenced. For instance, caffeine fights against adenosine.

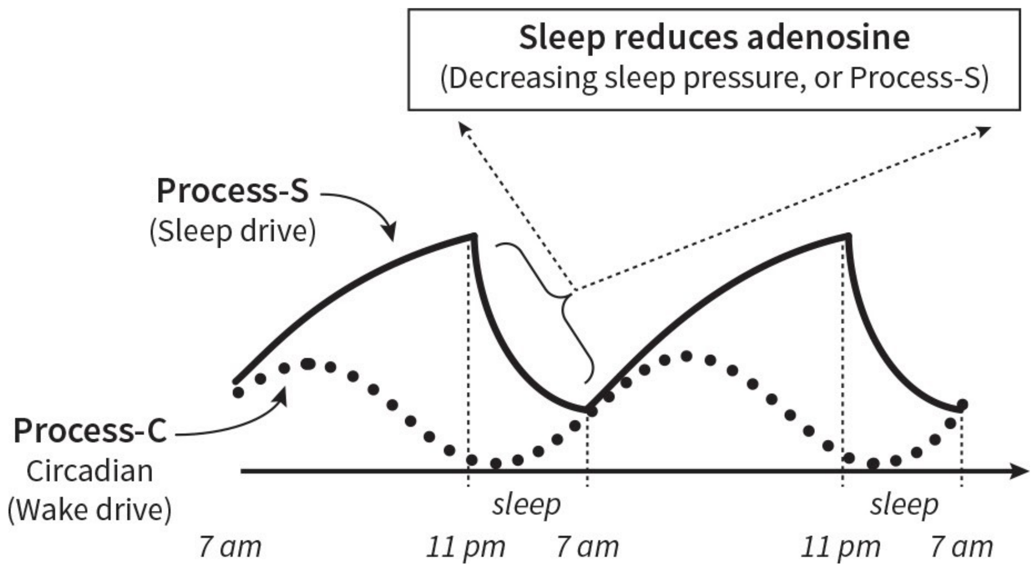


Figure 16: How the two factors regulate sleep and wake. Figure retrieved from the book why we sleep by Mattew Walker (2017).

3.4 How to identify and examine sleep

A simple way for individuals to examine if they get enough sleep is by asking themselves a series of questions, e.g. if you didn't set an alarm clock, will you sleep past that time?

There are different ways to identify if a person is asleep. First, people are good at recognizing signals that suggest another individual is asleep, e.g., stereotypical position, lowered muscle tone, no responsibility, etc. People can also determine if they are asleep themselves by feeling losing external awareness and having a sense of time distortion. Second, there is a gold-standard scientific verification of sleep, which requires the recording of signals, using electrodes, arising from three different regions: (1) brainwave activity, (2) eye movement activity, and (3) muscle activity. Collectively, these signals are grouped together under the blanket term "polysomnography" (PSG), meaning a readout (graph) of sleep (Somnus) that is made up of multiple signals (poly).

Figure 17 shows the sleep cycle of a human. Different stages of sleep have different functions in terms of balancing brain storage. Therefore, detecting the sleep stages can tell us about sleep quality.

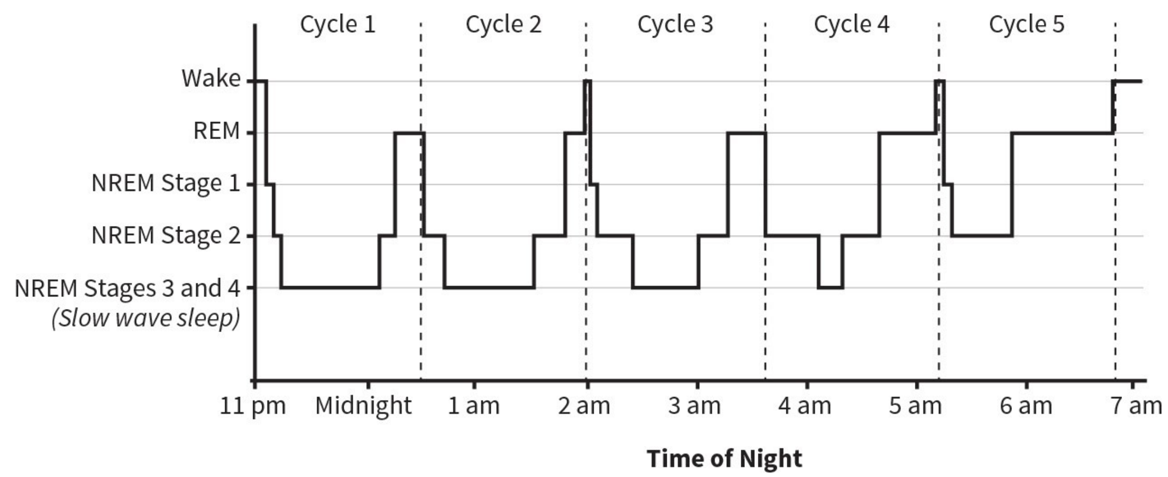


Figure 17: The sleep cycle. The different stages of sleep.

3.5 Morden sleep problems and contributing factors

According to the book, nowadays, people are commonly facing the problems of a) a lack thereof at night, resulting in b) an inability to remain fully awake during the day.

Five key factors have powerfully changed how much and how well we sleep: (1) constant electric light as well as LED light, (2) regularized temperature, (3) caffeine (discussed in chapter 2), (4) alcohol, and (5) a legacy of punching time cards.

3.6 Sounds and sleep correlation index

According to a clinical review article by Muzet (2006), the sleeping body still responds to stimuli coming from the environment, because the input to the auditory area of the brain through the auditory pathways is prolonged by inputs reaching both the brain cortical area and the descending pathways of the autonomic functions. The noise sensitivity of the sleeper depends on different factors. Some of these factors are noise dependents, such as the type of noise (e.g.continuous, intermittent, impulsive), noise intensity, noise frequency, noise spectrum, noise interval (e.g., duration, regularity, expected), noise signification, and the difference between the background noise level and the maximum amplitude of the occurring noise stimulus. Other factors are related to the sleeper, such as age, sex, personality characteristics, and self-estimated sensitivity to noise.

This article indicated that the objective measures of sleep disturbance could be quantified by number and duration of nocturnal awakenings, the number of sleep stage changes, and modifications in their amount. From this information, we derive the objective measurements that a product can make use of to determine whether and how the sleep is disturbed in the hospital compared to the sleep at home.

3.7 What is needed for good sleep - Inspiration from a fellow student

With previous literature studies on how to determine whether the sleep was disturbed and what caused the sleep deprivation, we tried to improve the sleep quality in a certain environment by tracking sleep disturbances, finding out the causing factors, and eliminating these factors. We were using "subtractive thinking" to solve the problem. From another angle, we can also explore solutions that add sleep-enhancing sounds or elements that beautify the soundscape for sleep into the environment. Therefore, we contacted Mert Bereket, a fellow master student of Delft University of Technology who has been researching and developing solutions that improve sleep for Philips. During this conversation, we shared information with each other about our findings and knowledge about sleep and sound. According to the research done by Mert Bereket so far, there are sounds proven to have positive effects on sleep, such as natural sounds and white noise. This information corresponds to a study by Mackrill et al. (2014) about exploring positive soundscape interventions for hospital wards. The results of this study suggest that the addition of white noise or steady-state sound (SSS) has largely, although not significantly, triggered the emotional-cognitive response of relaxation. Natural sounds have a significant yet not so huge effect on triggering the feeling of relaxation. This study also explored a third intervention, which is providing the patients with sound source information. The result shows this intervention also significantly yet not so largely evokes the feeling of relaxation.

The design solution proposed by Mert Breket at the time was about adding personalized sounds that evoke good memories of this person before sleeping. This idea adopted the approach of seeing the sound as a soundscape, which considers not only the acoustical properties of the sound, but also the meanings conveyed by the sound to individuals (Mackrill, 2004).

Summary

In this chapter, we seek to find design inspirations from the aspect of sleep. We explored how sleep can be and is currently disrupted by external factors. With the knowledge of how sleep is formed and what defines a good sleep, we gradually build the bridge between sleep and the positive sound interventions that can contribute to good sleep, and fill up the knowledge gap of how to assess sleep objectively. In the next chapter, we explore the existing products used in practice to objectively assess and track sleep for improving sleep hygiene, and strategies used to improve the soundscape in medical contexts.

Main takeaways

1. When trying to assess sleep subjectively, Pittsburgh Sleep Quality Index (PSQI) is commonly used.

2. The sleep researcher of Sonmox has recommended using a sleep tracking mattress to measure sleep objectively.

3. When measuring sleep disturbances, we can look at the following parameters: (1) number and duration of nocturnal awakenings; (2) number of sleep stage changes, and (3) modifications in their amount.

4.Since different people perceive the same sound differently, it can be valuable to profile the sleeper and take into account how sensitive the sleeper responds to sound during sleep.

4. Polysomnography (PSG) is currently the gold-standard way of assessing sleep. When evaluating the accuracy of a commercial sleep tracking project, we can compare it with PSG.

5. Despite creating awareness of sound, another value of mapping the soundscape is to provide the users with information about sound sources to increase the feeling of relaxation.

6. Inspired by fellow student, implementing personalized soundscape can be an idea to improve the sleep environmet in the hospital for individual patients.

Reflection points

Although the results of the survey described in Chapter 3 could not provide evidence to prove the lighting and temperature has a significant influence on the sleep of patients, according to the book by Mathew Walker, we learned that constant electric light as well as LED light, and regularized temperature have a negative effect on the circadian rhythm of people living in the modem society. Therefore, it is still valid to see lighting and temperature as sleep-disturbing factors, which leads to future research and design opportunities.

The book Why We Sleep by Mattew Walker was strongly recommended by the sleep researcher of Somnox. Indeed, it is good to read because the author explained complex and technical knowledge with words that are interesting to read and easy to understand. However, the professionalism and accuracy of the information in the book was questioned by the neurology experts from Reinier de Graaf. In the future, when choosing reading material, it is important to select the ones that are authorized and validated by the stakeholders. By doing this, it will be easier to convince the stakeholders that the proposed design solution is well scientifically informed.

Chapter 4

Current Solutions

This chapter presents both current solutions that have already been applied and future recommendations proposed in the literature.

Current Solutions

4.1 Background

At this stage of the project, benchmark research has been done to keep track of the state-of-art solutions that are used or suggested to enhance sleep experience in hospitals. Some of the latest sleep-enhancing tools for home use and hospitals have been collected and analyzed. Since this project has a focus on dealing with sound-related sleep-disturbing factors, current design interventions suggested by researchers have also been found and analyzed. The aim is to analyze the reason for the product to be successful and impactful, which kind of interaction is involved in using the product, so as to seek inspiration for the design phase of this project. The benchmark research provided insight into the potential design requirements for hospital sleep-optimizing interventions, thus helping to form the design vision.

4.2 Sleep-enhancing tools

A considerable amount of sleep-enhancing tools, products, or techniques are available on the market nowadays. We classify the common ones into two kinds: (1) sleep tracking tools for self-management of sleep hygiene; (2) tools helping create a sleep-friendly environment; These two are mostly used by the general population. While for patients suffering from severe sleep disorders, there would be a third kind of sleep-enhancing tool, which is for screening or monitoring the sleep of patients and let the sleep clinicians decide on the follow-up treatments. Since we cannot predetermine if the target users suffer from a clinical sleep disorder, we only focus on the products used by the general population.

4.2.1 Sleep Tracking Tools for Self-management of Sleep Hygiene

Many sleep-assisting tools nowadays use the philosophy of quantified self, with which the users (the quantified self) make the conscious choice to perform the measurements on themselves. The aim of this kind of solution is to help with self-management of sleep hygiene. Multiple studies show that by measuring sleep, people become self-aware. Furthermore, self-awareness triggers them to perform self-reflection and self-treatment, thus improving their sleep behavior. The Internet of Things (IoT), as a trendy technology, has been largely applied in the field of measuring sleep. The study by Vandenberghe and Geerts (2015) gives some examples of the sleep tools driven by quantified self-movement. For example, there are mobile phone applications for everyday sleep monitoring. In one study, using a smartphone app, persons are asked to respond to a tone at regular intervals. If the person is not responding, then he or she is sleeping. In another study, a smartphone is also used to remind people of good sleep hygiene by showing them tips on an active wallpaper. There is also a persuasive app designed to help people achieve their sleep-related goals. Paalasmaa et al. describe the use of an unobtrusive online monitoring system, by placing a piezoelectric sensor under the mattress topper and sending data to a web server for analysis. Users can also augment the recorded data with tags (e.g., stress, alcohol, or exercise). There are also commercial products available, for instance, the Fitbit tracking daily activity, including sleep, and the Beddit3 system combining the data of a sensor in the bed with an app to provide people feedback on their sleep. The Withings Aura4 combines a bed sensor with an app and a bedside device to monitor and even impact sleep by emitting light and sound.

There are also products made use of the sleep cycle. For example, Zeo is an alarm clock that measured sleep stages, in order to wake people only during light sleep.

The source of the studies and products mentioned above can be found in the research paper by Vandenberghe and Geerts (2015).

However, Vandenberghe and Geerts argued that there are still challenges lying in the current self-management tools for sleep. Firstly, the interpretation of complex sleep patterns can be difficult for an uninitiated person, even with the aid of advanced software algorithms. Secondly, people often can't relate cause and effect of certain problems, because they don't understand the broader context. This prevents self-reflection from being successful. Thirdly, The design of these tools lacks an understanding of people's self-reflecting needs, which makes a correct interpretation even harder. Pirzadeh et al. (2013) provide a deeper understanding of the process of self-reflection, and argue that enough information and a proper interpretation is required for successful self-reflection.

4.2.2 Tools helping create a sleep-friendly environment

Some commercial products tackle sleep by changing or influencing the sleep environment. For example, the Philips Wakeup Light lets people wake up in a more natural way, using light and sounds to mimic sunrise and nature. Many other popular gadgets on the market, such as LectroFan White Noise Sound Machine, Bose Noise-Masking Sleepbuds, SomniLight Red LED Night Light, and SmartDuvet Breeze, tried to introduce sleep-beneficial sounds or light into the environment, or even change the temperature.

Sleep tracking tools for self-management

Smart watch, sleep tracking mattress, and sleep tracking application. Picture from TechRader: Best sleep tracker to buy 2020.

Tools for creating sleep-friendly environment

Bose sleep buds.

Figure 18: Examples of sleep products for daily use.

4.3 State-of-art Sleep-enhancing strategies in hospital

4.3.1 SIESTA (Sleep for Inpatients: Empowering Staff To Act)

To address the importance of sleep and improve sleep in US hospitals, the SIESTA (Sleep for Inpatients: Empowering Staff To Act) program has been developed by the University of Chicago (University of Chicago, 2014). SIESTA is an educational intervention designed to prepare hospital staff to assist patients in obtaining better sleep in hospitals and recognize the importance of screening for sleep disorders.

Spampinato et al. from the University of Chicago described the content of SIESTA program as following: "The SIESTA education includes a trigger video vignette on common sleep disruptions that patients experience when getting sleep, and the resulting risks that they may face. In addition, the learners view a brief screencast that educates staff on safe practices for patients sleeping in the hospital as well as screening for sleep disorders. We also distributed several tools (including a pocket card with the STOP-BANG questionnaire and tape measure pen) to help learners screen their patients for sleep disorders, create a better environment for patients to sleep, and to refer patients for sleep studies if they were at risk. "

In the January 2019 issue of the Journal of Hospital Medicine, an experiment by Arora et al. has measured the effects of SIESTA with 1,083 general medicine patients. It has been proven that sleep-friendly orders increased more in SIESTA-enhanced units compared to the nearby hospital units.

4.3.2 Measures taken by hospitals in the Netherlands

The research by Wesslius et al. published on JAMA Internal Medicine suggests that raising awareness about the importance of adequate sleep in the vulnerable hospital population and introducing interventions to target sleep-disturbing factors may improve healing. The research paper listed some possible future interventions for sleep optimizations, such as: (1) dimmed lights in corridors and patient rooms; (2) silent footwear; (3) remote alarms in staff rooms and in the pockets of the nurses, (4) distribution of flight packages at admission that contain earplugs and eye masks; and (5) possibly introducing remote measurement of vital signs and nocturnal checkups via webcams. Align with the idea of SIESTA program, changing the timing and minimizing nursing activities early in the morning, avoiding unnecessary standard procedures, such as routine vital signs measurements, continuous intravenous drips at night, and diuretics in the afternoon could potentially improve sleep.

4.3.3 Proposed future sound management solutions for hospital

Critical Alarms Lab of Delft University of Technology has developed design interventions to tackle the sound issues in intensive care units for better sleep. As a suggestion for intervention, Doplor is a sound feedback device making the hospital staff more aware of their influence on the noise using calming and pleasing dynamic visualizations. (Figure 19) It is advised that a subtle approach might be equally effective as laying down stricter rules and guidelines regarding sounds, though less intrusive to the practices and habits of the hospital staff (Birdja & Ozcan, 2019)

Another sleep optimizing interventions suggested by Birdja and Ozcan (2019) is to implement sleep preferences of patients before hospitalization. "Patients of whom their stay in the hospital is planned before, could monitor their sleeping habits in the weeks leading up to their hospital stay, and this information could be used when they are hospitalized. Little adjustments in bedtime or other sleep-related preferences could be the small improvements in the overall interplay of sleep-related factors that make a difference in the sleep experience of patients."

4.3.4 Implications for this project.

It can be seen as design opportunities for this project to come up with a "nudge" solution that encourages doctors and nurses to avoid disruptions that are only minimally valuable. The other interventions, e.g., distributing flight packages, dimming lights of corridors, or letting hospital staff wear silent footwear, are relatively easy to be adopted by a hospital and to test their effectiveness. However, it is challenging to stick to these orders because it depends on staff to remember to implement the changes, according to the leader of the study for SIESTA (Easton, 2019).

Besides, to consider the suggestion of Birdja and Ozcan, starting monitoring patient sleep habits and preferences before hospitalization and make use of these data during hospitalization could help simulate a home sleep experience in the hospital, which can potentially reduce the negative influence of environmental sleep-disturbing factors in the hospital.

Figure 19: Doplor: Artful warnings towards a more silent Intensive Care.

Summary

This chapter describes the current solutions for improving sleep hygiene of people in their daily life and during hospitalization, as well as sound management strategies used or proposed to be used in hospitals. The takeaways from this benchmark research helped to and to form the design goals and shape the design solution proposed in this report.

Main takeaways

1. In current sleep products, the interpretation of complex sleep patterns can be difficult for an uninitiated person.

2. People often can't relate cause and effect of certain problems because they don't understand the broader context.

3. Current sleep tracking tools lack an understanding of people's self-reflecting needs.

4. It is valuable to brainstorm about nudging methods to help medical staff stick to the regulations and avoid unnecessary sound-producing events.

5. It is valuable to start monitoring patient sleep habits and preferences before hospitalization and make use of these data during hospitalization.

Reflection points

Since the medical context can be different from country to country, the benchmark research did not very effectively help to reflect on the context of a hospital ward in the Netherlands. Since making consumer products for individual use in the hospital is a relatively new area, not many existing products that are tackling exactly the same issues can be found. In this chapter, we explore sleep tools for daily use, but when using the same product in the hospital, the interaction and effect of the product may be different. Therefore, in this project, we cannot confidently predict whether our design is suitable for being used by patients and nurses in the hospital by analyzing existing products. Because none of the existing products were designed to be used in the hospital ward to tackle the exact same problem as we do. With limited information, we need to start building the design, prototyping it, and testing in the relevant context, keep reflecting on whether it is suitable for the target group to use in the target context. Then, more insights can be gained on how to improve the design.

Chapter 5

Design Brief

By synthesizing the takeaways from the research phase, a design vision and goals are derived and presented in this chapter. The design goals are further translated into design requirements.

Design Brief

5.1 Background

As the research phase is approaching an end, ViP design methods suggest the designers create a design vision based on the previous findings. In this chapter, the main takeaways from the previous chapters were translated into design drivers. A design vision has been created. Other factors, such as the target users and available materials in the contexts, were defined. This chapter describes a process of synthesizing the previous findings and preparing for the conceptualization.

5.2 Target Users

Though mapping the context and establishing the understanding of the context (See chapter 2), it is obvious that both the hospital staff (mainly the nurses) and the patients are contributing to the noise production. Nurses, as the healthcare giver, have the biggest power in terms of influencing the soundscape and taking care of the sleep of patients. From chapter 3 - the basics about sleep, we learned that the perception of sound during sleep largely depends on the sleeper. Therefore, the patients can not be neglected as the target user of the product. They are the ones who can communicate their perception of sounds and sleep experiences the best.

The target users and the relation between them and other stakeholders are presented in Figure 20.

Target Users

Patients: need to improve sleep hygiene in the hospital, feel in control of improving the sound quality in the sleep environment.

Hospital staff: need to be aware of patients' sleep experience in the hospital, which sound-producing activity caused the sleep problems of patients, and what actions they can take. They can use the information to inform visitors to avoid producing unnecessary sounds.

People being influenced

Visitors: wish to visit the patients at the right moment, which does not disturb the patients from taking a rest and follows the visiting schedule of Reinier de raff hospital.

Hospital: concerns the well-being of inpatients and the quality of service they deliver. What to understand the current experience of patients.

Figure 20: Introducing target users

5.3 Design Goal and Vision

By synthesizing the takeaways from the research described in the previous chapters, the following implications were revealed to form a design vision:

1. Inspired by previous work of critical alarms lab, we approach the sound issues and sleep issues in the hospital ward by mapping the soundscape and present the information to the stakeholders, so as to create awareness that sound-disturbing factors are negatively influencing the sleep of patients.

2. It is valuable to start monitoring patient sleep habits and preferences before hospitalization and make use of these data during hospitalization. The design of the product system should align with the reflection process of people. In the side note, an example of a reflection cycle is given.

The design vision:

To help patients have a home-like sleep experience during hospitalization, by providing them with means to improve their own sleep environment for a good-night sleep. As if the user is traveling to a new place, we want to "forecast" the climate of the destination, advise people to prepare for the climate differences, and keep tracking whether the user adapted to the new environment (has a positive experience).

Side note: self-reflection cycle

For inspiration, a number of the human reflection cycles were explored. Gibbs's reflective cycle is one of the most well-known models developed by Gibbs in 1988 to give structure to learning from experiences (Gibbs, 1988).

The model consists of the following stages:

1. Description of the experience
Feelings and thoughts about the experience.

2. Evaluation of the experience, both good and bad.

3. Analysis to make sense of the situation.

4. Conclusion about what you learned and what you could have done differently.

5. Action plan for how you would deal with similar situations in the future, or general changes you might find appropriate.

To solidate the vision, the design goal is defined as:

To create an information exchange platform to empower patients to improve their sleep experience in the hospital.

To achieve this design goal, main sub-objectives are defined as:

(1) Before the hospitalization, inform the patients with what kind of sound disturbance will be there during sleep in the hospital. Help them get used to these sounds and reduce anxiety towards hospital sounds. (related research insight: sound source information as a positive sound intervention in the hospital)

2) Help patients and medical staff understand how patient sleep was influenced by sounds in the hospital wards, compared to sleeping at home (related insight: help general users relate to the cause and effect of the sleep problem), not only from the perspective of sounds, but also profiling the sleeper to help health providers understand individual needs on sounds.

To fulfill the goal and objectives, the design phase of this project will be focusing on the designing of the enablers.

The enabler:

Tracking the environmental noise and patient sleep to help patients, hospital staff, and visitors regularly reflect on their sound-producing activities so as to take action to ensure a sleep-friendly sonic environment.

(related insight: self-reflection process)

5.4 Available Materials

The carrier of the information exchange platform largely depends on what is available and allowed to use in the Reinier de Graaf hospital.

<u>- A pc installed in the ward</u>

According to the hospital technician Rick Schoffelen, an additional desktop computer can be installed in the ward to show the information to the hospital staff and visitors.

<u>- The smartphone of patients</u>

The smartphone of patients can be used to capture sound data of the ward, track patient sleep (an external sleep tracker may be needed), and show the patients the data and insights. Due to privacy concerns, the sound should not be recorded in the hospital without permission because it contains personal data. Therefore in this concept, no sounds will be recorded and sent, but only the sound data such as decibel and frequency-related data will be measured and uploaded to a server. A smartphone is an option for doing this job because it allows people to give permissions when turning on the microphone for measuring, and it has the computing power to process the sound locally and only send the required sound data to the cloud.

A smartphone is not possessed by everyone, and not all patients may care about their sleep experience as others do. However, if some people use this system, others people will be benefit from it indirectly.

5.5 Preliminary Design Requirements

The design goals and vision was translated into a number of preliminary design requirements:

1. The product should be capable of capturing the sound-producing events and tracking the sleep cycle of patients.

2. The product should be capable of visualizing the relation between sound-producing events throughout the night and the sleep changes of the patient.

3. The visualization of the sound and sleep information should be comprehensible by non-professional users.

4. The product should start monitoring patient sleep habits, preference, and their exposure to sounds at home and use this information during hospitalization.

5. The sound report can be given in a way that is subtle and less intrusive to the practices and habits of the hospital staff. In this project, the subtle and non-intrusive warning behavior of the product is described as 'friendly'.

6. The design should be attractive to the users, so they are nudged to use the product, proactively take in the information that the product is trying to convey, and become more aware of the influence of sound-producing events on sleep.

7. As a wish, the design of the product system should align with the reflection process of people. In the side note, an example is given to demonstrate how to translate a reflective model into product functions.

Summary

In this chapter, previous takeaways were synthesized and translated into a design vision and concrete design goals and requirements. The target users and available materials in the design contexts were explored. The next chapter will present the process of selecting the technologies in preparation for building the design goal 'enabler' defined in this chapter.

Reflection points

During the process of coming up with design vision and setting the design goals, the system of the concept to be designed became complicated and too big for the time scope of this project. With the help of the project mentor Jered Verhoeff, I realized that it is important to extract the 'enabler' of all the goals and focus on the designing of it. I learned to prioritize the most fundamental and core function when facing a rather complex system of design goals.

Chapter 6

Technology

This chapter describes how technology was selected for developing the concept based on a series of criteria. The aim is to ensure the feasibility of the concept.

Technology

6.1 Background

As one of the main functions of the concept, a sleep tracker needs to be implemented to track patients' arousals during sleeping. According to the neurologist of Reinier de Graaf hospital, arousal during sleep means awake and transitioning from a deeper sleep stage to a lighter one. Because the transition could mean their sleep being disturbed by external factors, such as sounds. If knowing when the 'arousals' occurred and matching it with the noise produced simultaneously, the healthcare provider could understand whether a specific noise has disturbed the patient's sleep. Therefore, selecting a technology that can track and show the arousals is critical.

6.2 Criteria

The requirements are listed below and given different weights (from 1 to 10) based on the importance.

<u>Reliability (8):</u> Scientific paper shows that the data captured by the sleep tracking device correlates with Polysomnography (PSG). Or the reliability of the sleep tracking technology is validated by the neurologist of Reinier de Graaf hospital.

<u>Ease of use (10):</u> For users, a sleep tracking device should be easy to use and easy to be installed at home and transferred to the hospital.

<u>Intrusiveness (7):</u> The sleep tracking device should be as less intrusive as possible.

<u>Acceptance (8):</u> Daily use of the sleep tracking device should be acceptable for most users.

<u>API/SDK availability (6):</u> For the feasibility of prototyping, SDK/API of the technology should be available.

<u>Cost (3):</u> For production, the price should match the value added by the function.

6.3 Possible Technologies

Three common technologies have been chosen to represent wearable sleep tracker, non-wearable sleep tracker with external sensors, and non-wearable sleep tracker only using smartphone sensors.

1. Wearable sleep tracker: Fitbit

Fitbit wristbands have the function of tracking sleep, mapping sleep stages, etc..Fitbit company has been innovating on its sleep tracking technology. Their ambition is to "fit a sleep lab in a sensor". A few scientific papers showed the reliability of it by comparing to PSG.

2. Non-wearable sleep tracker: Withings Under-mattress sleep tracker

Withings Under-matters sleep tracker needs to be placed underneath the mattress. The reliability of it has been validated by the sleep researcher from Somnox and the neurologist of Reinier de Graaf hospital.

3. Smartphone-based sleep tracker: SleepScore application

It is a sleep tracking app using the sonar sensor of a smartphone. Scientific papers can be found on proving the reliability of the technology used by the SleepScore app.

6.4 QOC method (Question, Option, Criteria)

The QOC method has been used to facilitate the selection of technology.

QOC consists of questions identifying key design issues, options providing possible answers to the Questions, and criteria for assessing and comparing the options. (MacLean et al., 2011)

For this decision making activity, the Question is formed as the following:

<u>Which technology is most suitable for tracking sleep and showing arousals for this project?</u>

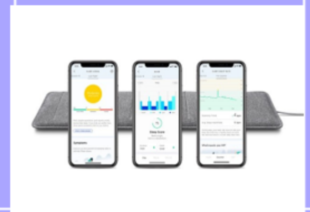
	Fitbit 	Withings under-mattress 	SleepScore app 
iability (8)	7	8	7
e of use (10)	10	6	9
n-intrusiveness (7)	7	9	8
ceptance (8)	10	10	6
/SDK availability	10	10	0
st (3)	6	4	10
erage score:	6.05	5.65	4.67

Table 3: Rating the three technologies based on criteria. The full score is 10.

6.5 Result

By calculating the mean score and considering that different criteria are weighted differently, Fitbit turned out to have the highest score and appears to be the most suitable technology to be implemented in this project. (see Table 3)

Summary

This chapter describes how the technology for sleep tracking is chosen for developing the concept. A QOC method has been used to motivate the decision. In the next chapter, how the chosen technology is implemented in the concept will be presented.

Main takeaways

A Fitbit wearable sleep tracking device has been selected as the technology to implement into the concept.

Reflection points

In this project, the most basic Fitbit model with a heart rate sensor (which is required for getting detailed sleep stage information) was chosen. In principle, all Fitbit models' accuracy with a heart rate sensor implemented should be equal because they use the same algorithm to process the sleep data. However, it is also possible that a more high-end model has better computing performance and better hardware-implemented, which influences sleep tracking accuracy and the user experience (e.g., faster synchronizing speed, more comfortable to wear, etc.).

Chapter 7

Initial Concept

As design requirements have been defined and technology has been chosen, This chapter presents the first concept generated.

Initial Concept

7.1 Background

The design goals and vision, selection of technology, and available materials in Reinier de Graaf hospital, led to an initial concept, a product-service combination. Due to the COVID-19 circumstances, access to facilities required for prototyping tangible products was limited. Therefore, it was decided that in this project, a software-based product will be made.

7.2 The Service-product combination concept explained

For the patients concerned about their sleep quality in the hospital, they can apply for temporary use of a Fitbit from Reinier de Graaf hospital before being admitted to the hospital ward. For those who already have a Fitbit tracker, they can directly use their own Fitbit device. The patient needs to install the application designed to be used together with the Fitbit. Before the hospitalization, patients wear Fitbit to sleep at home. At the same time, they use the sound capturing function of the application to record the sound data generated during the night (sound levels and detected sound-generating events). The next morning, a report is generated to show the patient how they slept last night and how last night's soundscape was. The application also presents the detected sound-generating events and the change of the patients' sleep stages on the same timeline to indicate how sleep is disturbed by different kinds of sound-producing events.

During the period of sleeping at home before hospitalization, the patient can use the program integrated to get familiar with hospital sounds. In this program, a playlist of pre-recorded hospital sounds is implemented with an explanation of what each sound is. This is to provide the patient with the sound information in advance to reduce the anxiety caused by not knowing the meaning of a certain hospital sound (see the takeaways of chapter 3). In chapter 5, when describing the design vision, we used the analogy of 'forecasting the weather condition' to explain the purpose of this function.

When using the product at home, the sleep habit (i.e., the patient's sleep schedule, duration, efficiency) is recorded by Fitbit and sent to the hospital. The user's sleep profile is also generated, which contains the information on whether the person is a light or deep sleeper and how sensitive they are towards sound disturbances. With such information, the nurses can deliver personalized service accordingly to their habits and sleep profiles. For example, if the patient appears to be a light sleeper and very sensitive to sound, he or she can be arranged in a single-person room. The nurses can adjust the schedule of performing healthcare activities for this patient according to their sleep schedule.

During the hospitalization, the patient continues to use the sound capturing and reporting functions of the application. The captured sound information and sleep data of the patients are sent to another application designed for nurses. The nurses can keep track of the patients' sleep quality and the soundscape of the ward. So as to reflect on how to improve the current sleep environment.

A storyboard describes how the service-product-combination concept works in context (Figure 21).

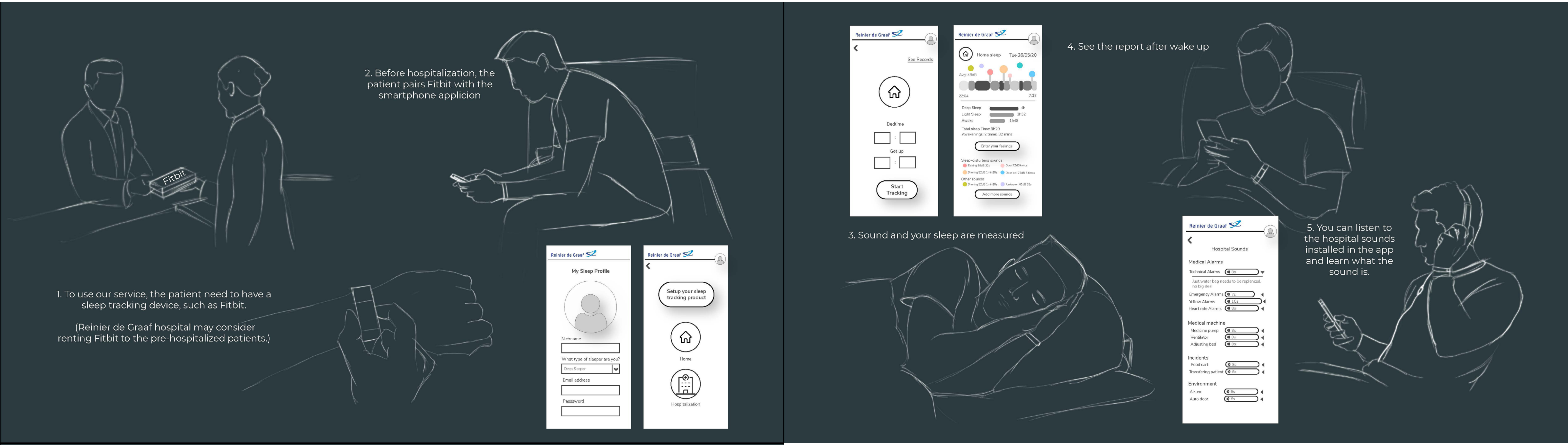


Figure 21: Story board explaning the service-product system.

7. 3 Elaboration on the product segment of the concept

As mentioned in chapter 5, the focus of the design phase will be on the product segment of the concept. In this chapter, the product segment of the concept will be elaborated.

The product is a software-based application consisting of two components: the patient-end of the application installed on a smartphone and a nurse-end displayed on a computer screen. The workflow of the application is visualized as Figure 22. During this project's time scope, attention is paid to the core function of the application, which is the sleep tracking and providing the users with visual feedback. The side functions, such as implementing a playlist of hospital sound to get the patient acquainted with the hospital soundscape before hospitalization, will be further discussed as further design recommendations.

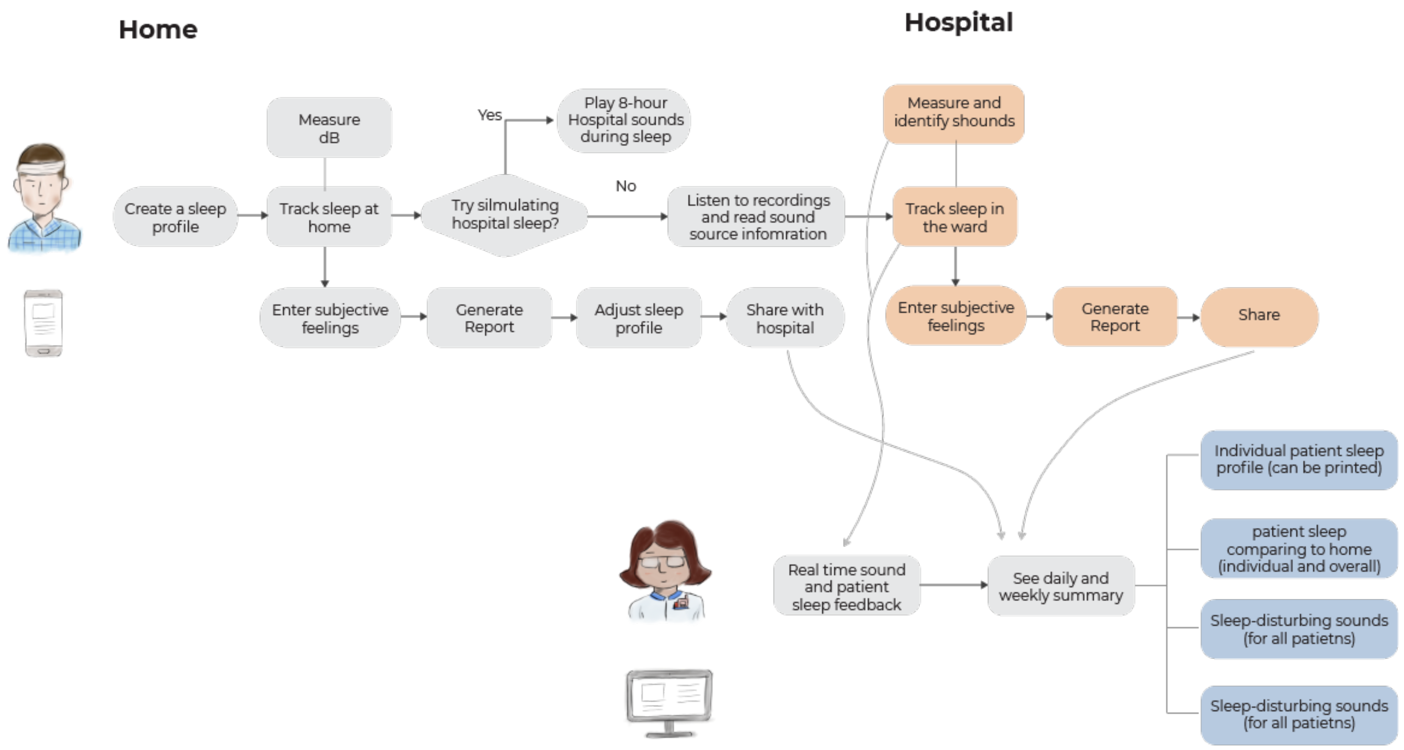


Figure 22: the workflow of the application.

The design of the interface of the application used a boat drifting on the river as an analogy. In the previous project, Doplor, an artistic warning of noise at ICU, used the analogy of sea waves to indicate sound intensities. In the Doplor project, different sea waves' levels of violence indicate different soundscapes (Figure 23). Besides, Doplor used different icons to represent different sound sources. As the analogy of waves and using icons to indicate sound sources were validated by Erasmus MC nurses previously and was appreciated by the client from Reinier de Graaf hospital, we decided to use Doplor as an inspiration for this project. Using a graphical style image (animation) as an analogy for the overall soundscape, and using different elements in the image to represent different sound-producing events are continued to be applied in this project. A similar analogy to the sea waves - the river, was used in this concept. The ripples on the river are a calmer version of waves on the sea, which is considered more suitable for the night. Since during the night, a colorful, bright, and actively changing animation is not necessarily desired.

In this concept, the boat drifting on a river is used to represent the person's sleep. Although patients may face a critical illness, they are in a safe place during hospitalization and are protected. It is like a person traveling across the river. The weather condition and the obstacles are unknown, but he has his boat as a "shelter," which carries him across the river. For the patient-end of the application, time is also included as a variable. The river is often used as a representation of a timeline in data visualization. This also motivated the decision to use the river as an analogy. We used a fisherman icon to represent speech sounds, rock for incidental sounds, flashlights for medical alarms, and bubble icons to represent snoring sounds. The reason for classifying the sound-producing events into alarms, snore, incidental sounds, and speech can be found in chapter 2.

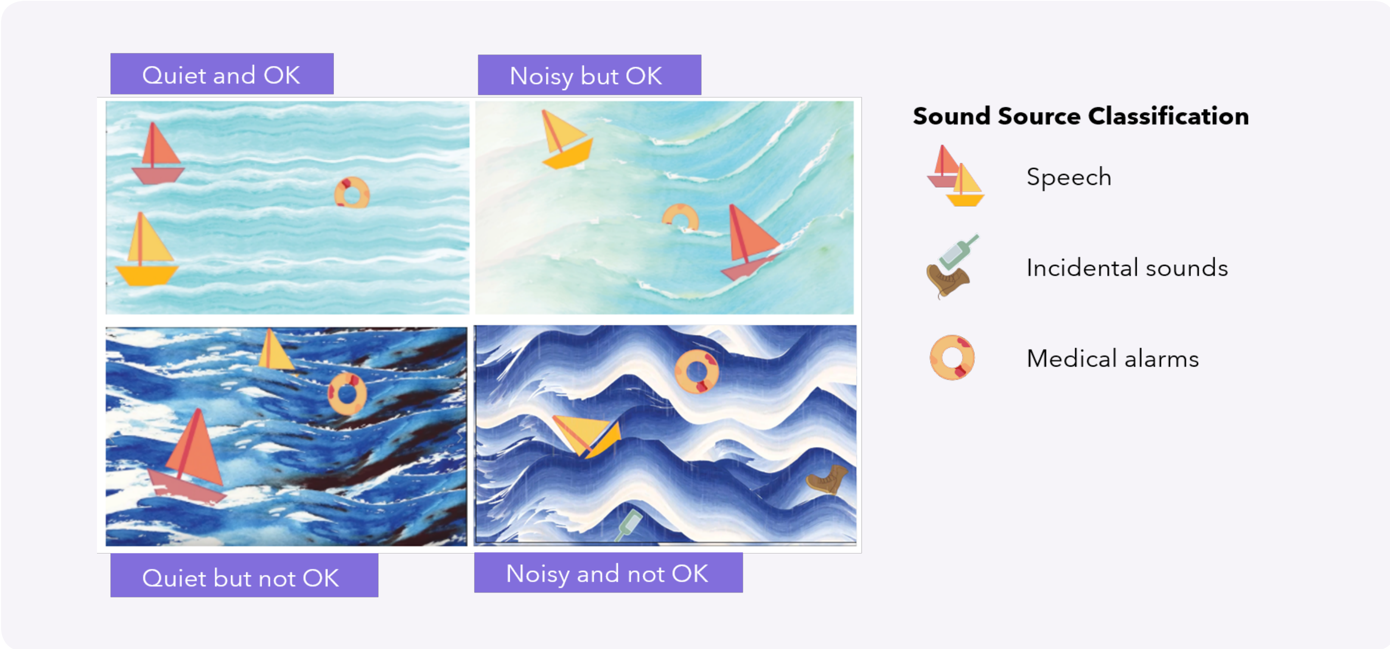


Figure 23: Previous project, Doplor, used different states of waves and weather to indicated different soundscapes. Different graphical icons represent different sources of sound.

In the new concept, we classified the soundscape into three levels.

Peaceful: Little sounds are produced. The ward is quiet (under 40 dB). There is no need to worry or take any action.

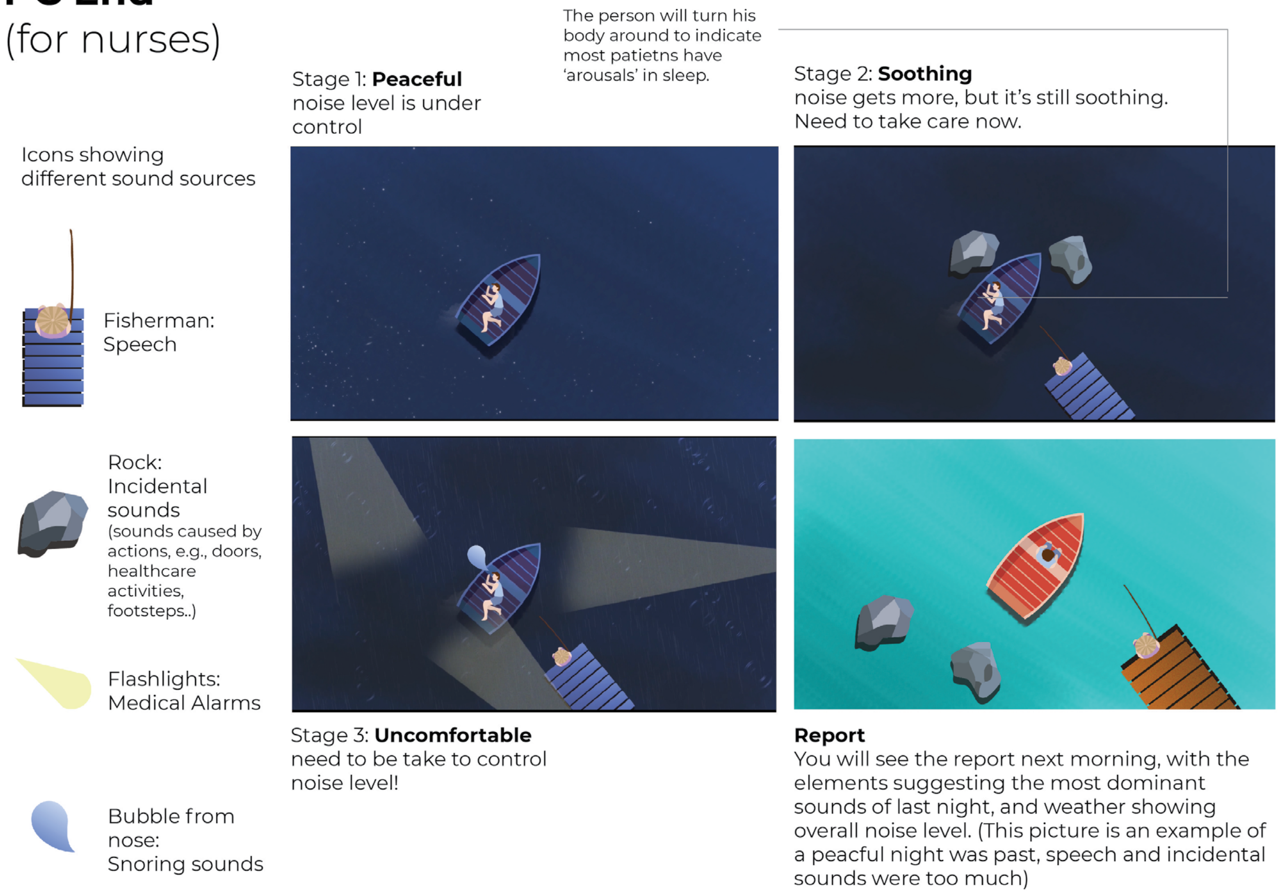
Soothing: A small amount of sound was produced, but the sound level is under control if nurses act a little more carefully. The loudness level is from 40 to 55 dB.

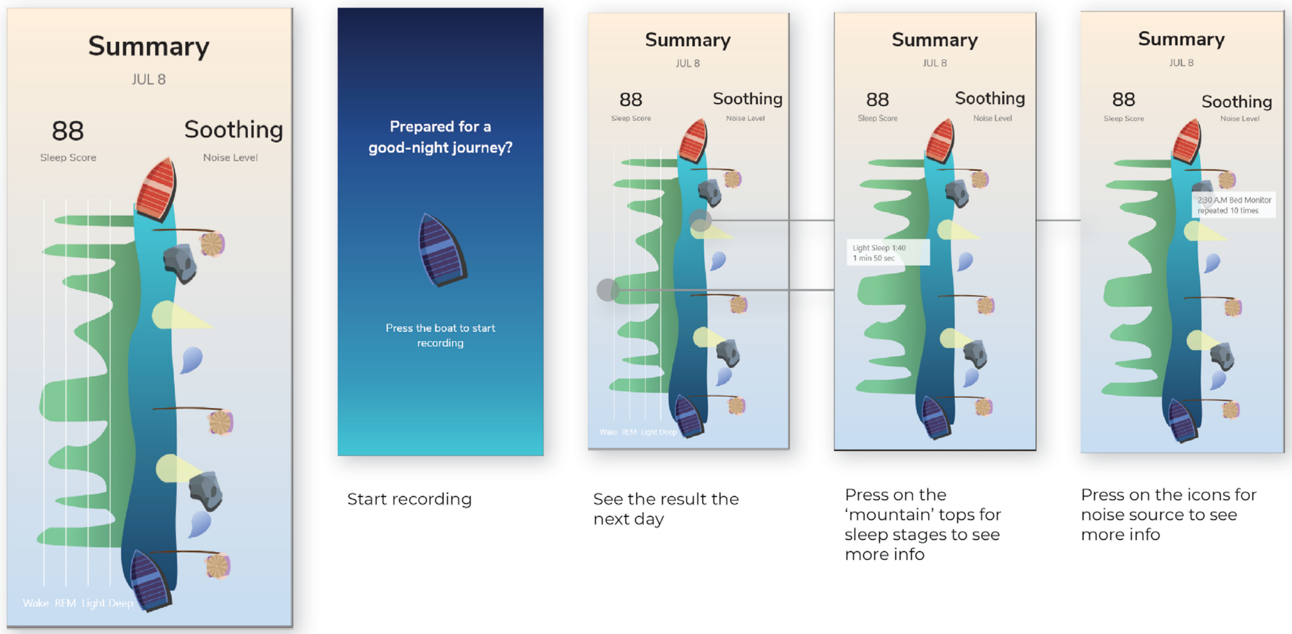
Uncomfortable: A considerable amount of noise is produced. The ward's environment is violent for the sleep of patients, and attention should be paid immediately. Actions need to be taken to reduce the currently present sounds. The loudness level is above 55 dB.

On the PC end for nurses, a dynamic animation is played during the night to show the ward's real-time soundscape. The weather conditions and state of waves indicate the violence of sound (Figure 24).

Using the patient end, the patient records the sound during the night. The next morning, the patient can see a data visualization reporting the soundscape last night and how well he slept. The mountain represents the pattern of sleep, which is plotted vertically on the left of the timeline. A river at the center represents the timeline. The icons representing sound sources are plotted on the right of the timeline. By clicking on the sleep pattern, detailed information such as sleep stages and corresponding time appears. When clicking on the icon, detailed information such as the corresponding time and duration of the sound is shown (Figure 25).

PC End
(for nurses)





Phone End
(for patients)

Same icons are used for the phone app interface

Figure 24 & 25: The nurse-end and patient-end of the application.

Summary

This chapter described the initial concept generated after the design vision goals, target users, available materials, and technology required are defined. The proposed design concept is a service-product combination. Due to time limitations, the product part of the concept was emphasized and will be further developed. The next chapter will present the iterative process of development of the product.

Main takeaways

1. Using an image of a landscape to visualize soundscape was an idea validated by users in the previous project Dopler.

2. The analogy of sea waves to indicate sound has received applause in the previous project.

3. The client (Reinier de Graaf hospital) liked about the Dopler concept using different states of the sea waves and weather conditions to represent the different levels of violence of the auditory environment.

Reflection points

In this concept, the soundscape is classified into three levels: peaceful, soothing, and uncomfortable. However, this classification is only based on sound levels. As we mentioned in chapter 2, soundscape is determined by the absolute sound level and the meaning of the sound. This means that when the patient perceived the soundscape as 'peaceful', it does not necessarily mean that the sound level is low. It may be that the sound-producing events occurring in the current environment make the patient feel peaceful, e.g., the gentle voice of a nurse who is comforting a patient. Therefore, it is a temporary decision to use sound level as an indicator to classify the soundscape. To consider the sound's meaning, many other parameters, e.g., the time of the day, the tone of people's voice, the meaning of a specific alarm, and whether it is a false alarm are needed. Further research needs to be done to generate an index for a more reasonable way of classifying soundscape.

Chapter 8

Concept Development

This chapter describes an iterative design process, which consists of two iterations on the product segment of the concept.

Concept development

8.1 Background

Unlike the research activities conducted in the research phase, in which we derive the results as expected. In the design phase, insights driving a new iteration are sometimes derived from a design activity that was conducted for another purpose. The first iteration of the concept was triggered by an experiment that compares the sleep data collected by Fitbit with and without the hospital sounds added into the sleep environment. The second iteration of the concept was triggered by giving a pitch in the Reinier de Graaf hospital to represent the up-to-date design progress. The nurses' opinions for the pitch led to an iteration on the way of data visualization for the summary page.

8.2 Iteration One - Inspired by an experiment and Fitbit users

Since no real data were collected before the conceptualization, an experiment was conducted for several reasons. First, we need to verify whether the design of the initial concept, especially the layout of the summary page of the patient-end application, is suitable for presenting the data. It was reasonable to imagine that the sound data can be densely presented and hard to fit on one page. Second, Since the current visualization of the summary for patients is too crowded with too many different kinds of data according to fellow design students' opinions, we need to find a create hierarchy to present the data and maybe separate them in layers. Therefore, we need to collect real sound and sleep data from people to understand how sleep data correlates to the sound data.

8.2.1 Method

For this small experiment, three subjects were recruited. The experiment lasted for two nights. For the first night, the subjects were asked to wear Fitbit to sleep without any sound intervention. For the second night, a seven-hour sound recording containing the four kinds of sounds were played while the subjects were sleeping. The three Fitbit devices used in this experiment were sponsored by Renier de Graaf hospital. The two nights' sleep patterns from each subject were collected and placed on the same timeline with the sound recording. (Figure 26,27,&28)

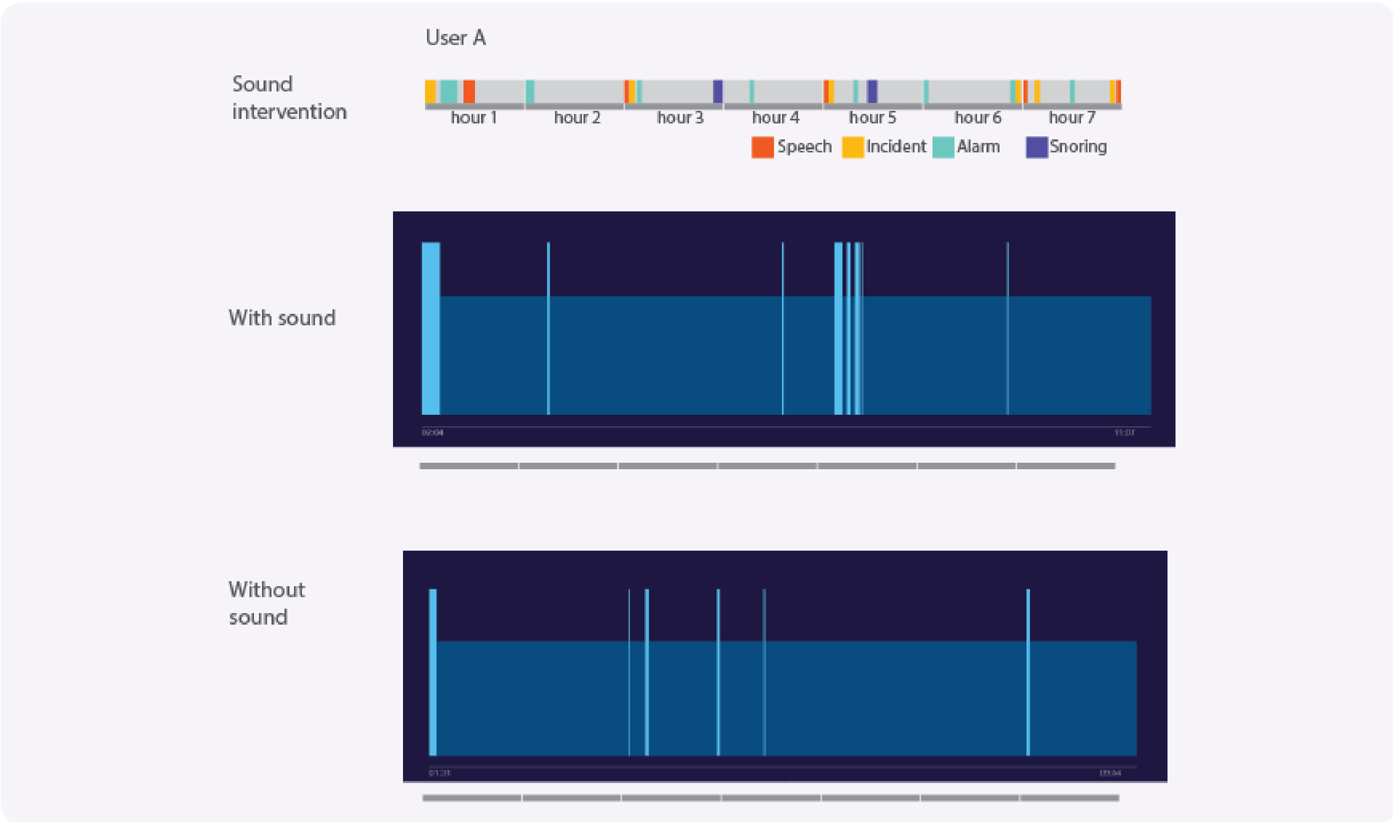


Figure 36: The sleep pattern of subject A mapped on the same timeline with the sound recording. Due to a technical issue, the pattern only shows the major (long-period) awakes and asleep. But we still find that the sound interventions caused longer periods of awakes.

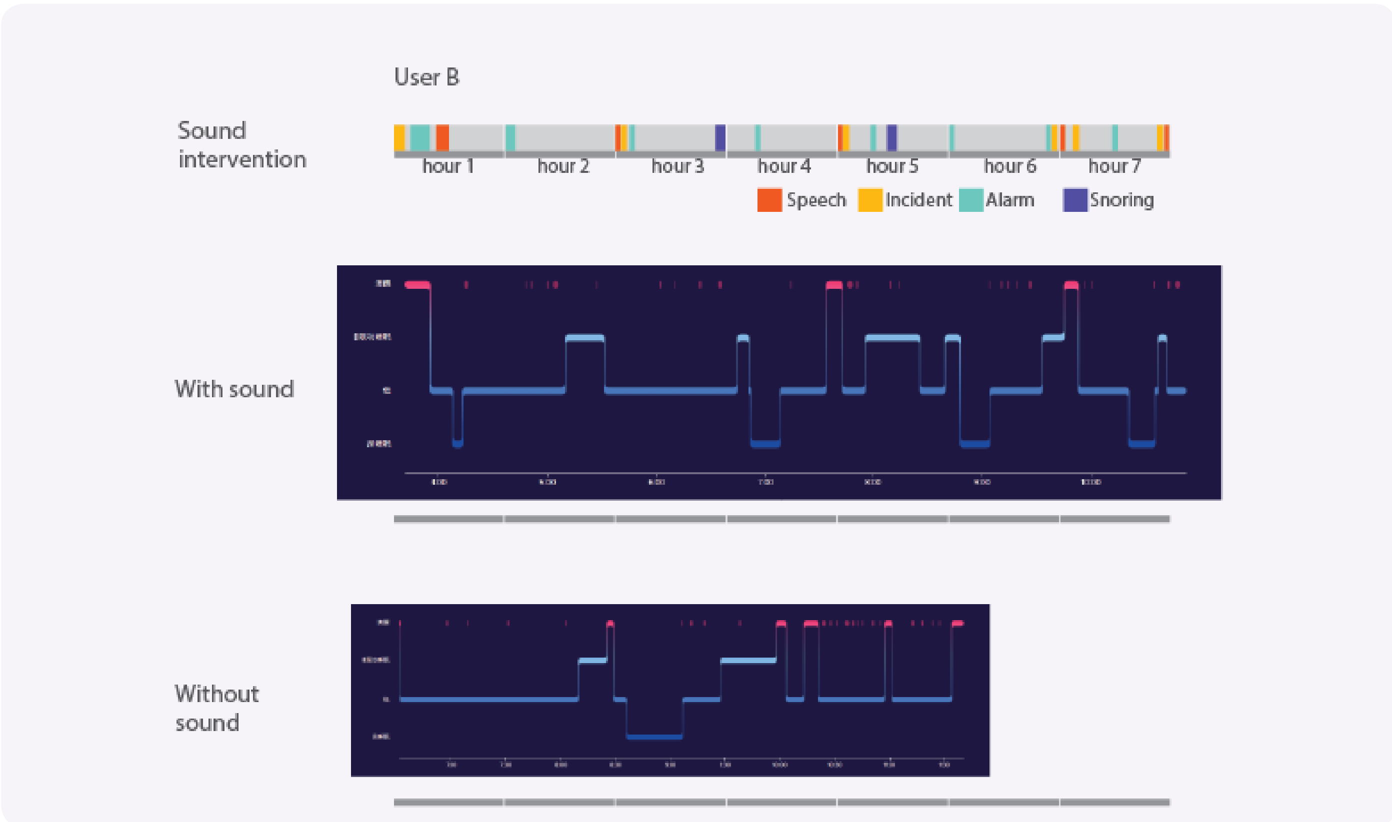


Figure FIXME: Subject B's sleep pattern on the same timeline with the sound recording. This figure shows that the sound intervention caused longer periods of awakens and transitions between different sleep stages.

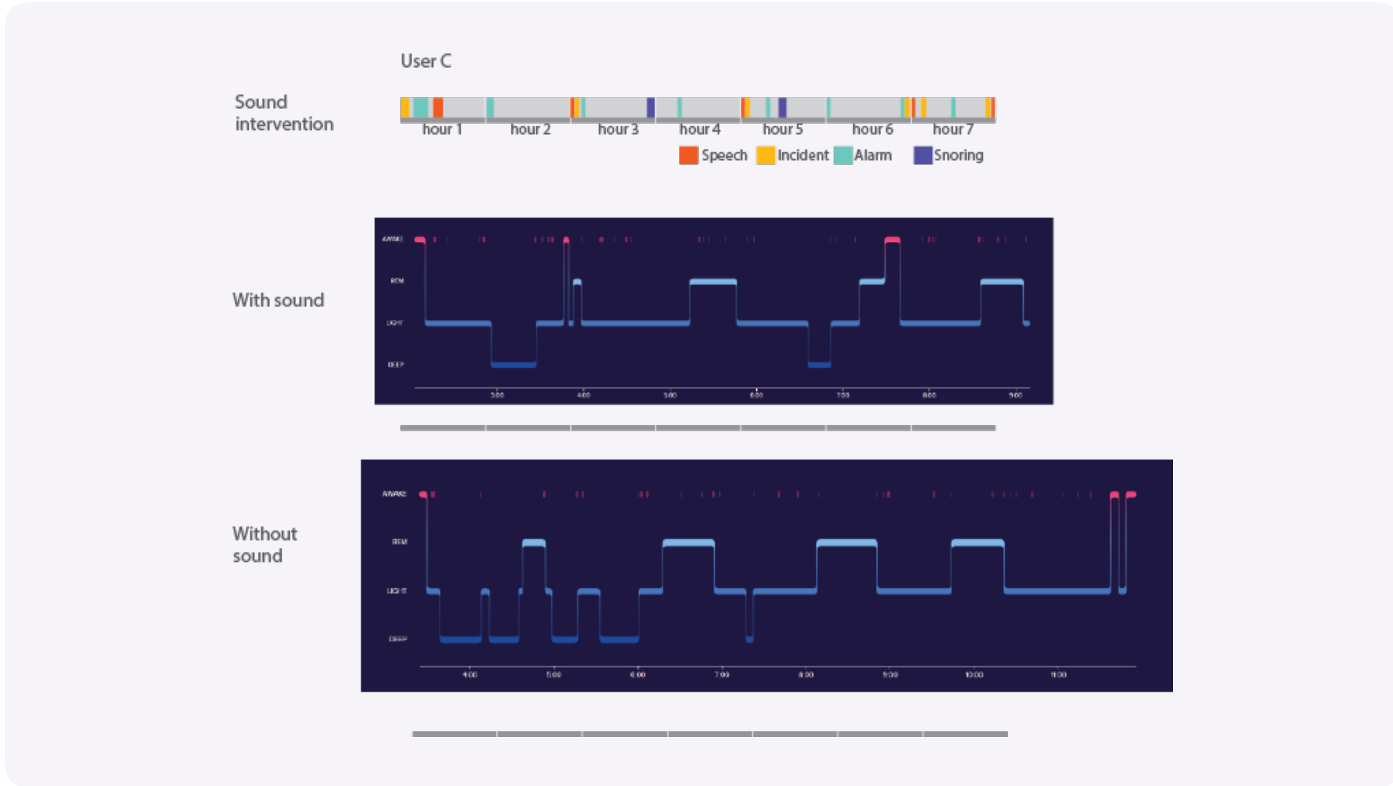


Figure 28: Subject C's sleep pattern on the same timeline with the sound recording. By only looking at the sleep pattern within the sound recording time frame, we can find that the sound interventions caused more long-period awakening.

8.2.2 Result and Findings

According to the figures, it seems that the sound intervention affects the long-period of awakes. The short period of awakes seems not affected by the sound. Besides, the sound also seems to affect the number of transitions between different sleep stages, which aligns with the literature research described in Chapter 3. However, scientific research needs to be done to verify these assumptions in the future. For this project, we decided to emphasize the relation between noise events, long periods of awakes and transition of sleep stages.

An unexpected finding in this experiment was that all three subjects expressed their preference for seeing the sleep stages presented horizontally instead of vertically. According to the three subjects, most sleep products show the sleep stages on a horizontal timeline. The sleep product users have already formed the habit of reading the sleep information in a horizontal format.

8.3 Iteration Two - Inspired by the feedback from nurses

The prototype for the nurse end has been presented at the Neurology department of Reinier de Graaf. The nurse generally appreciated the use of analogy to represent the real-time sound data. The main area for improvement was the missing of technical data and graphs. According to nurses, medical workers would prefer to work with numbers, texts, and scientific graphs. Therefore, in the iterated concept, a dashboard is used to replace the graphics, which summarizes the soundscape and patients' sleep last night.

Figure 29: Presenting the concept in Reinier de Graaf hospital and gathering nurses' opinions.

Summery

This chapter introduced the two smaller iterations during the concept development process. The number and scale of iterations were kept small because more time and effort is required for the concept embodiment stage. The final concept resulting from the two iterations will be presented in the next chapter.

Main takeaways

The biggest takeaway from this chapter is to find a balance between innovation and respecting the existing habit of the users. For general users, the existing sleep product has already, to a certain level, shaped their habit of interpreting the data visualization. For professionals such as medical workers, their habit is to analyze and gain insights from technical and reliable-looking data visualizations created with traditional charts

Reflection points

The concept development process was rather brief in this project. This was mainly due to time limitations and COVID circumstances. Although some efforts were paid to initiate a brainstorming or co-creating session with fellow students, it was not successfully organized due to the COVID issue. If this project can be continued, I would like to have another iteration to improve the data visualization and explore more possibilities of using different analogies and graphical styles.

Chapter 9

Final Concept

This chapter elaborates on the final concept and explains how it works.

Final Concept

As presented in the figures below, the patient version of the application consists of 1) A login page; 2) the sound capturing function (using the recording function of the smartphone) triggered by pressing on the boat icon; 3) a summary page of how well the person slept and how was the soundscape, which is shown after the user pressed on the boat icon again to finish recording; 4) An scrollable visualization of sleep stages and noise events during the night: 5) and a page where the patients rate for the subjective feelings of sleep quality and give feedback to the hospital.

1. Login page

The current prototype supports three users to use the system at the same time using anonymous accounts created in advance.

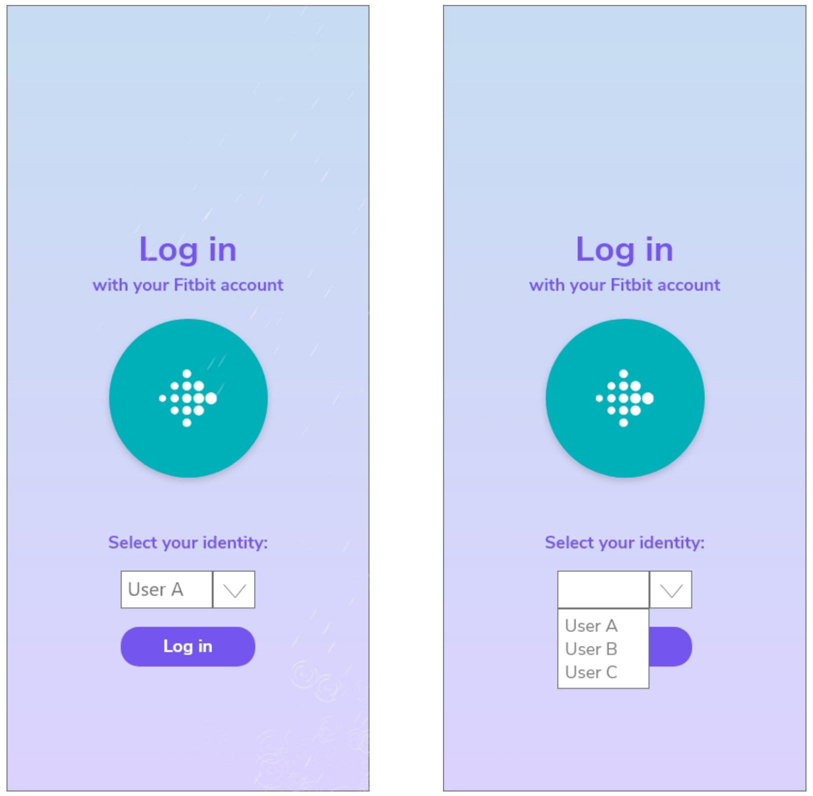


Figure 30: The Login interface.

2. Sound capturing function

By pressing the boat icon, the recording function is running on the backstage. When the boat is pressed again, the sound capturing ceases, a summary page providing general information about sleep and sound is presented.

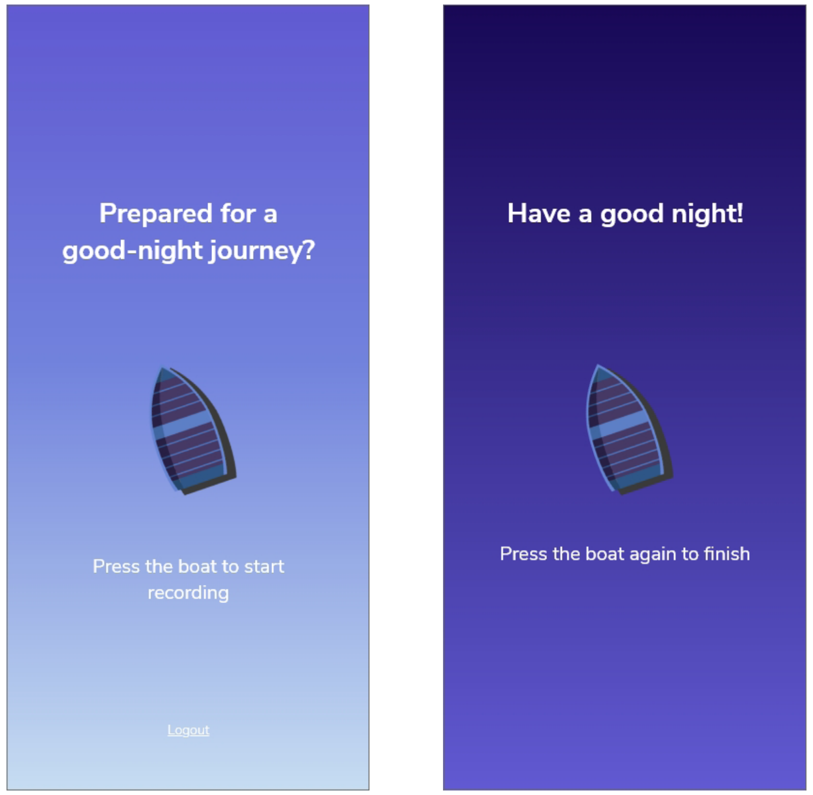


Figure 31: The interface of initiating the sound capturing process and stop sound capturing

3. The Summary page, scrollable visualization of sleep stages and noise events, and the subjective feedback giving page

The background of the summary page indicates the different level of soundscape by calculating the average sound level of last night.

Swiping to the left, a 'look back at the journey' page is shown. The boat serves as a pointer and is fixed in the middle of the screen. The river represents the timeline. By scrolling the river, a scene of the boat driving on the river is simulated. When the 'pointer' points at a time when a certain kind of sound was present, the corresponding icon is shown. The background of this page is also changing according to the decibel at that moment. Some texts around the boat are present to assist the user in interpreting the data visualization.

When swiping the screen to the left again, a page is shown, on which the patient can select their subjective feeling about sleep and leave comments. The input of the patient will be sent to the nurse application and shown on the summary page.

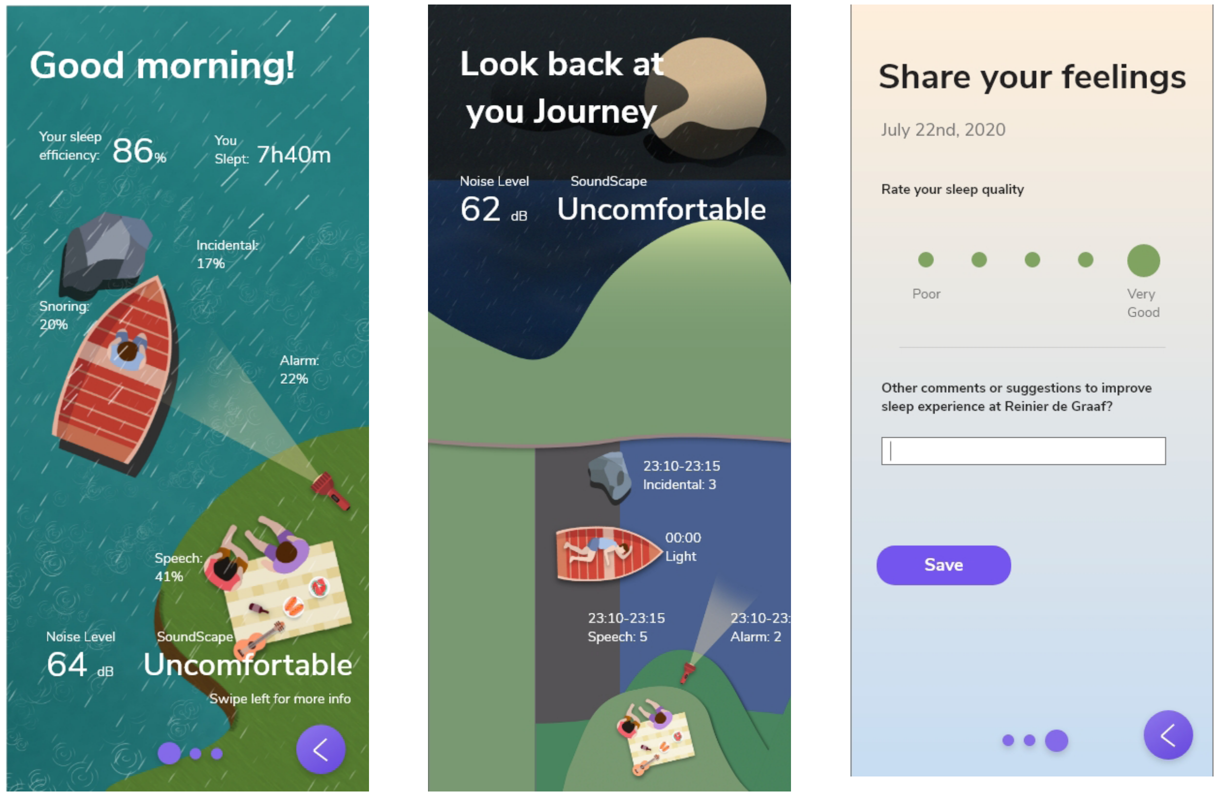


Figure 32: The Summary page, scrollable visualization of sleep stages and noise events, and the subjective feedback giving page

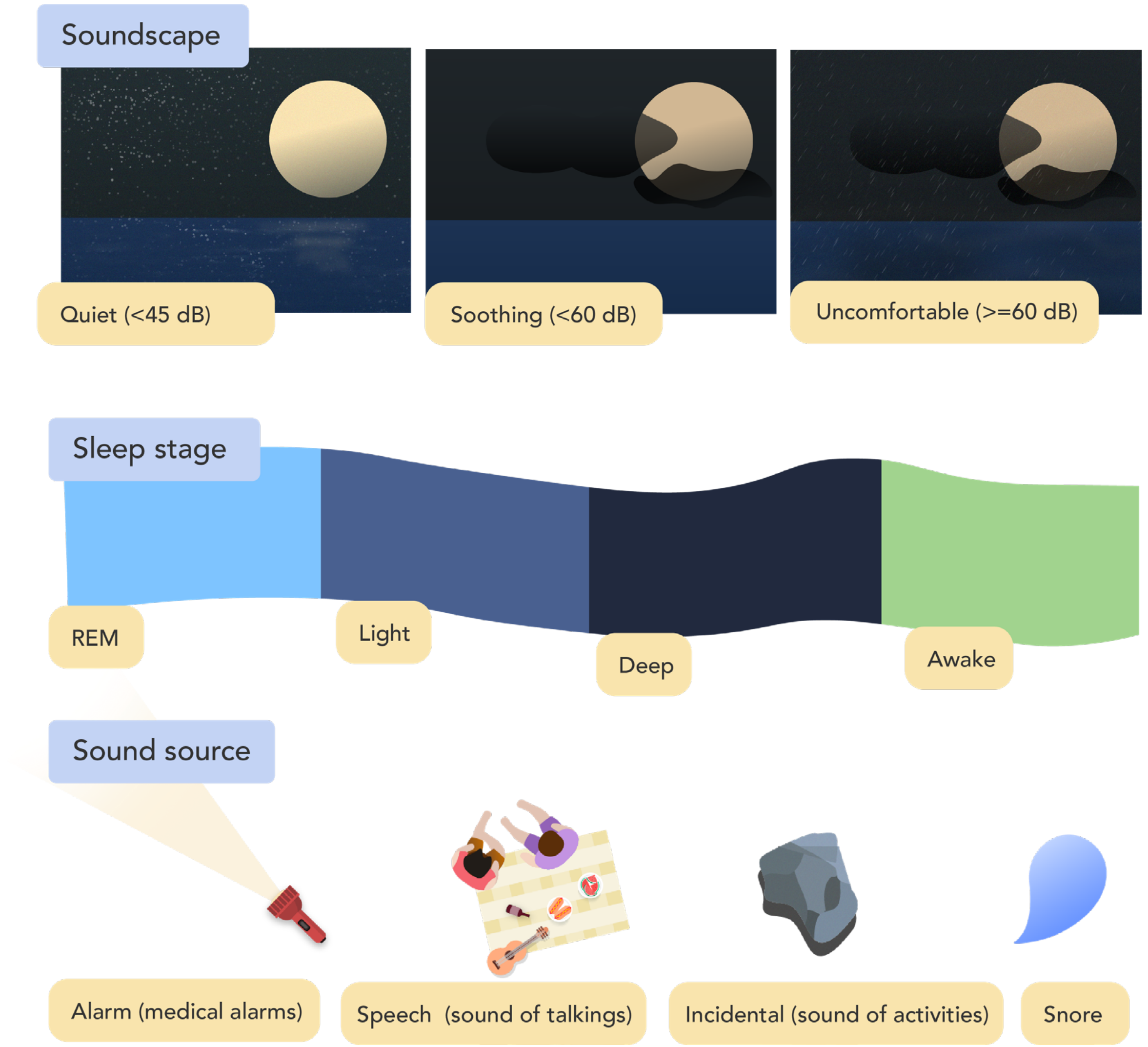
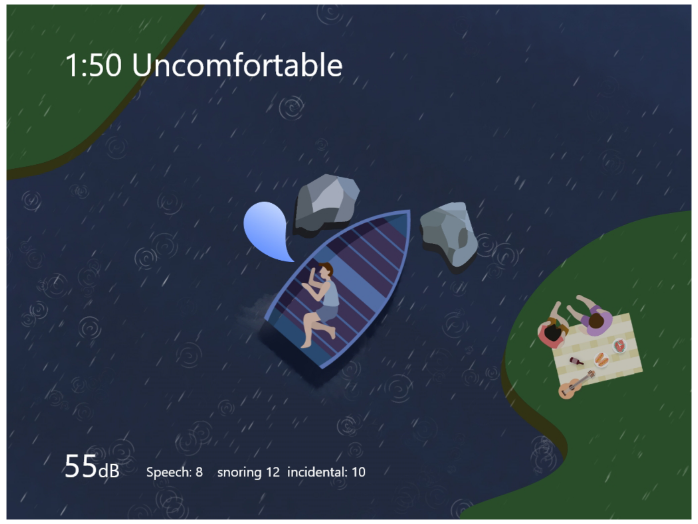


Figure 33. The graphical representation of soundscape, sleep stages, ans sound sources.

Compared to the previous versions, some icons were changed. A picnic icon was used to represent speech. Instead of just showing the flashlight effect on the patient end, the flashlight also shows to represent alarm. (Figure 33)

The nurse end consists of 1) the real-time animation presenting the current soundscape and noise sources; 2) the dashboard presenting the summary of how each patient slept and the correlations between patient's sleep pattern and noise events. The examples of how the screens look like are given in Figure 34 and 35.



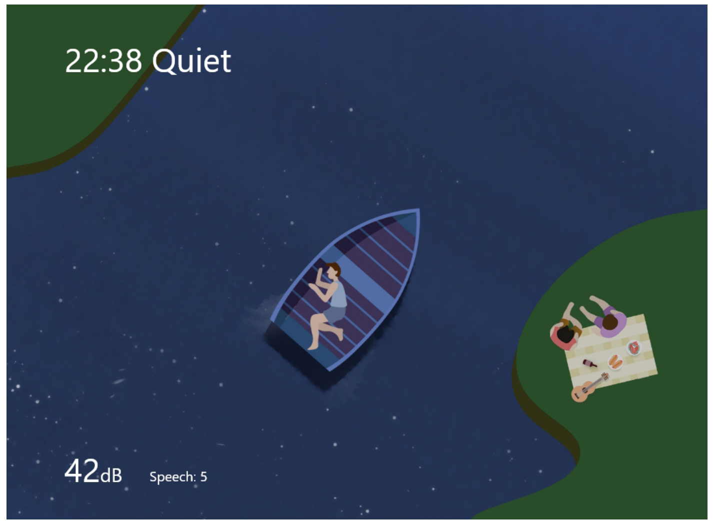


Figure 34. The dynamic animations showing the real-time soundscape.

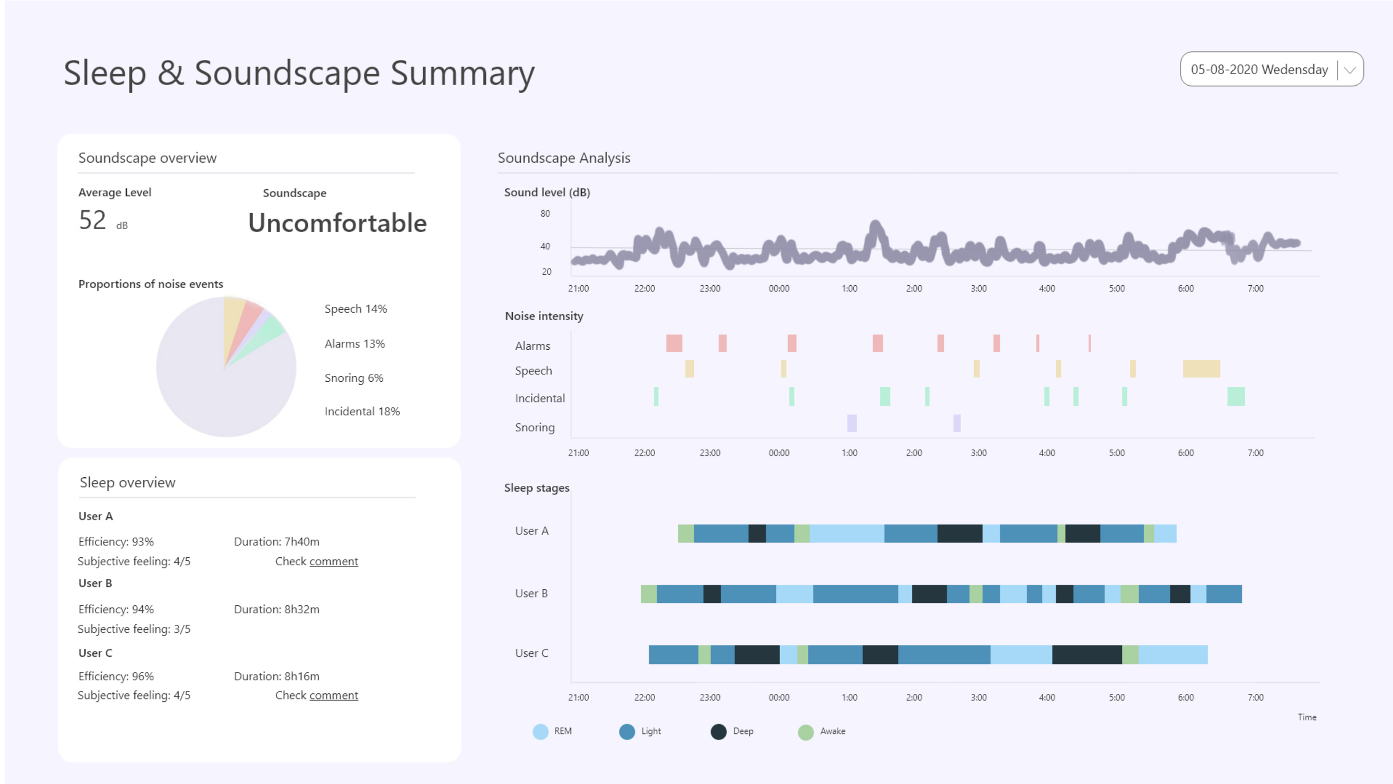


Figure 35. The Sleep and Soundscape summary page. After all the participants' Fitbit data has been transfered to the system, this page will show.

Chapter 10

Final Concept Embodiment

This chapter describes the embodiment of the product and gives suggestions on future development.

Final Concept Embodiment

10.1 Background

Similar to the previous Project - Doplor, the implementation of Doplor Sleep also consists of two parts. The first part is sound capturing and classifying, and the second part is data visualization. One of the main differences is that Doplor only displays the real-time data visualization, whereas Doplor sleep also needs to show a summary of data gathered during one night. Hence the sound data needs to be transferred and stored in an online database. Another difference is that Doplor sleep needs to use the sleep data gathered by Fitbit. This chapter describes the highlight work that has been done during the embodiment of Doplor Sleep. The following topics will be covered: the structure of the whole system, the sound classification method, and the limitations of the current prototype.

10.2 Overview of the system

The integrated development environment of Doplor Sleep is Android Studio, a Java-based IDE for building Android applications. Currently, the patient version of the application is built to run on an Android smartphone. The nurse application size is chosen to fit the screen of an Android tablet (e.g., Nexus 7). The idea is to use a Google Chromecast to display the application on a TV screen in the hospital ward's multifunctional room where the nurses take a break in between shifts.

The development of the applications used the object-oriented programming paradigm. The simplified workflow of the application is visualized as Figure 36.

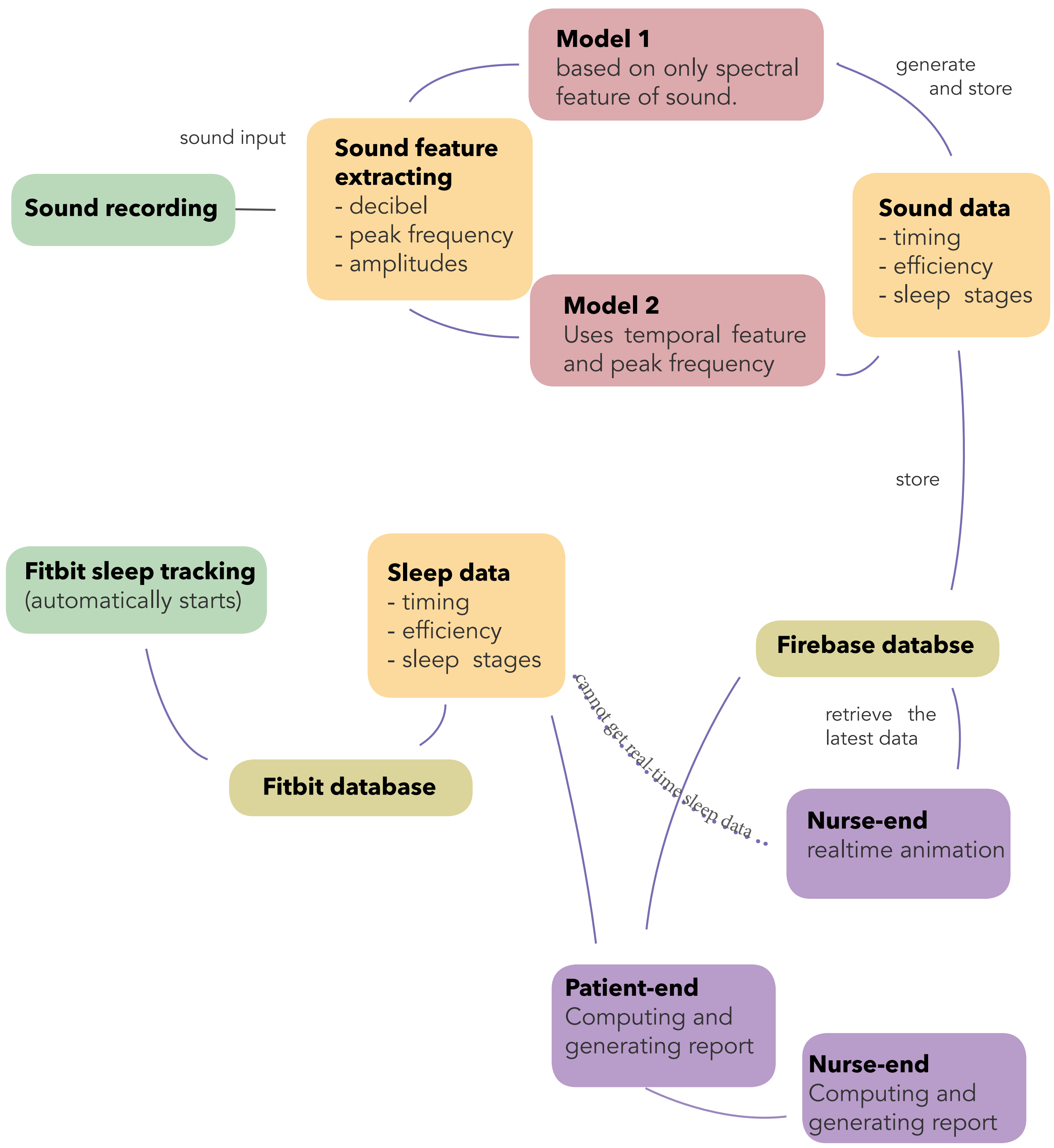


Figure 36. An overvoew of the system.

10.3 Sound classification method

In the previous project, for Doplor, sound classification was enabled by running Fast Fourier Transform to the sound data to reveal the spectro-temporal features of different sounds. As shown in Figure 37, different types of sounds have distinct features on the spectrogram.

For Doplor, only one model was used to classify the sounds, which was to compare the average intensity of the target frequency ranges to the average intensity of the frequency range outside of the target ranges. (Figure 38)

For this project, the method of sound classification was improved. For snore, speech, and incidental sounds, the same model was used as the previous project. For alarm, a temporal parameter has been added. The sound of alarm is a repetition of a couple of tones. When the first tone is detected, a timer is started to count down. Within a certain amount of time, if a second tone is detected, the time counter goes back to the initial state and restarts the counting down for detecting the third tone, until all tones are detected. If the second tone was not detected within the time, the alarm sound detection failed, i.e., the system thinks this is not a sound of alarm. Depending on how many tones an alarm has, the alarm sound is detected when all tones were detected. This model can be used for detecting all kinds of alarms with relatively high accuracy compared to the previous method.

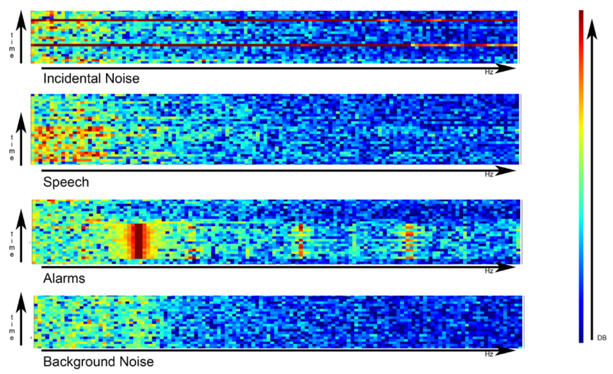


Figure 38. Spectral features of different kinds of sound.

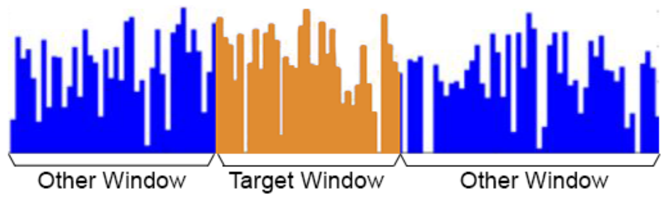


Figure 39. Previously used model. Comparing the aaverage intensity of the target frequency range and other frequency ranges.

10.4 Limitations of the current prototype

A few limitations of the current prototype need to be considered by people who would like to reproduce it or further develop it.

First, currently, the prototype is designed for only three users to use at the same time. Each user is assigned with an anonymous Fitbit account created by the designer. The aim is to protect the privacy of the users when the prototype is used for research purposes.

Second, the Fitbit API has an access token, which expires in thirty days. Once the access token is expired, a new token needs to be requested from the Fitbit SDK website. A step-by-step tutorial on how to request access tokens is available on the same website.

Third, currently, the summary of sound presented to the nurses only used the sound data gathered by the device of user A. Ideally, the sound data of all three users should be taken into account.

Lastly, the visualization of the 'looking back at the journey' page of the patient application needs to be improved. Currently, the icons only appear when the boat's location matches the time that the sound occurs, which makes the display of visualization look 'flickering'. Ideally, the icons can stay on the timeline at the time point when the corresponding sound occurs. Besides, the mountain in the background is not moving together with the river, making it look less authentic and may confuse the users.

Reflection points

This is the first time for me to get in touch with objective-oriented programming, and it was an eye-opening experience. The development of the current prototype was under the help of technical experts such as the project mentor and friends with a computer science background. During the process of collaborating with them, I realized the importance of building prototypes to communicate my ideas better. Orally explaining complex data visualization ideas is not the most effective way. When the data visualization is complicated and dynamic, Adobe XD is not the best tool for prototyping. In the late stage of the project, I found Adobe after effect as a powerful tool to communicate the idea of visualizing dynamic changing data. As a designer, I will continue expanding my knowledge about software programming and exploring the tools for prototyping my ideas.

Chapter 11

Final Test and Evaluation

This chapter presents the process and results of user evaluation on the product segment of the final concept.

Final Test and Evaluation

11.1 Background

The current prototype needs the approval of METC (medical ethical testing committee) to be tested in the Reiner de Graaf hospital ward. Before the committee approves the application, a user test has been conducted to evaluate the functionalities and user experience.

11.2 Method

The final prototype was evaluated by both laypeople (representing the patients) and the neurology department's nurses at Reinier de Graaf. The reason for recruiting laypeople to represent the patients was because they possess similar background knowledge of sleep and sound disturbances. Also, due to the COVID circumstance, it was difficult to recruit hospitalized patients for the test. The selection of the participants was random, regardless of gender and age. In total, seven laypeople and seven nurses participated in the user evaluation. The apparatus used for the evaluation are described below.

- For laypeople (representing patients)

Similar to the experiment mentioned in chapter 8, each subject was asked to wear Fitbit and use the product for two nights. For the first night, no sound intervention was added to their sleeping environment. For the second night, a sound clip containing various hospital sounds were played through a tablet in their sleep environment.

Figure 40 is an example of the test setup. In an apartment with three bedrooms, three housemates participated in this test. Each of them was assigned a Fitbit device and a Fitbit account. The prototype application was run on the three Android phones. Each of them took one phone and experienced using the application. The participants were asked to record the screen for the 'summary' and 'look back at the journey' page. The screen recordings were used to help them answer the questionnaire made with Google form. The full questionnaire can be found in Appendix C.

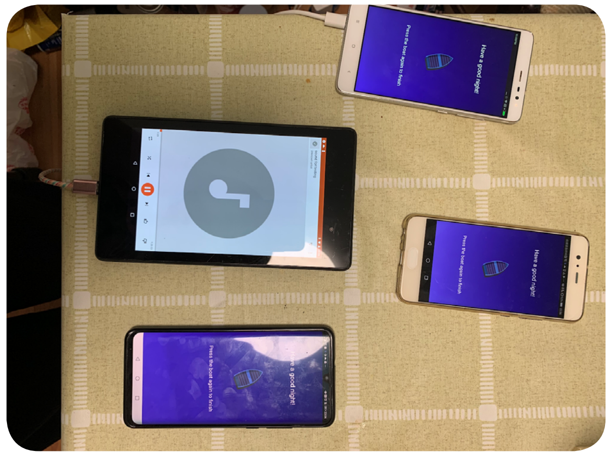


Figure 40. One of the test settings.

For nurses

The nurse evaluation was also conducted in the form of a survey. For the evaluation, a session was organized where the nurses first watched four showcase videos of the prototype, then answered the questionnaire. The first three videos showed the visualization of the real-time soundscape in different scenarios. The full questionnaire for nurses can be found in the appendix D.

The following requirements that need to be evaluated were taken into account when designing the questionnaires.

Requirements of functionality:

1. The product can provide medical staff with information about
The real-time sound level of the ward
which kind of sound is currently present
How the occurrence of different kinds of sound associates with the change of sleep stage and patients' arousals.

2. The product can increase the nurses' awareness of sound production events during patients' sleeping time.

3. The patients are informed about their
(1) sleep timing in the hospital ward, including sleep duration, starting time, and end time;
(2) sleep quality in the hospital ward;
(3) sound levels during sleep in the ward;
(4) how do the measurements above differ from that of sleeping at home;
(5) What caused the noise during their sleeping time in the ward (what kind of sound occurred);
(6) Which kind of sound may have caused their arousals or change of sleep stages.

Requirements of user experience

1. Nurses find it easy to interpret the sound information, sleep information of patients, and the links between these two kinds of data, as mentioned in functionality requirements.

2. Nurses are satisfied with the level of professionalism of how the data are presented.

3. Nurses find the way of presenting the data and information fits the culture of a medical environment.

4. Nurses find the way of the product trying to create the awareness of sounds as a sleep-disruptive factor is friendly (non-aggressive).

5. Patients find the information provided about sleep, sound, and the relations between sleep and sound is easy to interpret.

6. Patients find the way of the product trying to convey such information is friendly.

7. Patients feel the product is supportive in letting them know the sound disturbance to their sleep.

8. Patients feel the product is supportive in terms of managing their sleep hygiene.

11.3 Findings

- From the perspective of lay people (patients)

Six out of seven subjects managed to give answers to every question. The following findings are derived from their responses.

1. More friendly than clear.

The subjects generally find the data visualization delivers a friendly meaning. All of them rated six or seven on the friendliness. For clarity, the subjects' opinions were diverse. Although most people rated six or seven, some people gave low scores, e.g., two or three.

2. Not all icons are clear.

The subjects found the bubble is a very clear and intuitive representation for snore. The picnic icon also makes sense to them, but the rock and flashlight are too abstract for some subjects. One subject suggested using the picnic as the icon for incidental sounds, which would make more sense than the rock.

- From the perspective of nurses

All nurses who participated in the evaluation managed to answer all questions and well motivated their answers. Most nurses found the concept both clear and friendly (rated higher than 5). The following insights were derived.

1. sensitive to number

When ask how noisy do you think it is, most laypeople answer with words or expressions, such as "quiet," "nice," "noisy," etc.. However, nurses mostly filled in the decibel values for this question, which shows that they tend to give objective answers and feel more comfortable using numbers.

2. Possibility for personalized service.

During the evaluation session, some nurses questioned whether it is possible to show each patient's data separately to deliver personalized service. Currently, the data collected are anonymous. Although it may risk patients' privacy, data-enabled personalized service is an interesting design opportunity for the future.

Summary

This chapter documented the final user evaluation of this project. The method section described how the forms of testing are different for laypeople and nurses. Iy also mentioned basing on which requirements the questionnaires have been made. Findings for future inspirations were derived.

Chapter 12

Conclusion and Discussion

This report ends with a conclusion of the project and the main outcome. It follows a discussion of the project, including the limitations and future opportunities.

Conclusion and Discussion

General Summary

This chapter documented the final user evaluation of this project. The method section described how the forms of testing are different for laypeople and nurses. Iy also mentioned basing on which requirements the questionnaires have been made. Findings for future inspirations were derived.

This master graduation project is a process of discovering and understanding the problem and designing for a solution. The insights gathered during the research phase, and the final design solution are both considered the project outcomes. This chapter mainly discusses the results and reflects on the tasks defined at the beginning of the project. Limitations and future opportunities will also be discussed.

12.1 Summary of the outcomes

During this project, through conducting literature research, interviews, and surveys, the current environment sleep disturbances in hospital wards were analyzed. With a focus on the sound issues, a concept has been designed and prototyped. The current design aims to create awareness towards sounds, to influence the behavior of people. With the technology implemented, this product can also be used to research the relations between arousals during sleep and sound disturbances.

12.2 Reflection on the tasks

As described in Chapter 1, the scope of the project includes two takes. The level of accomplishment of the two tasks are hereby discussed.

Task 1: Identifying environmental-sleep-disturbing factors in Reinier de Graaf hospital.

By conducting a survey study with Reinier de Graaf hospital's inpatients, we aim to verify whether the lighting, temperature and sounds have become sleep-disturbing factors. Due to the COVID circumstance, this study was delayed. With time limitations, the sample size was too small to generate statistically valid results. The results of the survey were not significant. This leaves space for future research.

Besides the survey study, a study to measure the sound in the wards was planned. With the technology implemented, Doplor sleep can be used as a tool to measure and capture sounds and identify the sound source without harming patients' privacy. However, a METC approval is needed for this test. Getting approval is not realistic within the time scope of the graduation project.

Task 2: Design for solutions to tackle sleep-disturbing sound.

Based on the previous concept, Doplor, a new concept is proposed in this project. Doplor sleep has the same goal as the original Doplor concept: creating awareness towards sound-producing events. Doplor Sleep added the sleep data into the system. The aim was to strengthen awareness by letting people see how sounds influence sleep.

Different from Doplor: a device for nurses to gain awareness of the soundscape, Doplor Sleep included patients as users too. One thing of Doplor Sleep that the client was interested in was collecting and bringing patients' sleep habits and environmental preferences into the hospital.

12.3 Limitations

The project approach contains a considerable amount of literature study, but not enough design activities such as brainstorming or co-creating sessions. The understanding of context and problem is also highly based on the knowledge gained from literature. More diverse research activities, such as context mapping and user journey mapping, could help synthesize and facilitate creative thinking. Without the COVID issue, more observations and conversations with nurses can be made in the ward of Reinier de Graaf. Currently, there are also limitations to the technology implemented in the product (see chapter 11).

12.4 Future opportunities

The current findings and outcomes of the project led to the following future opportunities:

1. Further research can be conducted to identify environmental sleep-disturbing factors.

2. An exciting research direction is to index sleep disturbances. This requires the continuation of the test in the hospital to measure sound, detect sound categories, and track patients' sleep.

3. The existing non-sonic sleep-disturbing factors, such as lighting and temperature, opens up new design opportunities for future designers. A good scenario is that multiple designers with different interest areas (e.g., lighting, sounds, etc.) team up to design for a larger system that influences the hospital's sleep environment, e.g. an IoT system.

Reference

Black JM & Matassarin-Jacobs E (1993) Medical-Surgical Nursing: A Psychophysiologic Approach, 4th edn. Saunders, London.

Birdja, D. & Özcan, e (2019). Better Sleep Experience for the Critically Ill: A Comprehensive Strategy for Designing Hospital Soundscapes. Multimodel Technologies and Interaction.

Coleman, A., Lord, J., Pinnell, N. L., Black, J. M., & Matassarin-Jacobs, E. (1993). Instructor's manual for Luckmann and Sorenson's medical-surgical nursing: A psychophysiologic approach, fourth edition. Philadelphia: Saunders.

Easton, J. (2019, January 07). SIESTA project reduces inpatient sleep interruptions. Retrieved September 24, 2020, from https://www.uchicagomedicine.org/forefront/patient-care-articles/siesta-project-reduces-inpatient-sleep-interruptions

Fillary, J., Chaplin, H., Jones, G., Thompson, A., Holme, A., & Wilson, P. (2015). Noise at night in hospital general wards: A mapping of the literature. British Journal of Nursing, 24(10), 536-540. doi:10.12968/bjon.2015.24.10.536

Gibbs' reflective cycle. (1970, March 20). Retrieved September 24, 2020, from https://www.ed.ac.uk/reflection/reflectors-toolkit/reflecting-on-experience/gibbs-reflective-cycle

Grossman, M., Anderson, S., Worku, A., Marsack, W., Desai, N., Tuvilleja, A., . . . Arora, V. (2017, February 15). Awakenings? Patient and Hospital Staff Perceptions of Nighttime Disruptions and Their Effect on Patient Sleep. Retrieved September 24, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5263086/

Konkani, A., & Oakley, B. (2012). Noise in hospital intensive care units—a critical review of a critical topic. Journal of Critical Care, 27(5). doi:10.1016/j.jcrc.2011.09.003

Krueger is an Assistant Professor in Nursing, C. (2017). Neonatal Intensive Care Unit Sound Levels Before and After... : MCN: The American Journal of Maternal/Child Nursing. Retrieved September 24, 2020, from https://journals.lww.com/mcnjournal/Abstract/2007/11000/Neonatal_Intensive_Care_Unit_Sound_Levels_Before.9.aspx

Mackrill, J., Cain, R., & Jennings, P. (2013). Experiencing the hospital ward soundscape: Towards a model. Journal of Environmental Psychology, 36, 1-8. doi:10.1016/j.jenvp.2013.06.004

Mackrill, J., Jennings, P., & Cain, R. (2014). Exploring positive hospital ward soundscape interventions. Applied Ergonomics, 45(6), 1454-1460. doi:10.1016/j.apergo.2014.04.005

Maclean, A., Young, R., Bellotti, V., & Moran, T. (1991). Questions, Options, and Criteria: Elements of Design Space Analysis. Human-Computer Interaction, 6(3), 201-250. doi:10.1207/s15327051hci0603&4_2

Mokhlesi, B., & Arora, V. (2019, March 15). Effectiveness of SIESTA on Objective and Subjective Metrics of Nighttime Hospital Sleep Disruptors. Retrieved September 24, 2020, from https://www.journalofhospitalmedicine.com/jhospmed/article/191315/hospital-medicine/effectiveness-siesta-objective-and-subjective-metrics

Muzet, A. (2007). Environmental noise, sleep and health. Sleep Medicine Reviews, 11(2), 135-142. doi:10.1016/j.smrv.2006.09.001

Paalasmaa, J. (2014). Monitoring Sleep with Force Sensor Measurement. Retrieved September 24, 2020, from https://helda.helsinki.fi/bitstream/handle/10138/42609/paalasmaa_dissertation.pdf?sequence=1

Park, M. J., Yoo, J. H., Cho, B. W., Kim, K. T., Jeong, W., & Ha, M. (2014). Noise in hospital rooms and sleep disturbance in hospitalized medical patients. Environmental Health and Toxicology, 29. doi:10.5620/eht.2014.29.e2014006

Passchier-Vermeer, W., & Passchier, W. (2000, March). Noise exposure and public health. Retrieved September 24, 2020, from https://www.ncbi.nlm.nih.gov/pubmed/10698728

Sleep for Inpatients: Empowering Staff to Act - Full Text View. (n.d.). Retrieved September 24, 2020, from https://clinicaltrials.gov/ct2/show/NCT02025959

Tamaki Postdoctoral Research Associate, M., & Sasaki Associate Professor, Y. (2020, March 02). How half our brain keeps watch when we sleep in unfamiliar places. Retrieved September 24, 2020, from https://theconversation.com/how-half-our-brain-keeps-watch-when-we-sleep-in-unfamiliar-places-57975

Vandenberghe, B., & Geerts, D. (2015). Sleep Monitoring Tools at Home and in the Hospital: Bridging Quantified Self and Clinical Sleep Research. Proceedings of the 9th International Conference on Pervasive Computing Technologies for Healthcare. doi:10.4108/icst.pervasivehealth.2015.259267

Walker, M. P. (2018). Why we sleep: The new science of sleep and dreams. London, UK: Penguin Books.

Doplor Sleep

A project by
Yiling Liu
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TUDelft Reinier de Graaf Critical Alarms Lab