Doplor:
Artful warnings towards a more silent Intensive Care.

Chair: Dr. Elif Özcan Vieira

Mentor: Tessa Dekkers, MSc.

Erasmus MC

Quietyme

TU Delft

Industrial Design Engineering

Critical Alarms Lab

IPD Master Thesis

Medisign

Roel Redert
4275683


Critical
Alarms Lab
QUIETYME
Erasmus MC

GRADUATION THESIS

Performed by Roel Redert

To all my friends and family. Special thanks to Elif Özcan Vieira and Tessa Dekkers for supporting and coaching me throughout my graduation. A great thank you to Erna Dijtmaars for facilitating multiple visits to the IC, and Karin van Weelden, for helping me understand the human sleep cycle and Intensive Care patients better. Thank you Quietyme, for letting me use your resources for the benefit of my thesis and lastly a warm thank you to the Critical Alarms Lab, for all the meetings, coachings, and fun times throughout all of our graduations.

word list

For easier reading, sometimes abbrevations are used. When unfamiliar with these words, reading can all of a sudden become difficult. Therefore a word list was added at the beginning of this report, explaining the meaning of used terminologies.

Contribuant	A contributor to (...). In this thesis often used as contributor to auditive disturbances.
Delirium	A medical state in which patients are seemingly asleep, non-aware or reduced aware of their surroundings, are confused. These patients are suffering from mental disabilities.
EMC	Abbrevation for Erasmuc Medical Center (MC)
IC	Abbrevation for Intensive Care - A critical care environment within a hospital. In this thesis mainly referred to the Intensive Care within the Erasmus MC hospital.
ICU	Abbrevation for an Intensive Care Unit, this is a room in which a patient rests and 'lives' when being hospitalised.
PTSS	Post Traumatic Stress Syndrome. Being surrounded by an environment as hostile as the Intensive Care can cause long term effects. Even when patients are at home, they can still feel the stress of being in the IC.
Quietyme	America-based company with which is collaborated. This company creates sensors that can measure environmental factors like light and sound.

contents

preface

A small step to a big change.

Walking into an Intensive Care is in itself not a big task. You press the button 'open door', you walk in, and you are there. Hypothetically very simple and easy to do. However, this is neglecting all emotional factors. Walking into this same Intensive Care, knowing that people inside are fighting for their lives, that patients' relatives are sitting at their bedsides praying for them to recover, and that everywhere you look is a chaotic beeping mass of machines.. Then walking into this same Intensive Care becomes a big-loaded task.

Knowing that the environment is so incredibly dense, Iit was tried to lighten up the Intensive Care by improving the acoustics, or better said, it was tried to eliminate the causers of noise. When you are so unlucky to have a relative hospitalised within an Intensive Care Unit, the last thing you want to focus on is all different alarms. You have come to the ICU to be with the patient, sit by their bedside, comforting them saying that everything will be fine again.

I myself have had multiple encounters with people dear to me hospitalised in the Intensive Care, and I definitely was not feeling comfortable when visiting them. All the different sounds in this crowded environment made me anxious, and I could only imagine how horrible it would be to lie in that bed all day. Exactly for this reason I am grateful for the opportunity to improve the overalll experience of the IC through design and technology. This experience would not only be for the patients, but also for the caring staff.

Throughout my graduation I have constantly asked myself "how would nurses and doctors look at this product, and how would visitors react?" This helped me greatly with designing what was relevant, and what was not. In the following chapters I will explain what exactly an Intensive Care is, what the auditory environment is like there, how nurses behave around all different nurses, and how I tried to tackle all found problems. In the end, all that counted was the solution on how the improve the life (even if it's a little) of the ones that are struggling with their health, and the ones trying to care for them.

introduction

[1] Quietyme (2018). *The Latest in Hospital Noise Reduction Research and Articles*

[2] Waterhouse et al (2012). *Daily rhythms of the sleep-wake cycle.*

[3] Jones et al (2001). *Memory, delusions, and the development of acute posttraumatic stress disorder-related symptoms after intensive care*

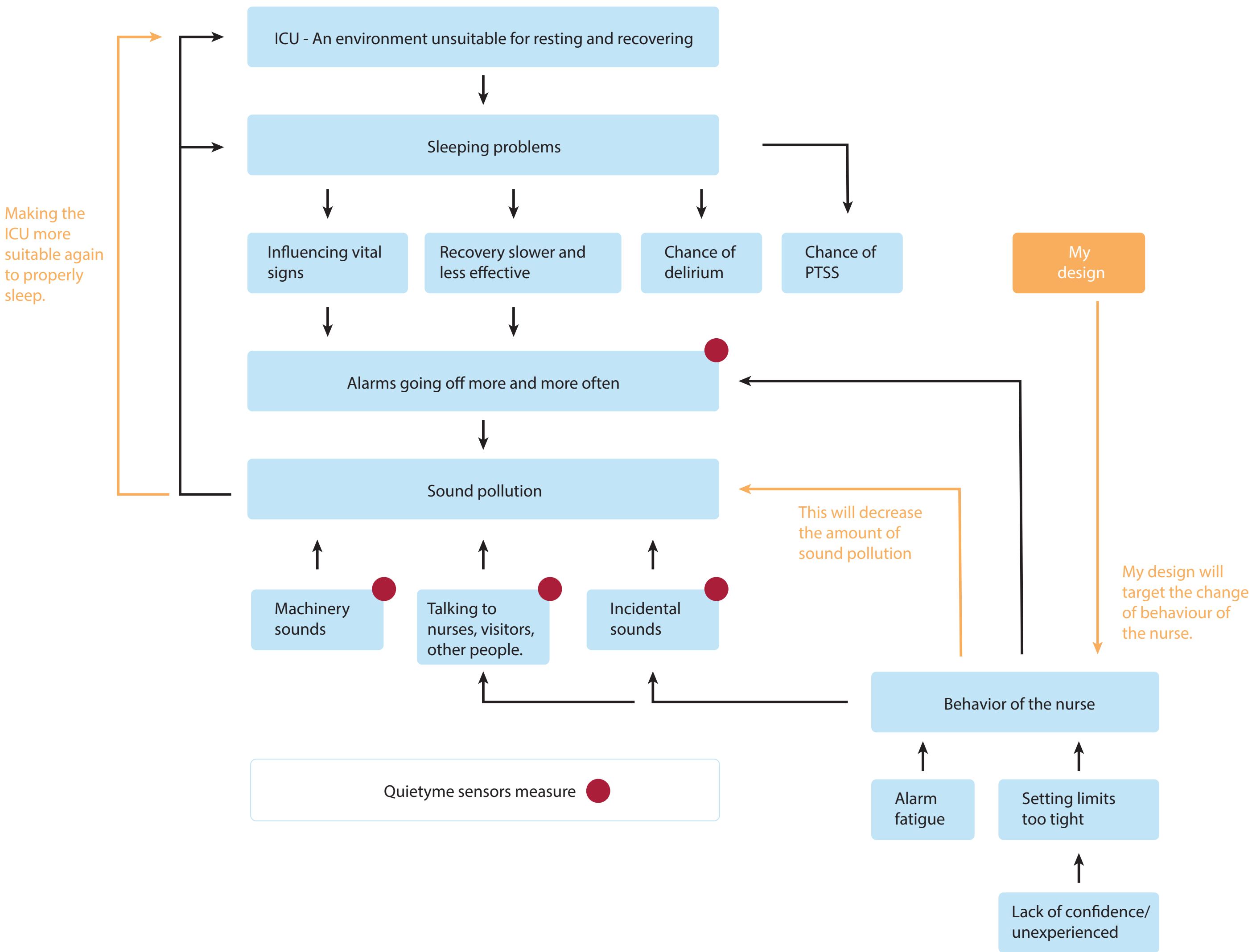
No healthy person wants problems getting into sleep. Neither do patients in the Intensive Care. Sound pollution influences the possiblitiy of getting into sleep, and especially in a critical care environment, this sound pollution is very prevalent. Noises created in the Intensive Care can be of all sorts, but they have four core origins: speech, alarms, background noise, or incidental[1]. Yet, they have something in common, apart from the Machinery sound they are all mostly caused through the behaviour of nurses and visitors.

With mentioned prevalent sounds creating an unsuitable environment to sleep properly, it gets difficult for patients to recover properly[2]. Vital signs of the human body are negatively affected, and there are chances that the patient will get into Delirium or develop PTSS after being unable to rest and restore for a longer period of time[3].

The main aim of this graduation was to design something that could lead to a behavioural change within the Intensive Care of the Erasmus MC, restoring a peaceful environment for patiens to restore and recover in.

Using Quietyme technologies to analyse auditory disturbances in the IC, frequent visits to the IC for interviews and observations, and multiple short tests during the design process (Design Thinking methodology), Doplor was created.

Doplor is a design that displays a symbolic representation of the auditory environment. Targeted at the behaviour of nurses, the envisioned goal was decreasing their amount of produced sound pollution, leading to an Intensive Care that would be better suitable to sleep in again.



executive summary

This report encloses the beginning of observations and literature research on the Intensive Care to the creation of the final design. The Design Thinking[3] method was used during this graduation, leading to a design that was developed with the end-user and has been tested throughout the process of creating it.

Phase 1 - Empathising

This graduation project took place in the Intensive Care of the Erasmus MC in Rotterdam. The main aim was to increase sleeping time for patients by decreasing the amount of auditory disturbances happening, thus making the sleep more recovering for patients. The first step was to familiarise in the critical care context, and followingly plan meetings with nurses and try to understand their behaviour and see how everything works. These results can be found in Chapter 1 and 2. Four different sources of auditory disturbances were found(background noise, alarms, speech and incidents), of which three (alarms, incidents, and speech) appeared to be behaviour induced. Most importantly, nurses were not aware of the sounds they created as they got deaf for them, similar to alarm fatigue. Also Quietyme, an american company that creates sound measuring sensors and analyses their data, has been researched and included.

Phase 2 - Defining

Having seen nurses at work, knowing what the surroundings are like. All findings needed to get into place. Using psychological models all findings could be combined in one overarching research and design question: "How to design for more awareness of the auditory behaviour in nurses, in the Erasmus MC Intensive Care, for patients to have a shorter recovery time? " As can be found in chapter 2 and 3. With this question in mind...

Phase 3 - Ideating

...has been ideated. Firstly looking at Industrial Design students, getting to know how to get someone's attention, and in the end finding that visualisations work best. With this result an interactive painting, called Doplor, was created. Then with students was looked for what aspects in visualisations could be used to describe an either loud or quiet environment, and a list of visual characteristics was made. Hostility of a video could be used to create a clear distinction between a loud and quiet video, and greater difference could be added with the use of color, speed, and clarity. All these findings can also be read in chapter 3 and 4.

Phase 4 - Prototyping

With the design being nearly finished, multiple 3d models of Doplor were made and prototyped. Also the code was made to create a prototype that was fully functional. Using the list of visual characteristics, visualisations were designed in four different states according to the created alarm philosophy. The design had a total of four different functions: Doplor listens to the environment, determines whether sound levels are adequate, and responds accordingly with a visualisation. If more information is desired, people can walk up to him and interact with him, to understand what actually the causes of the loud environment were. More elaborate information about these steps can be found in chapter 4 and 5.

Phase 5 - Testing

The prototype was used to understand whether all prior research about the environment, and the findings of the researches were accurate. First with Industrial Design students, and later also with the nurses, the prototype was tested. Chapter 5 and 6 explain all about this. Both groups thought that the design was interesting and could help with quieting down in the IC environment. More elaborate testing still needs to be performed to be sure that an increase in sleeping time, an improvement in nurse behavior, and a decrease in the amount of auditory disturbances actually occured. Such a test could however only be performed after Doplor would be implemented for a longer period of time. A market plan and this test have been explained in Chapter 7.

Privacy

The core of this graduation was about nurse behaviour, how nurses can sometimes be loud, and how I would like to change this environment and behaviour. A certain amount of privacy and dignity belonged with this project, even though I wanted to create an accurate overview of the observations and interviews that were performed. Therefore it was chosen to address all different nurses and doctors that were interviewed to be called Nurse A, Nurse B, .. and so forth.

[3] **Design Thinking**

This method of designing consists of 5 phases: Empathising, Defining, Ideating, Prototyping, Testing.

By doing observations in the field, and empathising with the users in this environment problems are defined. Small solutions are ideated upon, prototyped, and through testing with the users small solutions become part of the final design.

Alarm philosophy

Dependent on the sound levels for the past hour as measured by the Quietyme sensors and algorithm, the IC can be in a total of four different states. Quiet and okay (all is well). Quiet and not Okay (it was okay for quite some time, but it is becoming significantly louder), Loud but okay (an emergency is happening, and there should not be worried about the loudness) and lastly Loud not Okay (it has been loud over time and it does not seem that the sound levels will drop over time).

Chapter 1: problem definition

At the beginning of this graduation, Erasmus MC was searching for a solution to improve patient curing time. This project was very much in line with their mission: "Erasmus MC is committed to a healthy population and excellence in healthcare through research and education.[4]" and vision: "Erasmus MC is a recognized leader in innovations for health and healthcare.[5]"

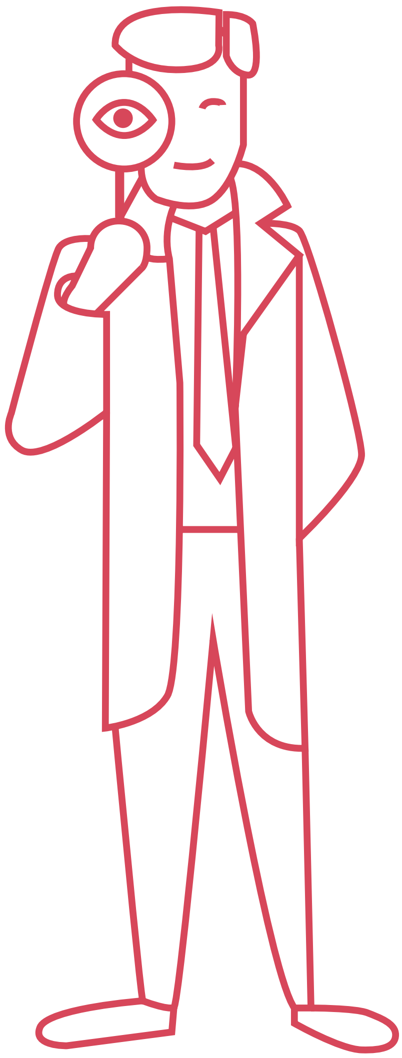
[4] Erasmusmc.nl (2018). Erasmus MC zichtbaar beter: *Onze missie.*

[5] Erasmusmc.nl (2018). Erasmus MC zichtbaar beter: *Onze visie.*

The overalll goal of this thesis was to create a design that could help against sleep deprivation in critically ill patients. Deprivation of sleep can have multiple causes, but within the Intensive Care environment the main cause is the prescence of auditory disturbances. These disturbances have different origins, and during days of observations all different origins were found: speech, alarms, incidents and background noise.

This chapter introduces the problem definition, the context which has been designed for, and how sleep works and is affected by sound. The following take aways will be discussed:

- Erasmus MC has moved from an old and loud to new and silent hospital. They are looking into solutions to become even more patient friendly and make recovery faster.
- Sleep deprivation has great implications on recovery in critically ill patients.
- Sleep is a repeating circle of bodily occurrences and processes, where deep and recovering sleep is achieved after the first 20 minutes.
- Main causes of sleep deprivation are incidents, alarms, and speech in the IC environment.



I am trying to find all initial observations in this chapter.

Section 1.1

Erasmus MC: The design space

The first goal to design for in the Intensive Care, and thus the first part of this thesis, was to actually fully understand what the IC is all about and how it generally works. Without this prior knowledge it would have been impossible to design anything related to nurse behaviour or the critical care environment.

The Erasmus MC as hospital

The Erasmus MC is an innovative hospital located in Rotterdam, already serving patients since 1840[6]. Since then a lot of innovation has taken place in curing patients better and trying new treatments. However, after an informative meeting with a nurse of the IC, it became clear that nurses have the tendency to be quite loud (quote 1).

Within the hospital there are many different departments, and with this graduation taking place in the transition phase from the old hospital building to the new hospital, multiple environments of implementation were witnessed. As the coming design was envisioned to also work outside the Erasmus MC (anywhere where patients try to sleep, but sounds are needed to maintain proper health), this shift in environments showed different ways on where and how a design could be implemented.

Among all different departments of the Hospital, the Intensive Care (figure 1) was the main topic of research. In these ICs, both old and new hospital, was therefore also where all research happened.

Quote 1: Nurse A

"It would not surprise me if the nurses of the Intensive Care are the loudest of the complete hospital. " (Nurse A, 2018)

[6] Erasmusmc.nl (2018). Geschiedenis van het ziekenhuis.

Figure 1 Corridor of ICU's in Erasmus MC Wytemaweg (Old building).

The Intensive Care

The Intensive Care can be described as one of the most complex spaces within a hospital aimed at recovering patients as effectively as possible[7]. This was observed to be very similar in the Erasmus MC (figure 2).

The environment is crowded, and to outsiders (e.g. visitors) this place seems organised but very closed, noisy and extremely dynamic[8]. All tools and equipment are placed in such a way that they are easily accessible and close to the patient for nurses and doctors[9], and when the slightest changes in bodily health of the patients are detected by the monitoring or support devices, they give an audible and/or visual warning for the nurses to act on[10].

Figure 1 and 2 show the visited Intensive Care in the Erasmus MC Wytemaweg. Each patient has their own room, closable with a manual sliding door. The pictured IC was at the first floor of the building. The 4th and 10th floor also had an IC, with similar lay-out rooms, but they all specialized in different parts of the human body.

[7] Hayes-Roth et al (1992). Guardian: A Prototype Intelligent Agent for Intensive-Care Monitoring.

[8] Backes, Erdman & Büscher (2015). The Living, Dynamic and Complex Environment Care in Intensive Care Unit.

[9] Koch et al, (2012). Intensive care unit nurses' information needs and recommendations for integrated displays to improve nurses' situation awareness.

[10] Kristensen, Edworthy & Özcan, (2016). Alarm fatigue in the ward.

Figure 2 ICU in Eramsus MC Wytemaweg, unoccupied and with no bed.

The Intensive Care in the EMC has a very clinical atmosphere and it feels grim. People walk in and out with tears in their eyes or pacing by uncomfortably. The sound culture at first is seemingly quiet, but after some time, you hear alarms more and more often. People, or patients, in a critical state are transferred to the IC. That is why the IC is also known as the place where patients are fighting for their lives.

For understanding nurse behaviour, a lot of observations were performed in this old situation. However, during the research of this thesis had all ICs moved to their new place in the Nieuwbouw Building. Because of this, in a later stage of my graduation, more observations were performed in the Nieuwbouw hospital setting.

In the Nieuwbouw building, the workflow is a bit different. Two nurses have a small desk located next to the boxes in which the patient is that they are caring for.

A window offers sight on the patient, making it possible to see how the patient is doing without actually having to be in the ICU. This is a step towards a more silent ICU (figure 4). This step did however not completely work as planned. Nurses were used to having a central nurse post and gathered all around one table in the IC corridor. This affected the sound quality greatly, as will also be explained in chapter 2.

The new style ICUs are broader, lighter, but also a lot more clinical. All medical equipment is distributed even more evenly for easy acces of all devices when necessary (figure 3). The ICUs are now also enclosed with an electrically closable door, that keeps sounds out of the room.

Figure 3 ICU in Erasmus MC Nieuwbouw, un-occupied but with bed.

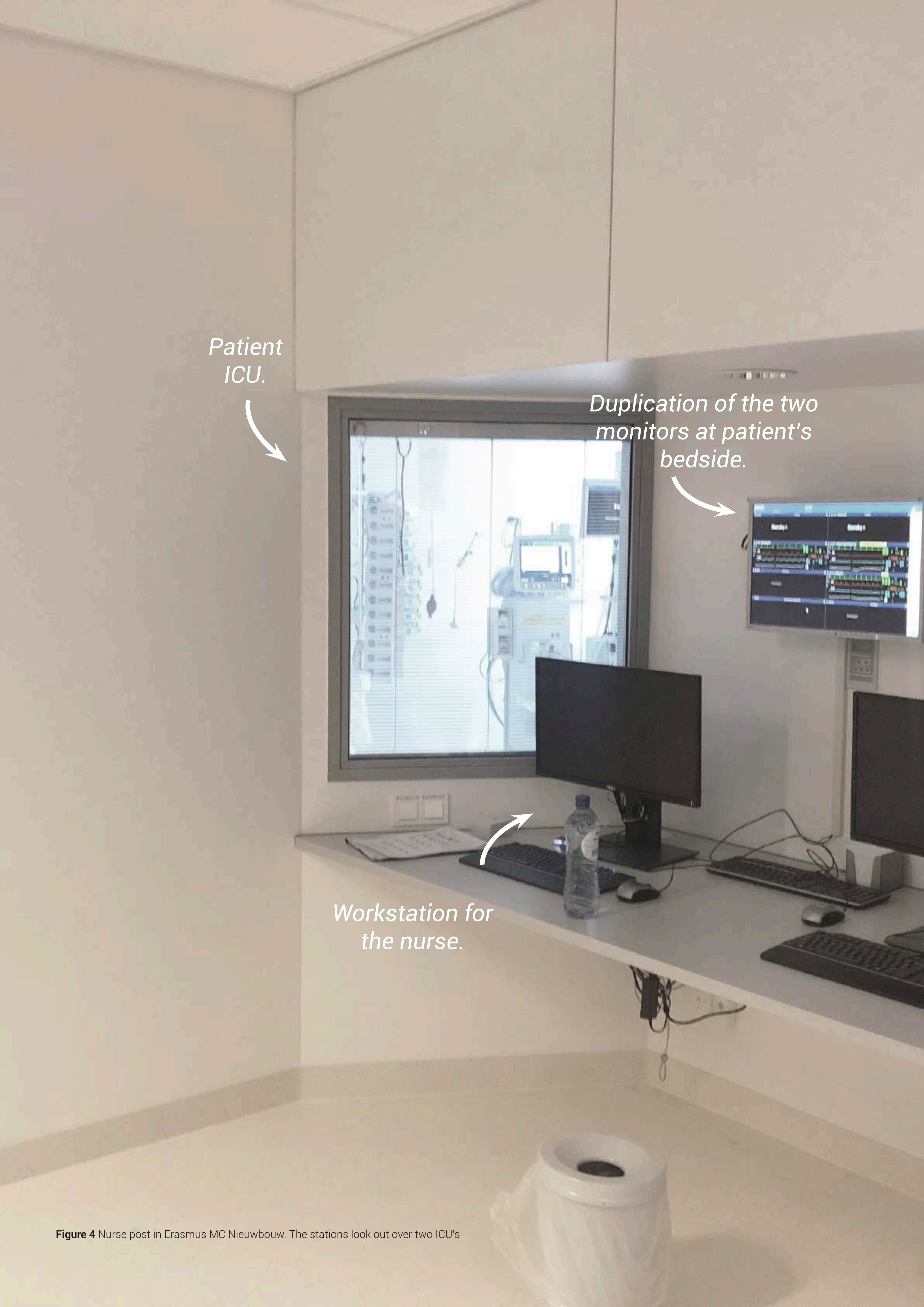


Figure 4 Nurse post in Erasmus MC Nieuwbouw. The stations look out over two ICU's

Section 1.2

Sleep. One of life's basics

In this section an elaborate research into sleep will create an understanding in how sleep works. The different stages of sleep, tolerable sound levels, and an initial step in nurse behaviour will come to light. Multiple facts depend on observations and findings from field research and interviews. All different findings in the text are indicated with a number in a circle, like this: ❶. Accompanying research can be found in the Appendix.

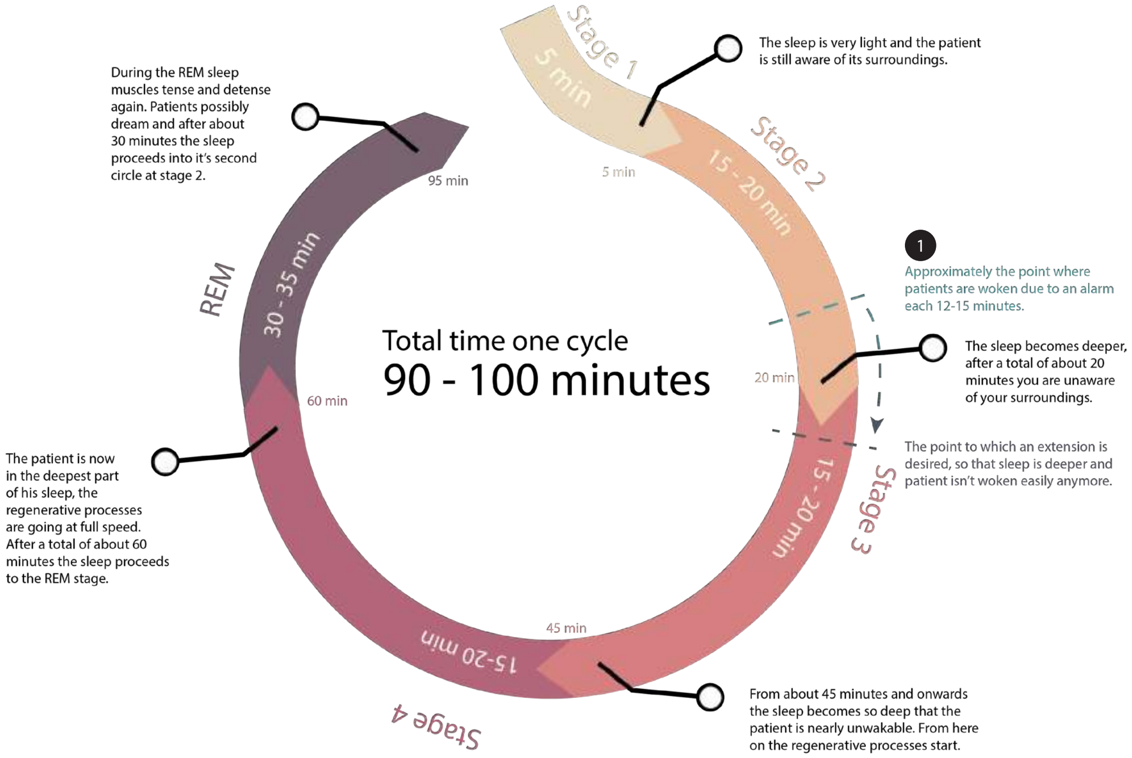


Figure 5 The sleep circle explaining the 5 stages of sleep in humans.

A proper sleep means a proper restoration of your body[1]

People spend approximately a third of their life asleep[11], and with a good reason. Sleep is a process in which the human body can restore itself in both a physiological and neurological way[12]. When spoken of the day-night rhythm, or the awake-asleep rhythm, this is often referred to as the circadian cycle[13].

The importance of sleep in patients has already been proven in multiple researches (as also found in Minton & Batten's research; quote 2). However, to design for sleep, it should first be explained what sleep is and how it works.

Sleeping is a restorative process consisting out of a total of five phases, in which the sleep gets deeper and deeper as time passes. To explain the difference between these different states, the research of McGonigal's[14] research was used as a reference for the following passages.

Of the total five phases of sleep the first four are Orthodox (which means that rapid eye movement does not occur), the last phase is paradoxical (the rapid eye movement occurs). The understandability of the following paragraphs can be supported with Figure 5.

The first phase, Stage 1, is a very shallow stage lasting only a few minutes. During this stage of sleep the patient is still aware of his surroundings and he might experience involuntary muscle jerks. After a few minutes the patient progresses to stage 2.

In this second stage the patient is not aware of his surroundings anymore, but he is still very easily woken as the sleep is still very light. For 15 to 20 minutes he stays in this second stage. If the patient manages to sleep for this long, the sleep will progress to stage 3.

This third stage is in which the sleep becomes deeper and deeper exponentially, making it more difficult to be awakened by the minute. restorative processes are initiated and after another 15 to 20 minutes the sleep continues in stage 4.

❶ This finding can be found back in chapter 2 on page 28, and in appendix A1.

[11] Aminoff (2011). *We spend about one-third of our life either sleeping or trying to do so.*

[12] Waterhouse et al (2012). *Daily rhythms of the sleep-wake cycle.*

[13] Korompeli et al (2017). *Circadian disruption of ICU patients: A review of pathways, expression, and interventions.*

[14] McGonigal (1986). *The importance of sleep and the sensory environment to critically ill patients.*

Quote 2
Patients in an unconscious or critical state have less chance of surviving as wound healing is delayed and cardiovascular and respiratory vital signs rapidly change and are negatively influenced when environmental conditions are poor (e.g. too much sound) during their sleep. (Minton & Batten, 2015)

Quote 3
"For patients, being cleaned and then undergoing treatment, feels like having run a marathon. I always try to give my patients a bit of rest before their visitors come in the afternoon (Nurse C, 2018).

Quote 4
"They lie in bed with nothing much to do, and we can not blame them for taking frequent cat naps. I am sure that many hours of half-sleeping and dozing off are less beneficial than a few hours of deep sleep, and I believe they encourage a certain confusion of mind." (Asher, 1947)

2 This quote was gained in a conversation with Nurse C, the complete transcribe can be found in Appendix A2.

Stage 4 is a stage where all restorative processes are working fully and where the sleep is deepest of all. It is difficult to awake the patient, even if you would deliberately want to do so. This last phase also lasts 15 to 20 minutes, meaning that it will take about a total of 60 minutes before the last phase commences. The REM sleep.

This paradoxical (REM) sleep, is the phase in which the patient dreams and alternates between rapid eye movements, muscle twitching, and muscle relaxation. This stage takes longer than the others, about 30 to 35 minutes. When the sleep cycle is completed, the cycle continues at stage 2 again, until the patient awakes.

It is until stage 3 that patients are easily woken. With the ICU being noisy with sounds of all sorts (especially during day-time), it is difficult for patients to reach stage 4 or 5 sleep. On average an auditory disturbance was measured every 12-15 minutes (as will be explained in chapter 2), meaning that patients are awakened just before their restorative and deep sleep kicks in. An improvement of 5 minutes between auditory disturbances could lead to patients actually reaching stage 3 sleep, meaning they could have a restorative sleep cycle during day-time.

A research performed by Eberhardt et al (1987) shows that when people are exposed to continuous background noises of 45-55 dB (like an airco - very similar to mechanical ventilators), that the amount of REM sleep was decreased and of lower quality when exposed as peaks, but that the overall sleeping quality was not affected majorly when the noises were continuous.

Through contact with a different nurse, Nurse C, who had graduated on the human sleep cycle, it was learnt that patients should not sleep for the whole day. When they do, it happens often that they can not sleep at night anymore. However, for patients it feels like 'having run a marathon' when they have been cleaned and had some treatment after the breakfast (quote 3). Therefore it is wise to create some sort of afternoon break of about 1.5 hours (about the length of one sleep cycle) , so that every patient has the opportunity to sleep restoratively during the afternoon.

With auditory disturbances occurring often, a similar result as Asher's (1947) was found (quote 4). Without a clear day-night rhythm it is not sure that patients will rest and restore properly. Therefore it is advised that nurses create an artificial rhythm for patients (which in some cases already happens 2), making sure that people are aware that they need to be more quiet when patients are asleep.

IC patients make a persistent shift in their circadian sleep-cycle. They do get enough sleep (7 to 9 hours) but are often awakened and sleep frequently during daytime (Delaney, 2015; Friese et al., 2007). Due to these disturbances, most sleep is not deeper than phase 1 (Weinhouse, 2005). This shift in the sleep-cycle can cause trouble sleeping months after patients are discharged from the IC (Daffurn et al, 1994) or even more severe symptoms leading to PTSS (Kitchiner, 2013).

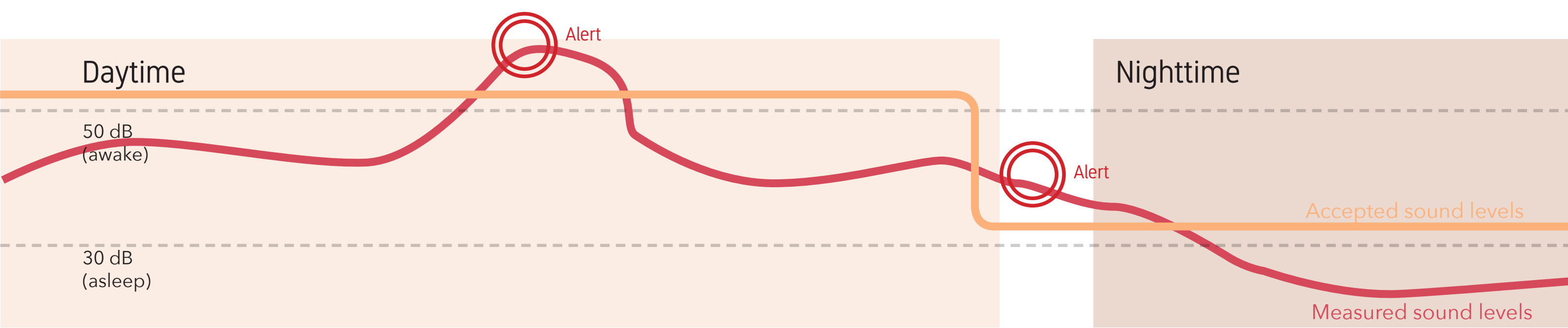
Concluding

Adequate sleeping time is often overlooked in critical care environments. When patients get the chance to sleep, they only do so in the lower stages 1-2 and often awake before more restorative sleep stages (3-4 and REM) are reached. It was advised to make the periods of sleep longer without auditory disturbances, instead of creating more shorter opportunities of sleep.

When considering the sleep and the cycles that are made within, most often patients are awakened by noise in either the first or the second stage. Alarms ring on average approximately once every 12 minutes (Cvach, 2012 via Bogers, 2018), making it difficult for the patients to reach the more restorative stages 3 or 4 in the sleep-cycle.

Once a patient is in stage 1, and thus their sleep cycle initiated, it should be quiet for at least 20 minutes, so that the patient arrives at sleep-stage 3. Then it can be a bit less quiet for some time (45 - 65 minutes), as waking from stage 4 and 5 is much more difficult. Implementing a patient's sleep break during the nurse's lunchbreak could help patients recover faster.

Figure 6 During awake-time the sound limit is 50dB, sleep-time has a 30 dB limit.



Section 1.3

Observational studies at the IC

The first goal to design for in the Intensive Care, and thus the first part of this thesis, was to actually fully understand what the IC is all about and how it generally works. Without this prior knowledge it would have been impossible to design anything related to nurse behaviour or the critical care environment.

Alarms are one of the key aspects of the Intensive Care.

Or actually, alarms are even one of the key aspects of a hospital in general. Patients are monitored continuously, and when measured values seem out of place, an audible alarm is elicited by the monitoring machine[15]. These alarms are there with a reason, they have been there for a long time as alarms were deemed necessary by the FDA, following the ANSII:AAMI EC13:2003 standard. Having such standards made it possible for nurses to get to know whenever values differed and put the responsibility with the hospital instead of the manufacturers.

The fact that all alarms are necessary, was taken over by life monitoring device companies like Philips and Drager. This means that all measurements that possibly indicate a failure in a bodily process are accompanied by an alarm, just to make sure that the potential death of a patient can not be caused by the manufacturer. This has led that a total of 97% of all alarms can not be directly acted on, they are just there as a mere indication (Pediatric ICU doctor, 2018). The other 3 percent are actual urgent alarms on which should be acted in a short time.

These urgent and non urgent alarms can be described as follows. When looking at alarms, there are two types (figure 7). Alarms within the yellow zone, and alarms within the red zone. Often are the alarms within the yellow zone not life threatening and often they cannot directly be acted on. These yellow alarms are only to attend the nurse of the current state, and is therefore in many cases unnecessary. In most cases it is possible to extend the alarm limits, making it initiate less frequent. The red alarms are critical alarms which have to be acted upon directly. (3)

Alarms and fatigue caused by them are only a very small part of the behaviour of the nurse. The complete behaviour is much bigger, much more complex, and difficult to map in just one model. Getting to know the behaviour of someone is a time intensive task. After all, you only get to know people when you are with them for a longer time. To make gathering information and insights more effective, not only observations but also interviews with multiple nurses and one patient were performed. Doing so made it possible to, in a relatively short time, get a general overview of the behaviour of nurses.

The team working in the hospital is multidisciplinary, there are surgeons, radiologists, doctors, nurses, cleaners, and everything in between. In the Intensive Care all different members of this team can be found, on different times of the day, all performing a different task.

Overalll speaking, the main occupants caring for the patients are the nurses, the doctors are for curing the patients (Pediatric ICU doctor, through personal contact, 2018). As field research has shown, nurses only want to see data that they can directly act upon, knowing if something is wrong right now (like can be seen in Appendix A3). Doctors want to see the trends, whether a patient's health status is improving.

A lot of observations have been performed throughout the research phase (and even afterwards) to see a pattern in behaviour. The main inspiring moments are taken up in table 1. Part of these observations can be found back in the Patient Journey in chapter 2.

(3) This finding was gained in a conversation with a Pediatric ICU Doctor, the complete transcribe can be found in Appendix A3.

(4) These are all observations the were found during multiple visits, see the Patient Journey in Appendix A4.

[15] Kirstenen, Edworthy, & Özcan (2016). *Alarm fatigue in the ward.*

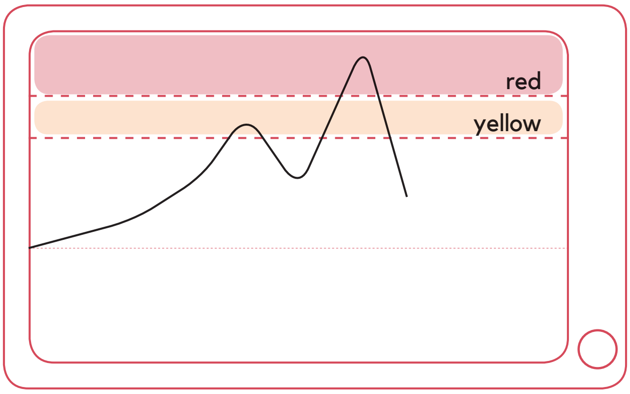


Figure 7 Yellow alarms do not always need to be acted upon, red alarms are urgent.

Table 1: observations at the IC

Occurence	Observed happenings in the IC ❹ *possible underlying reason:*	Desired behaviour in the IC to create a more silent atmosphere
Patient is rolled on a hospital bed into the IC	Nurses gather from all over the IC to see whether they can help with setting up the room. Devices are searched and hooked up to the patient. *This could be happening because nurses have been observed to be real team players.*	Only a sensible amount of nurses rush to the new patient, so that everybody has their space to properly function around the patient.
Carts with medication or meals are pushed around the corridors	Doctors and assistant nurses are not very careful, dropping boxes or plates, and being unnecessary loud cause a lot of sound pollution. *Cause could be that nurses have a high workload*	Not loading carts too full so that nothing falls off. When more people are driving carts carefully wait for each other to pass.
Meetings in the corridors around the post	Nurses stand in front of ICUs, talking about their weekends and how much fun they had, laughing unnecessary loud. *Nurses want to vent their feelings because they have to process a lot each day.*	Nurses have similar conversations, but at places less close to the patients in a more toned down way.
Alarms ring at the IC	Both at the patients bedside and in the nurse post alarms ring, until either dismissed or acted upon by the nurse. *The safety of medical devices play a role here, making sure alarms are not missed.*	The alarm only rings at the place where the nurse is, or the alarm is always with the nurse. Making sure alarms are not elicited in places where they are not necessary.
Alarms are dismissed at the nurse post or in the patients room	Alarms ring for approximately 5 to 7 minutes, nurses grow tired of them and they either dismiss it or they are stopped by themselves. *Because of all alarms, nurses get fatigued by them. They do not hear alarms anymore.*	Only the more necessary alarms are initiated as boundaries of the alarms are set more relevant to the patient.
Change of the shift	Nurses 'take over' the patients from the nurses whose shift is almost to an end. When someone is not present everybody start discussing whether they have seen the nurse or not. *Once again, nurses are team players.*	Everybody arrives in time, and one nurse speaks while the rest listens instead of speaking over each other.
Complete transfer of patients, part of change of shift.	In front of every ICU the health status, cause of hospitalisation and current treatment of the patient in the ICU is explained. When alarms initiate, they are left until they are dismissed *Treatments and patients need to be discussed properly, this combined with alarm fatigue could be the cause.*	Similar, it is necessary for each nurse to know exactly what is going on with each patient, so that they can help at any given time. Have one assistant nurse look after alarms to make sure that they do not ring unnecessary.
Patient is dismissed from the IC and transferred to a regular hospital room.	*Not witnessed-*	Ideal would be to only have the necessary doctors within the ICU, before undoing the important cables first turning off the alarms, and then transferring the patient.

Chapter 2: in-depth research

The environment has been discussed and there are some initial steps on understanding what are the causes of patient's sleep disturbance. The goal of this chapter was to understand why these different disturbances happen so often that they interfere with a patient's sleep rhythm.

[16] Boogers (2018). *CareTunes: Music as Nurses' monitoring tool.*

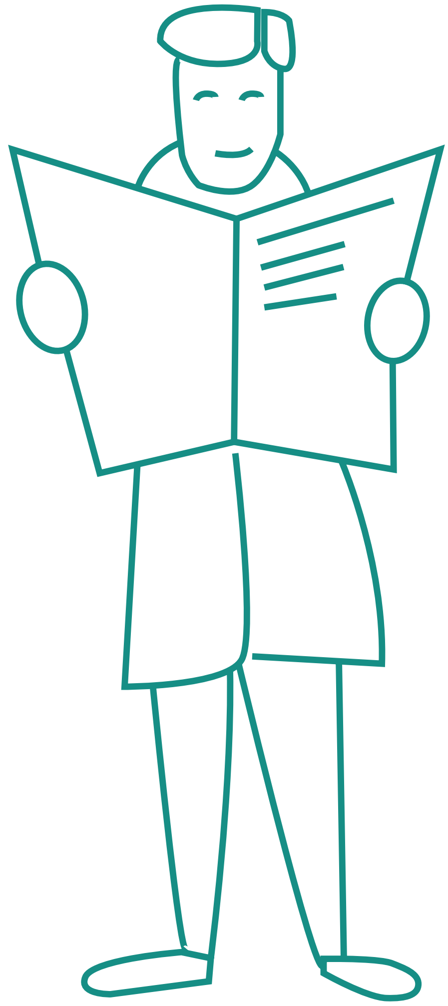
Through previously mentioned observations a patient journey was made, showing that nurses are often unaware that they make a sound. This remains the case regardless of whether nurses know that sleep deprivation inhibits proper restoring of patients.

By implementing observed findings into psychological models the result was gained that a design within the IC is needed that removes the confrontation between quiet and loud nurses, the design should become something to grasp back to when speaking about the auditory environment.

Nurse behaviour is also mapped in a behavioural model, as was designed by Boogers in 2018, showing that the main point of attention is making sure nurses set their alarms right and that the proper amount of sensitivity to sound is lacking.

As discussed before, alarms and fatigue caused by them is only a part of the noise problem. From all research an overarching Problem Definition was created, which will be designed for in chapter 3. For now, in chapter 2, the following take-aways will be discussed:

- Nurses in Critical Care environments are unaware of sound they make, even though they are aware of implications that noise has.
- Almost all auditory disturbances are behavior induced (mainly by nurses, but also by doctors and sometimes visitors). When this loud behavior is tackled, the problem of a space unsuitable to sleep in is tackled.
- Psychological models show that the confrontation between loud and quiet nurses should be eliminated by a design.
- Behavioural models show that nurses have lost their sensitivity to sound.
- In the IC, on average auditive disturbances happen once every 12-15 minutes. Increasing a few minutes in between of these disturbances could lead to patients being able to get into deep sleep.



In this chapter I try to get to the bottom of all behaviour research through observations and literature.

Section 2.1

Patient journey

Over multiple days, a general flow of behaviour was found and mapped. A patient journey map was made according to the guidelines as set up in the MOOC: Design in Healthcare: Using Patient Journey Mapping.

speech
incidents
alarms

MAINLY CAUSED THROUGH BEHAVIOUR

background

Figure 8 Sounds caused by speech, incidents and alarms are mainly behaviour induced.

Alarm fatigue Nurses are during their workdays continuously surrounded by sounds and alarms of all sorts. Mainly alarms are very repetitive sounds, which after longer exposure, are tireing and deafening. That is why becoming 'deaf' to alarm sounds is called alarm fatigue.

The four different observed auditive disturbances (figure 8) were Alarms, Speech, Incidental and Background noises, these all occured throughout the day. Alarms rang multiple times at patient's bedsides, sometimes in multiple ICU boxes at once. Incidental sounds were during the day caused by dropping boxes and moving trolleys. Speech was also often witnessed as being a polluter to the sonic environment. Lastly there are the sounds that are always present in the ICU, like a mechanical ventilator. These polluters are called background noises, but as the accompanying machines provide life sustaining functions, they were not within the scope of improving during this thesis.

From all different time slots as occurred during the different observation-days, the findings were clustered to show one of the four disturbances. In figure 9, on the next page, only the important factors have been taken up in a condensed patient journey. The complete patient journey and the result from the MOOC can both be found in Appendix A4.

Speech was not only witnessed to be care related, sometimes nurses had to discuss a lot about their private life as well. Having to discuss patients at the beginning of the day obviously is no sound pollution, nurses needed to know what had happened to which patient. Discussing how the children did during the football match when multiple alarms were ringing were in my opinion more polluting. Having such conversations are necessary as well, nurses need to vent their feelings (Nurse C, 2018). It would however be advised to be more conscious about your decision *where* you are talking to your colleague nurses.

Some people are clumsy, some are not. That is understandable. When looking at a critical care environment this remains similar. However, it should be noted that sometimes nurses were far too uncareful, by multiple times dropping boxes from an overloaded cart or closing doors excessively loud.

Lastly there are the alarms, which can be set accordingly to what a nurse deems necessary with a patient's health status. When a patient needs to be closely monitored, it is understandable that alarm limits are set tight. Nurses are being taught how they can alter these limits, and some nurses also found a way of how to make the environment a bit more silent (Nurse B, 2018). It happens however often that nurses do not feel like or dare to change the alarm limits, making them initiate too often and causing alarm fatigue.

When evaluating these three sources of noises, they can be directed back to three behaviour traits. Tackling these traits would tackle the core of the loud environment. When discussing at the IC Nurse A and Nurse B agreed that these cores of disturbances were accurate.

The main eye-opener that was not yet discovered was why the behaviour of nurses was so loud. After discussing it with Nurse A, and looking back at the mapped behaviour, it became clear that noises are present quite often as nurses are unaware of the sounds they actually make. Similar to alarm fatigue, nurses seem to be 'deaf' to mostly all actions that make sound as they continuously are operating in a very loud environment (Nurse A and a shift of nurses, 2018).

Concluding

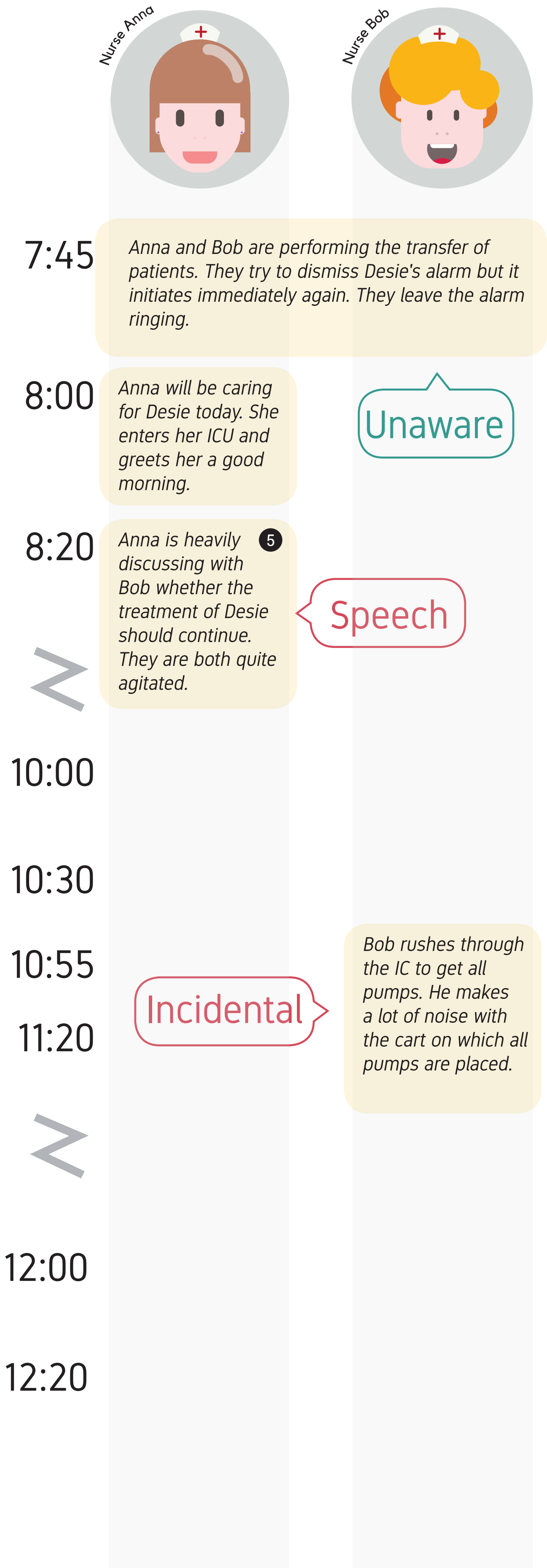
The different sources of auditory disturbances (Background, Alarms, Speech, and Incidental) as found in literature, were also found in reality. Three of these four sources are mainly caused through behaviour.

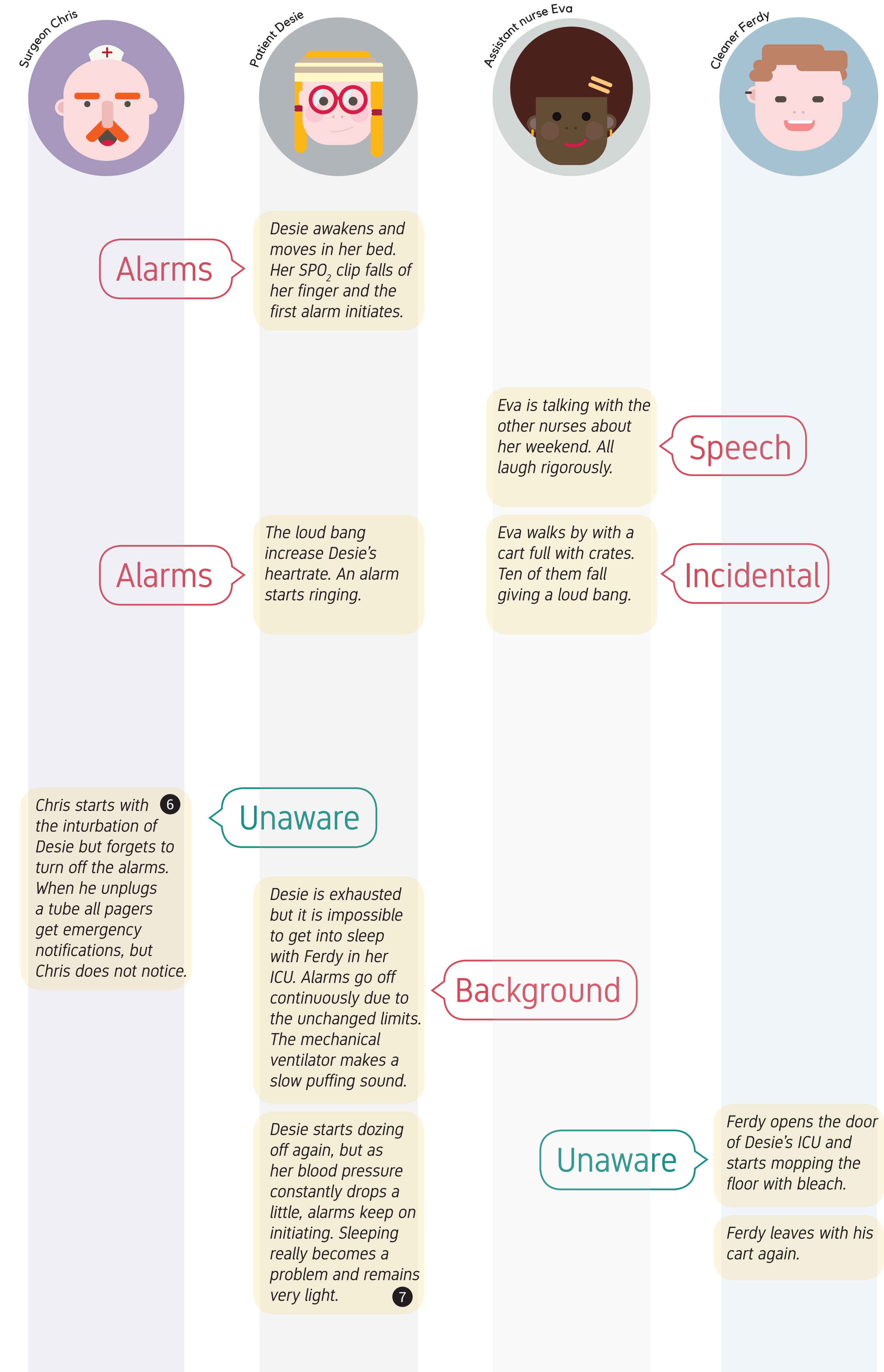
The noises occur as nurses are unaware of the loud sound they make, mainly because they are surrounded by loud sounds continuously.

5 Nurse A told on 09-04-2018 that nurses get louder and more unaware over time, read more about this in Appendix A5.

6 The same result was found when speaking to a Pediatric ICU Doctor from the Wilhemina Kinderziekenhuis on 19-03-2018, this and more findings can be read in Appendix A6.

7 This finding was based on a short interview with patient Riet who has priorly been multiple times a patient on the Intensive Care. Read these short but inspiring findings in Appendix A6.




Surgeon Chris
Patient Desie
Assistant nurse Eva
Cleaner Ferdy
Alarms
Desie awakens and moves in her bed. Her SPO_2 clip falls of her finger and the first alarm initiates.
Eva is talking with the other nurses about her weekend. All laugh rigorously.
Speech
Alarms
The loud bang increase Desie's heartrate. An alarm starts ringing.
Eva walks by with a cart full with crates. Ten of them fall giving a loud bang.
Incidental
Chris starts with the inturbation of Desie but forgets to turn off the alarms. When he unplugs a tube all pagers get emergency notifications, but Chris does not notice. 6
Unaware
Desie is exhausted but it is impossible to get into sleep with Ferdy in her ICU. Alarms go off continuously due to the unchanged limits. The mechanical ventilator makes a slow puffing sound.
Background
Desie starts dozing off again, but as her blood pressure constantly drops a little, alarms keep on initiating. Sleeping really becomes a problem and remains very light. 7
Unaware
Ferdy opens the door of Desie's ICU and starts mopping the floor with bleach.
Ferdy leaves with his cart again.

Section 2.2

Behaviour explained psychologically

As just concluded with the Patient Journey, the different actors in the Intensive Care are unaware that they produce a lot of sound. An example would be that Desie finally started dozing off after an intense treatment, and Ferdie all of a sudden starts mopping the floor in Desie's ICU. This awareness can also be related back to multiple psychological theories.

Theory of reasoned action

Based on the Theory of Reasoned Action [17, 18, 19], there was searched for a link between the behaviour observed of the nurses and the personality traits in individual nurses. Creating such understanding made it possible to find the purpose of the yet unknown and partially what functions the design must posses.

Found through the TRA (figure 10) is that nurses do know that silence is better and they like to have the patients recover as soon as possible. They do however not like to be monitored continuously (the way Quietyme is installed at this moment is very obvious and prone to pranks, which will be highlighted in section 2.5), and neither do they want to be completely quiet for a whole shift. This leads to an attitude of wanting to work in a quiet environment as long as it costs little to no effort. It seems that being quiet is not rewarding enough yet.

This corresponds with the normative belief. If nurses do not see other nurses quieting down, then they do not feel the urge to do so themselves either. The motivation was found to be a group effort, and as long not everybody is respecting this group effort, then no individual nurse wants to be more quiet. This finding hints at the phenomenon that no reward can be found in more silent behaviour.

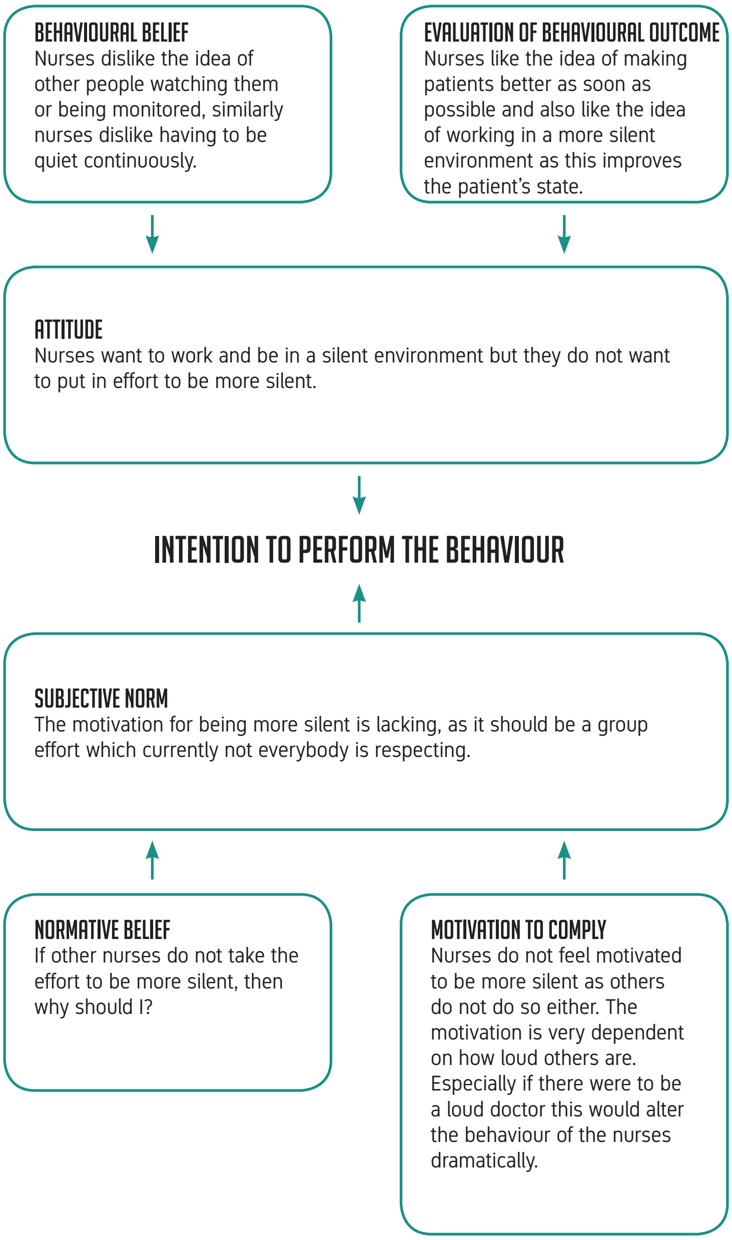


Figure 10 Theory of reasoned action filled in for IC nurses.

Theory of reasoned action
This theory shows someone's intention to perform a certain behaviour. Through observations and interviews can be found what motivation people show to comply to a belief (e.g. it is beneficial for patients to be silent as a nurse) compared to their attitude.

[17] Fishbein (1967). *A behavior theory approach to the relations between beliefs about an object and the attitude toward the object.*

[18] Fishbein & Ajzen (1975). *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research.*

[19] Fishbein & Ajzen (1980). *Understanding attitudes and predicting social behavior*

Bandura's Social Cognitive Theory

Bandura's Social Cognitive Theory
This theory shows and explains the different interactions between actors and environment. Three actors (the environment, the product, and the user) all have current emotions, and these are changed into desired emotions. These desired emotions can be used as a guideline during the design phase.

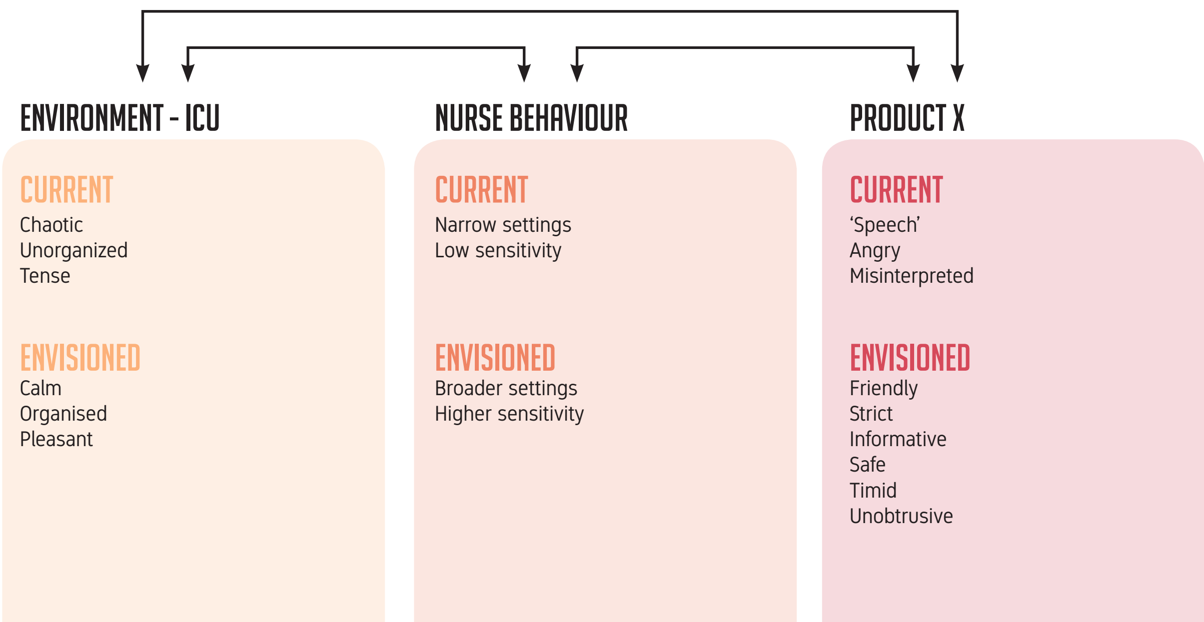
[20] Bandura (1977). *Self-efficacy: Toward a unifying theory of behavioral change.*

[21] Bandura (1986). *Social foundations of thought and action: A social cognitive theory.*

The human-product-environment interactions were explored to gain insights in the emotions envisioned for the design. This model is based upon Bandura's Social Cognitive Theory[20, 21]. In this model all interactions have been assigned to the different key-players. Each 'player' has different interactions with each other. The interaction between the product and the environment might be very different than the interaction between the nurse and the environment. The difference lies with the user-behavior link, which was shifted towards a nurse-product link. In the current design space nurse-behavior interactions made more sense than a user-behavior link, as the behaviour could in this situation only be related back to the nurse.

In the model can be seen that the current environment interactions can be described as chaotic, hostile and complicated. Even though still quite abstract, through observation it became clear that the environment of the IC is quite chaotic, with a continuous leaving and coming of different people. In the future, after my design would be implemented, a desired vision was created. The IC will then be more friendly, controlled, pleasant and tranquil. For the nurse interactions can best be looked back at the nurse behaviour as described in the previous section. The difference will lie in how narrow the alarm settings are set by nurses, and how sensitive the nurses still are to sound. Whereas in the current situation the settings are often quite narrow and the sensitivity is quite low, this is expected to change in the future. After implementation of the yet unknown design (product X) the nurses will put the limits of their alarms wider and they will hopefully will become more sensitive to sounds again.

Figure 11 Banduras Social Cognitive Theory applied to IC nurses.



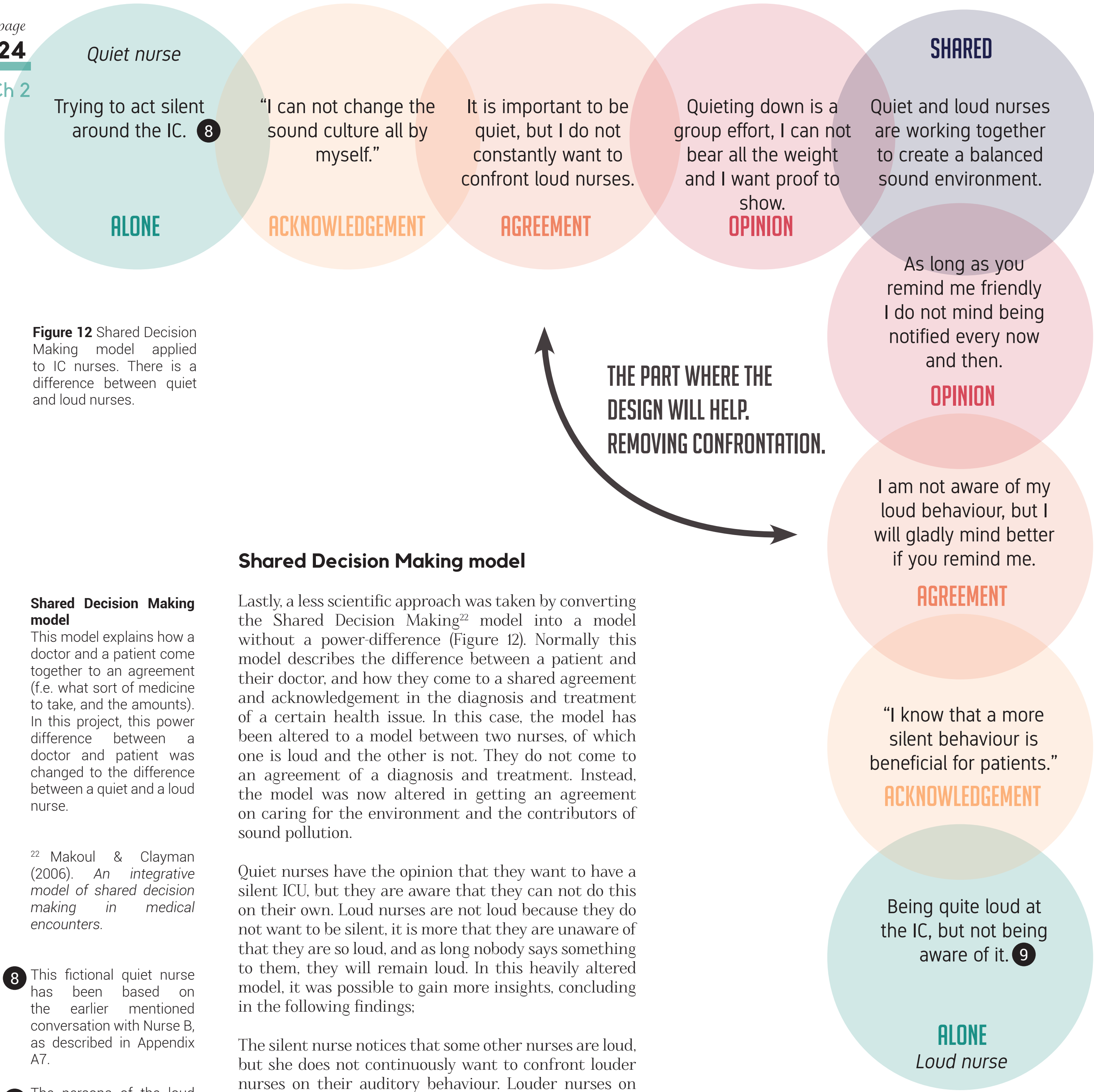


Figure 12 Shared Decision Making model applied to IC nurses. There is a difference between quiet and loud nurses.

Shared Decision Making model

Lastly, a less scientific approach was taken by converting the Shared Decision Making[22] model into a model without a power-difference (Figure 12). Normally this model describes the difference between a patient and their doctor, and how they come to a shared agreement and acknowledgement in the diagnosis and treatment of a certain health issue. In this case, the model has been altered to a model between two nurses, of which one is loud and the other is not. They do not come to an agreement of a diagnosis and treatment. Instead, the model was now altered in getting an agreement on caring for the environment and the contributors of sound pollution.

Quiet nurses have the opinion that they want to have a silent ICU, but they are aware that they can not do this on their own. Loud nurses are not loud because they do not want to be silent, it is more that they are unaware of that they are so loud, and as long nobody says something to them, they will remain loud. In this heavily altered model, it was possible to gain more insights, concluding in the following findings;

The silent nurse notices that some other nurses are loud, but she does not continuously want to confront louder nurses on their auditory behaviour. Louder nurses on the other hand, as described before, are unaware of their loud behaviour. Following the structure of the SDM-model, both have the opinion that the ICU should be more silent, but not all by themselves. Quieting down is a group effort. Therefore neither of the nurses want to make the first step in actually becoming more quiet. My design should relieve this moment of confrontation, and by making both nurses aware of the audio environment, they can make the shared decision on minding their work rhythm.

To create this feeling of working together in becoming more quiet, a vision and analogy were created. These will be explained in section 3.1 and 3.2.

Shared Decision Making model
This model explains how a doctor and a patient come together to an agreement (f.e. what sort of medicine to take, and the amounts). In this project, this power difference between a doctor and patient was changed to the difference between a quiet and a loud nurse.

[22] Makoul & Clayman (2006). *An integrative model of shared decision making in medical encounters.*

8 This fictional quiet nurse has been based on the earlier mentioned conversation with Nurse B, as described in Appendix A7.

9 The persona of the loud nurse is based on the fly-on-the-wall research performed on 01-05-2018, as can be read in appendix A8.

Section 2.3

Nurse behaviour modelled.

Nurse behaviour was mapped in a model especially targeted at recognising auditory behaviour traits in nurses. First all observations were put together in an 'observed behavior map' and a second 'desired behavior map' was created. When put over eachother, it was found that the needed design should help with getting the nurses' sensitivity to sound back.

With the help of Boogers' research (2018)[16], the auditory behaviour of nurses could be mapped.

This model evaluates nurse behaviour on six behaviour traits: settings, alarms vs intuition, sensitivity to sound, experience, being neat and organised, and stress. On the ends of all traits there has been put a scale for applicability. For example, stress is on the one end 'too sensitive for stress' and on the other end 'resistant to stress'. While perhaps thought to be true, it is not necessarily the case that all behavioural traits should be on the right side of the model.

The model was filled in with the observed behaviour (figure 13). This model shows that the nurses in the Erasmus MC tended to set their settings quite narrow, with alarms ringing often. However, the nurses relied on their intuition. It seemed that nurses looked at the patient and saw that nothing was wrong, dismissing or neglecting the alarm. This showed that the nurses were simultaneously confident in their choices, but their discipline lacked in cases where the alarms were completely neglected causing a continuous stream of sound pollution.

The loud conversations in the hallways showed that their discipline could be better, but also that they were quite resistant to stress. The great amount of alarms present gives an indication of a lower sensitivity to the sound, something that could be resolved by resetting the settings and altering the alarm limits.

Figure 14 is the ideal situation created by a new design. When a new patient is admitted, a nurse will be by the bedside until the patient is a bit more stable (Nurse B, 2018), without having to be in alarms continuously. Alarm settings can be put wider as the nurses in this new scenario will already have familiarised themselves with the patients better. Not having to rush around the IC makes them more resistant to stress and more neat and organised. With alarms ringing less frequent, nurses will also suffer less from alarm fatigue.

Concluding

Nurses have to improve their sensitivity to sound, which can partially be achieved by putting alarm settings wider. When the desired model and witnessed model were combined (figure 15), the trait that had to be improved revealed itself. A clear difference was found in the 'settings' and 'sensitivity to sound' traits.

To create a decrease in auditory disturbances, exactly the same thing had to happen. When alarm settings would be set more wide, an increase in the sensitivity to sound could be created. Such an increase in sensitivity could then again lead to more environmental awareness, where nurses are aware when they make a louder sound.

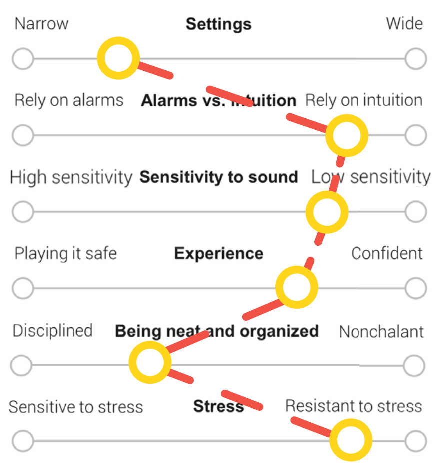


Figure 13 Observed nurse behavior

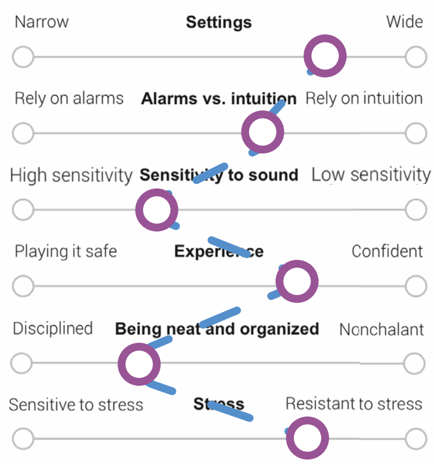


Figure 14 Desired nurse behavior

Figure 15 Observed and desired behavior combined

Section 2.4

A combined foundation

During all phases of research, there was continuously explained in short what the problems or conclusions were. In this short chapter all conclusions were combined, creating one structured summary of what the exact problem was that has been dealt with, what the design vision with this problem has become, and why this direction was relevant for the future of the Intensive Care.

The research question

Speaking to each other about unwanted behaviour is observed to be difficult, and therefore a friendly, informative, safe and unobtrusive design was needed that can inform colleague nurses when sound levels are inadequate.

Some nurses have the urge to make the IC more silent, but have difficulty doing this all by themselves and have no interest/gut to constantly speak to others about their auditory behaviour. On the other hand there are other nurses that are not aware of their loud behaviour (keep in mind, nurses love to do what they do) and as long as they are not talked to about this behaviour, it often happens that they remain loud. These louder nurses would most probably be more quiet if they are talked to about it, as long as the conversation remained friendly. The needed design would remove the unwanted and uneasy confrontations and conversations between loud and less loud nurses.

Apart from removing the confrontation between nurses from their daily tasks, the design should show when sound levels are within limits or not, and when they are not, alarm nurses accordingly.

When it would be the case that sound levels are measured that are out of boundaries, the design should show what the main contribuants of these disturbances are. This makes it possible for everybody in the IC to act more conscious of their environment.

In the end what should be obtained is an increased time between auditive disturbances, so that patients can get into deep sleep for one sleep cycle during day time. This would have great impact on the recovery time of patients. The final research question has become 'how to design for more awareness of the auditory behaviour in nurses, in the Erasmus MC Intensive Care, for patients to have a shorter recovery time.' As also can be found in figure 16.

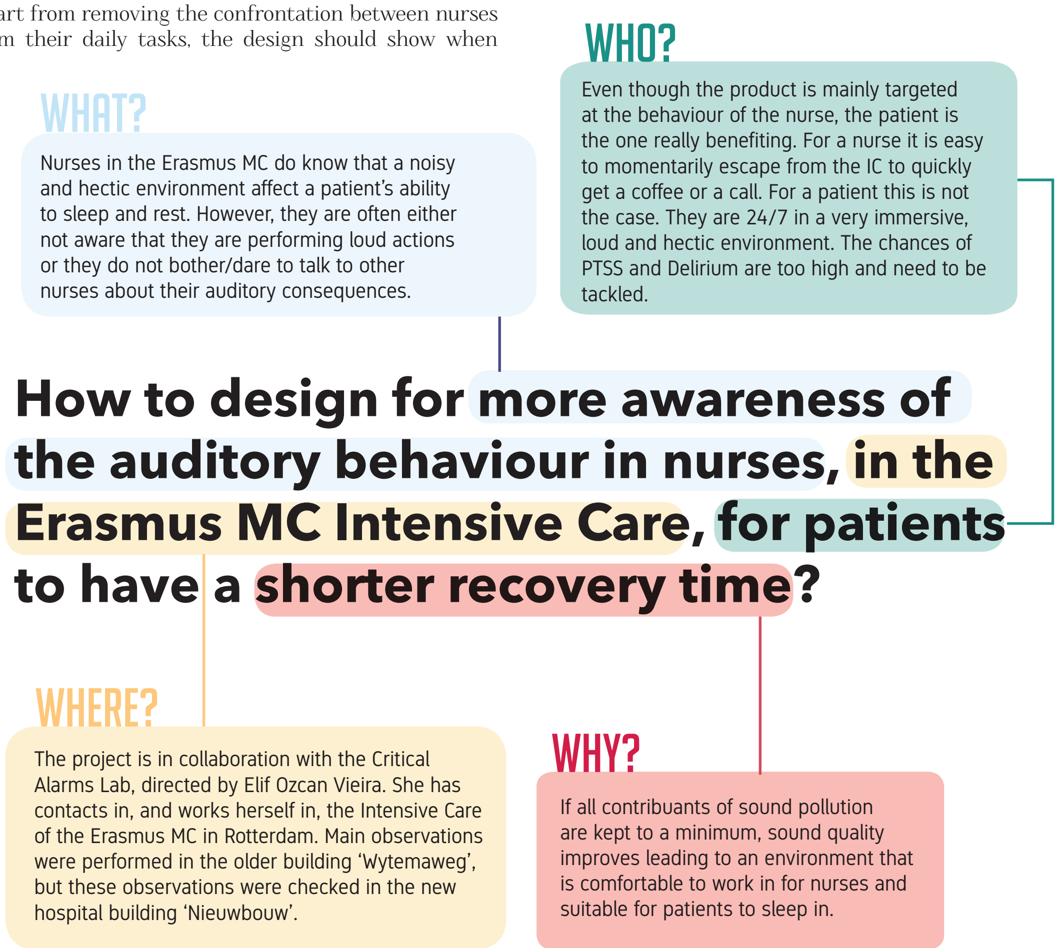


Figure 16 The main research question of this thesis explained.

Section 2.5

Measuring noise

Even though on paper it sounded nice that there should be a division in the different sources of sounds, and that these should be measured individually and automatically, it needed to be made sure that the technology to do so actually exists. Luckily it did. An American company called Quietyme produced sensors that can measure different environmental factors.

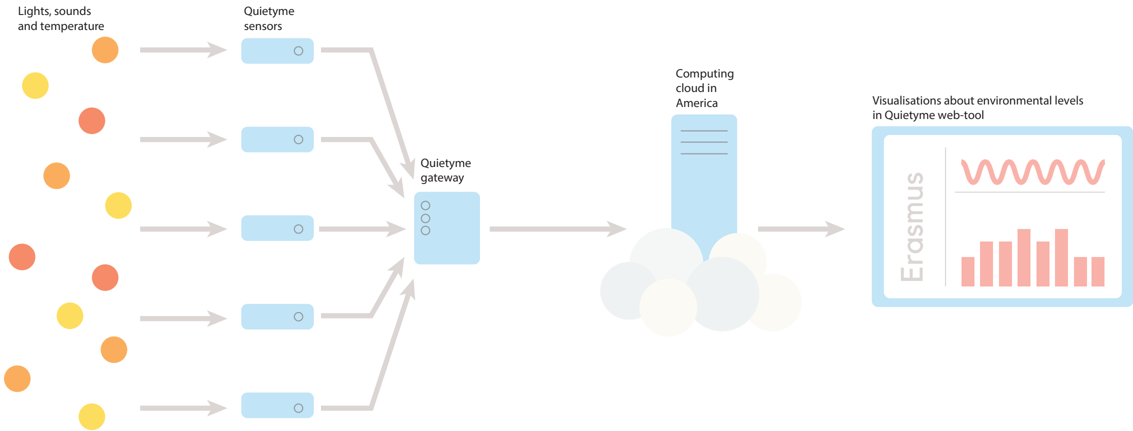


Figure 16 Global scheme of how Quietyme works

The generic structure of Quietyme is simple.

Quietyme sensors would be placed in different rooms and nurse posts where they collected environmental data like light intensity, humidity, temperature and decibels. The sensors forwarded this data to the quietyme gateway which then forwarded small packets to the computing cloud in America. During this analysis large strings of decibels were converted by an algorithm[23] to the origin of the sound (one of the four contribuants).

On the 9th of April a visit to the IC in the EMC took place. During this visit, the package containing the QT sensors (figure 17) and the gateway arrived from America. These sensors were installed and tested to see whether everything worked. Immideately after placement it was noticeable that the nurses were sceptic about the sensors.

"Now we have to talk very silent.", "I will deliberately scream into it", and "We're being spied on." was said by individual nurses. They said this already without knowing the exact reason why the sensors were installed and what the sensors actually measured. After an explanation to the nurses, and explaining that no speech could not literally be recognised out of only decibels, the nurses opened up a little. Still some nurses remained stubborn, deliberately shouting into the sensors, which in some cases introduced measurement-errors.

The sensors remained installed and measurements were made over a stretch of 30 days. All calculated data was made visual in the quietyme webtool, which also sent a textual alarm when sound levels reached a certain amount of decibels. The web-app thus indirectly warned nurses when sound levels were insufficient, but in still a quite unresponsive and non-interactive way.

Data within Quietyme's web-tool was visualised into multiple graphs, as can be seen in figure 18. A line graph showed the amount of noise being made using a so called Quietyme-score, a second bar chart shows an breakdown of which of the four different sound types had been the noisiest over time. Using only the web-tool proved to be difficult as the data was difficult to interpret with only a Quietyme score and amount of decibels. (nurses during the fly on the wall research, Appendix A8, 2018)

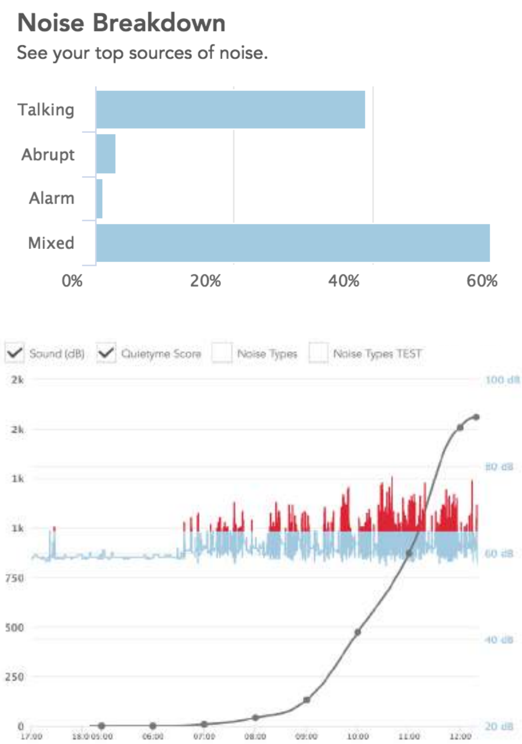


Figure 18 Quietyme web-tool graphs.

[23] **Algorithm Quietyme**
An attempt was made into understanding Quietymes algorithm. When looking at a long string of measured decibels, different patterns can be found describing occurrences. Incidental sounds can be found as sudden peak in a line of decibels over time. Background noise can be described best as a slightly fluctuating line. An alarm can be seen when there is a clear repetition in the decibels. Lastly, speech is recognised when loud but very inconsistent sounds are measured (speech is seldom repetitive)

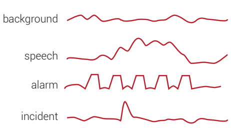


Figure 17 quietyme sensor

Getting data more insightful.

Luckily the website also offered the possibility of exporting CSV files (Comma Separated Values) for a specific time for a specific room. When doing so, the user receives hourly values like amount of alarms, length of alarms, average length of speech and some others in a table layout (a table explaining all obtained value will be elaborated upon in section 5.4, where the data is used in the final design. A table with relevant data for now can be seen in figure 19). Retrieving a CSV per day per room made it possible to generate a graph with average amounts of alarms, for each hour of the day. With Quietyme sensors not all being as accurate in defining what is an alarm, speech or background sound, the choice was made to look at which rooms had the most accurate and sensible measurements. During this study this turned out to be room H307.

As explained, the sensors measured data in the Intensive care for a few weeks to get to understand Quietyme and its webtool. From these measurements a CSV was exported, so that insights could be gained in trends over time.

	13 apr	14 apr	15 apr	16 apr	17 apr	18 apr	avg.
0	0	4	1	3	2	3	2,17
1	0	2	2	3	1	3	1,83
2	0	1	0	4	8	4	2,83
3	0	0	0	3	5	3	1,83
4	0	1	3	0	0	0	0,67
5	2	6	0	2	0	4	2,33
6	0	0	0	6	3	5	2,33
7	1	1	2	2	11	7	4,00
8	3	7	4	3	6	22	7,50
9	5	18	22	10	11	2	11,33
10	21	5	8	4	13	7	11,60
11	19	9	18	11	12	21	15,00
12	20	22	21	7	7	2	13,16
13	22	7	11	9	4	23	11,50
14	20	10	11	5	13	14	12,17
15	18	2	6	20	12	21	13,16
16	9	15	11	11	2	3	8,50
17	1	8	7	9	6	8	6,50
18	0	1	2	5	25	5	6,33
19	0	9	8	6	17	7	7,83
20	0	2	1	1	6	0	1,67
21	0	5	6	4	3	6	4,00
22	0	1	1	25	2	1	5,00
23	0	7	3	7	1	4	3,67

Peak during day-time

Figure 19 Amount of alarms measured each hour in the period from 13-18 april in Room H307 in Erasmus MC.

In figure 19 is shown that during day-time a greater amount of alarms was measured. The peak lies around 11-12 o'clock with about 13 alarms a minute. This comes down to an alarm every approximately every 5 minutes.

In night times, alarms initiate much less often, between 1 and 5 times each hour. This is at most one each 12 minutes. This makes the goal of getting patients into deep sleep achievable. The maximum amount of alarms each hour during night time equals 4 each hour.

Concluding

The Quietyme system, even though sometimes a bit faulty, seemed to work. The system can adequately measure surrounding environmental data and in America all data can be converted into the sources of auditory disturbances and place them in a CSV file. Therefore, Quietyme's algorhythm seems to work, but it could use a bit more development to make the distinction between different disturbances more accurate.

The shape and appearance of the sensors are however too explicit for nurses. They give the nurses a feeling of being monitored and some nurses prank the devices to deliberately create inaccurate data. A following design would therefore ideally have best all sensors implemented, making it less obvious for nurses that they are in a monitored area.

Chapter 3: design initiated

Getting the Intensive Care silent should be seen as a diet for sound, and still, it should be something that everybody wants to work for with a smile. After all research was performed, there was first thought of a vision and an analogy, which could later on be referred to when design-decisions would be made.

With the analogy and vision, the possibilities were still endless. To create some clarity in the fuzziness, it was decided to make How-to booklets which resulted in three directions: Machinery altered, Carry around, or Static device. Of these three, the Static Device was the direction best suited with the vision.

With user tests being performed and ideation of different sorts the design in mind was already limited to a device that created visual non-auditory alarms, which were always visible. In short, the take-aways of this chapter are:

- The vision is to create a design that tackles loud behavior among nurses together, with a smile from all.
- The analogy is the sound diet, quieting down is like losing weight. You have to do so gradually and sometimes you make mistakes, and people should not feel ashamed of that.
- How-to booklets gave insights in three general directions: carry around, machinery altered, and static device.
- Ideation led into the direction of creating non-auditory alarms.
- An user test showed that such an alarm should always be there and be perceived and understood in the wink of an eye.

Section 3.1

Vision and Goal

Getting the Intensive Care silent should be seen as a diet for sound, and still, it should be something that everybody wants to work for with a smile. A vision and an analogy were created, which helped with setting an initial design direction. This vision would later on also be referred to when design-decisions would be made.

The design that would be created had to consist of multiple functions. All functions also had to be in line with the designed vision, making everybody simultaneously comfortable with quieting down. The real goal of the design, as illustrated in figure 20, is to get nurses willing to collectively quiet down together. As a team.

Followingly functionalities were created, for making a design and setting up new tests and processes. These functionalities can be seen as the list of requirements,

List of functions

» The design should prevent further deprivation of a patients' sleep.
» The design should identify whether the environment is loud.
» The design should be able to distinguish the different sources of auditory disturbances.
» The design should create a non-auditory alarm when the environment has been louder than 45dB averagely over one hour.
» The design should be kind, inviting, and futuristic.
»The design should encapsulate Quietyme sensors.
»The design should help nurses getting their sensitivity to sound back.
»The design should remain interesting over a longer period of time.
»The design should show a clear relation to the auditory environment.
»The design should remove the confrontation between quiet and loud nurses.

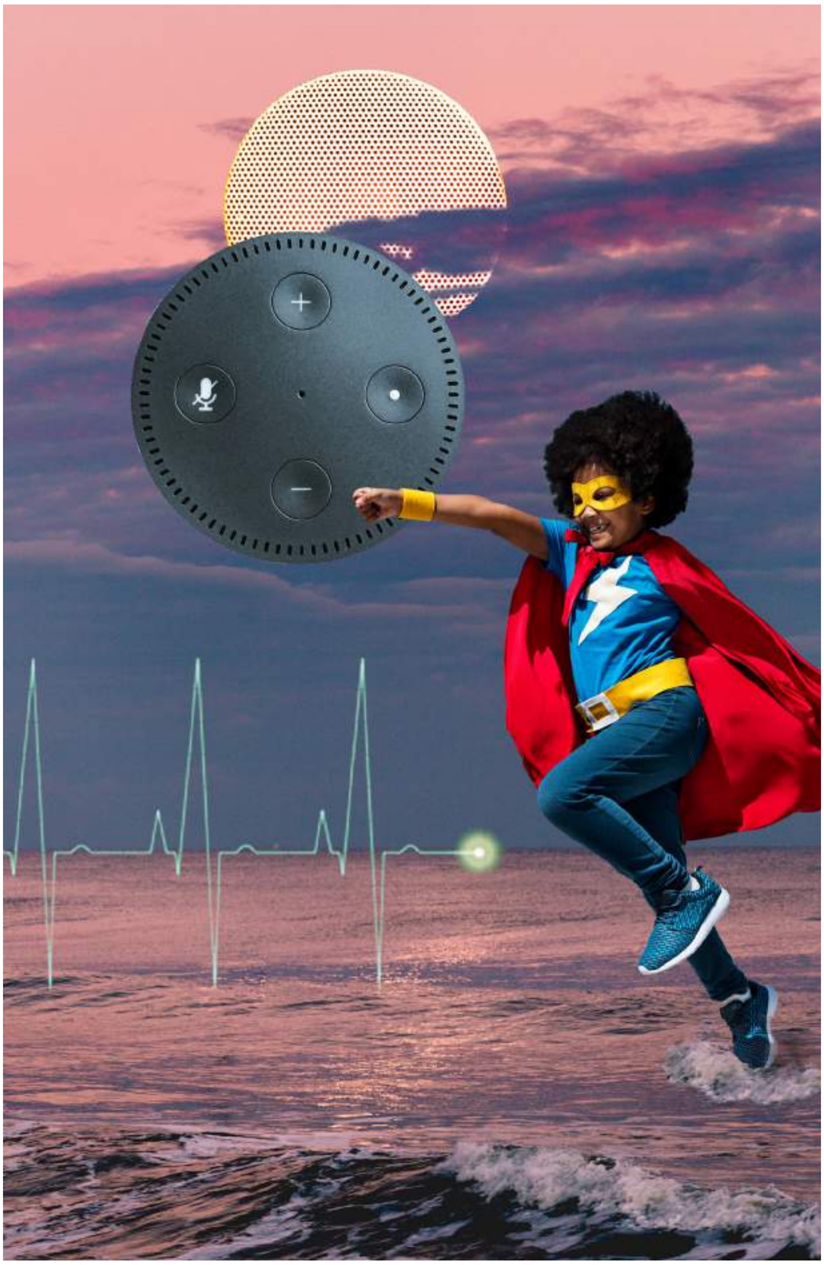


Figure 20 Vision

In this collage, the little confident boy shows happiness and satisfaction in actively trying to get lower sound-levels. He seems to be doing this on own initiative instead of feeling forced to, as he still has a great smile on his face. By actively engaging in his activity, he can see the environment in which he is operating getting more and more silent, as there are only little alarms left that need to be acted upon.

Section 3.2

Design analogy: The Sound diet

Designing a tool for the Intensive Care to make it more silent should be seen as going on a diet. It is a gradual process of finding what sounds are okay, which sounds are not, and sometimes a mistake is made during this process. Nobody should feel ashamed of that.

Sounds belong in an hospital and in an Intensive Care, you can simply not demand nurses to completely say nothing anymore, or eliminate every single alarm out of this context as these both have good functionalities as well. Nurses have a little talk and laugh with each other as they have to vent their feelings with their colleagues as it is a very fatiguing job to constantly be around critically ill people. Alarms are also within the critical care context with a reason. When something is wrong, nurses need to be made aware of this as soon as possible.

The key to this sound diet is to filter the good sounds from the bad. The same as with trying to size down your clothing, you filter the good food from the bad. Alarms can (and should) be there, but they should be limited in how long they are exposed. Small talk in the corridor and in the nurse post between nurses is necessary, but this does not mean that it should interfere with their work or become too loud. Incidents like dropping a plate can happen, but everybody should remain careful at all times.

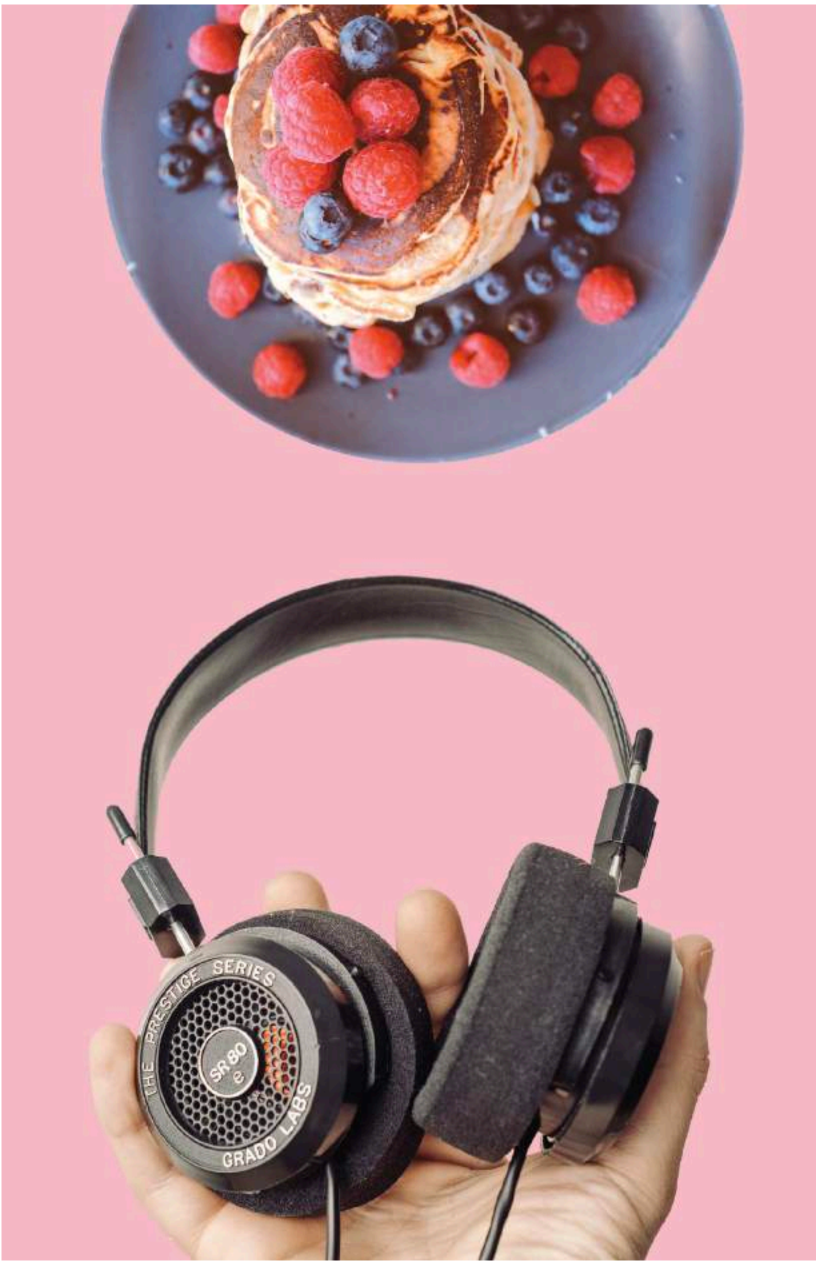


Figure 21 Analogy

This simple collage is used to strengthen the thought of how similar getting people quiet and trying to lose weight are.

Section 3.3

Research 1: How-to booklets

A total of 8 how-to booklets were designed and issued to a total of 12 Industrial Design Master students. The booklets were not yet useful for ideating on ideas or concepts, but they were used for creating design spaces.

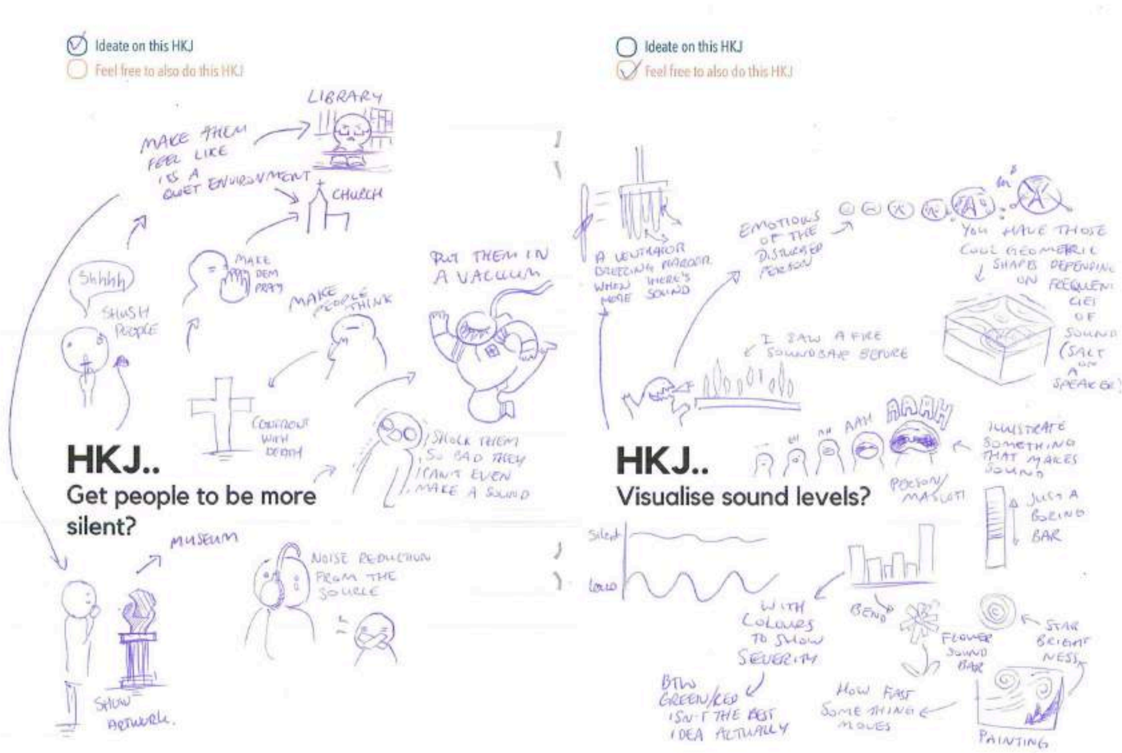


Figure 22
Take outs from the HKJ booklets.

The functionalities of the design did not tell anything yet about the shape of the design, so the following How-to questions helped understanding which directions to design in were possible:

» How to convince others to change their behaviour?
» How to get other people to be more silent
» How to visualise sound levels?
» How to produce an alarm without the use of audio?
» How to communicate big bulks of information in an understandable way?
» How to communicate notifications on a static place?
» How to communicate notifications wherever you go?

From clustered responses (as can be seen in Appendix A10), three design directions arose. The *carry around*, the *machinery altered*, and the *static device* (Figure 23).

The carry around direction is about having a personal reminder wherever you go, the user itself will be notified when they are too loud.

An alternation of machinery could include voice recognition on monitoring devices to make it easier to dismiss alarms, or a local soundblocker making it seem like you are very silent while in fact you are not.

The static device is about including a product in the environment that monitors all users simultaneously, and generally shows whether auditory quality has been sufficient over time.

Figure 23
The three design directions based upon the results of the How-to booklets.

After consideration, the static device direction was continued with as nurses do not enjoy continuously having to take out their mobile phone (Nurse B, 2018), and bands around the arm are prohibited as these are difficult to clean and could cause infections when in contact with wounds.

Moreover, having such a personal carry around device is rather targeting at an individual than actually trying to quiet down as a team effort.

From my personal perspective it was not wise to continue with the machinery altered direction, as this would tackle the actual problem. It would only create an environment where your actions do not have direct effect on the sonic environment, and could make nurses even louder without them noticing.

Section 3.4

Developed ideas

Simultaneous with the design directions, also designs were created. Each design had it's own characteristics and all were still scattered over the multiple directions. By creating a morphological chart[24],and by manual ideation, a total of six different ideas were found to fulfill most requirements.

[24] **Morphological chart**
Creating a morphological chart is a method where all possibilities of key-functions are put next to eachother in a table. When from each row one or two components are selected, ideas can be generated that fulfill all requirements.

How to get attention?	Light flashes	Heat	Vibration	Smell	Wind/Touch	Being shiny
How to change behaviour?	Show current situation	Show desired situation	Succesful stories	Ranking	Idilic treats	
How to convey information?	Spoken message	Written message	Gestures	Icons	Changing color	
How to place it?	Wearable	Floor	Wall	Ceiling	Furniture	Windows/doors
How to make people silent?	Isolation	Take away sound	Notifications	Make people read	Make people think	
How to visualise sound levels?	Waves	Contributor charts	Infograph	Zones on map	Analogy	Written explanation
How to neglect in case of emergency?	Dismiss for now	Turn off (evt. automatic)	Do not respond	Become invisible		
How to keep the design positive?	No personal attacks	Positive messages	Friendly appearance	Changing appearance		

Figure 24
Morphological chart

The morphological chart (figure 24) has a total of 8 How-to questions filled in, all being a part of the requirements. All six ideas, as will be elaborated upon on the following page (figure 25), have been filled in in this chart. These results can be found in Appendix A11.

local sound-blocker

Sound blocking is a technique that is seen more and more across devices like headphones and other sound related devices. The principle is quite simple. Sound consists of all sorts of waves that continuously shift over frequency and amplitude. When these waves are measured, and in near real-time the same waves are played backwards, the waves cancel each other out. This means a local near silence experience.

disturbant floor

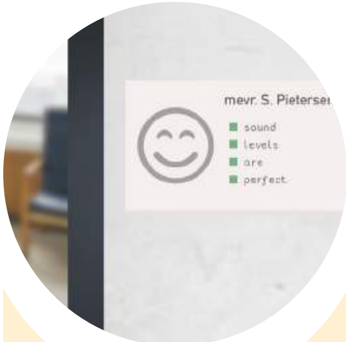
An accessible way of bringing over information would be via either the floor or the walls. Remember how a disco-floor is always drawn? Full with tiles that light up in all funky colors. This is something similar, but then toned down and more informative to be suitable for a hospital environment. Screens are placed all over the floor and show circles in areas where there have been multiple disturbances already. Around the circle can also be found what the source of the sound disturbance is.

sound panels

The padded wall panels act like long tubes being filled with sound. The fuller the tube, the louder the environment. The 'fillings' of the tube consist of all sorts audio, and are being displayed by RGB leds, but there is a way to distinguish which sort of sound polluted most. There will be three different colors making up the complete content. The more hostile the sound-sort is, the heavier it flows.



Figure 25
All wishful ideas.




patient card

The patient card. The patient card is a digital way of showing not only easily accessible health information about the patient. It can also show data similar as found on the Quietyme web-tool.

1. Upon approach the patient card seems like a regular paper. Using E-ink the name of the patient is displayed. The LED smiley next to the name shows whether the patient is doing well or not. If for example the sound quality or the patient's health values are not good, this can be shown visually as a less happy smiley.

2. When sound levels are too high this can be elaborated upon on the side. Three or four icons show the different sources of the sounds and also show in a bar-chart style which were the main contribuants.

changing painting

The interactive and informative painting. This idea is all about art, as art (and for me especially paintings) has something mesmerizing and silencing in it. As soon as I stand for before a painting, my eyes start exploring the emotion hidden within the canvas. This design has something similar within it, except instead of paint being used, all is displayed on a natural matte screen. The usage can be seen as a sequence of steps.

1.The painting measures whether the sound quality is suitable for the time of the day.

2.The painting converts its calculations in a scenery (in this example a small movie of the sea). A quiet environment has a nicer video than a loud environment.

sound bracelets

Color changing bracelets. Another possibility would be to give all nurses their personal bracelet that acts like a smart watch. Dependent on the nurses and bracelets location, the location will display what the local sound quality is like. Green is good, red is bad. When sound quality is low, an unhappy smiley says: 'whoops'. And a keyword like 'alarms', 'speech' or 'interaction' is displayed.

1. The bracelet receives information dependent on the location where the nurse is. Quietyme sensors are used to measure the environment, the bracelets appearance is depending on the nurses location.

2. When sound quality is poor, the bracelet will give a notification. The bracelet will vibrate to gain attention.

Section 3.5

Research 2: Multisensory understanding

A total of six wishful ideas was generated, but after a test into multisensory understanding only one idea truly remained feasible. This second research was performed to get an answer to the question: "what sensory input is easiest to receive and understand?" Results of this test could explain how to get someone's attention, and how to convey information when you have the attention.

Figure 26
Being in a foreign country of which you do not speak the language, would you know what to do when crossing the street? Written information, lights and buttons try to help you, but you have to try a few times to completely understand.

Signal
A signal can be seen as a continuous variable, like the km/h dial in your car. When driving, you continuously perceive data that on itself conveys little information. If you do not know on what road you are driving, it is difficult to say how fast you should drive.

Sign
That is why there are signs. A sign is information to be perceived as something to activate or modify (predetermined) actions. Continuing on the previous example, if next to the road there is a sign saying 60, you know that your speed as indicated in your car should also be 60.

Symbol
A Symbol goes further than a sign or signal. A symbol is more thorough, contains more information, and can be related back to features of the external world. My design should resemble a symbol the most.

Understanding information

Users need a visual stimulator to be informed when sounds are disturbing in an environment. When they want to know how the noise has occured, information is conveyed best through a written message. That was the result of this test.

There was no significant literature found on how people react to different sensory stimulations in relation to the speed in which they turn off a sound. Therefore a test was set up to find whether there is a link between different sources of actuation (like a flashing light occurring when sounds are present) and reaction on the production of sound (how long it takes to turn off sound).

Sensing, acting, and understanding

Sensing, acting and understanding are three very different things. When a child sees an iron, it will perhaps not understand that it might be hot. It is only after sensing (touching, feeling, and then crying regrettably afterwards), that the child in the future will understand not to touch the iron again. When the child gets older, it will also understand that the blinking red light indicates that the iron is heating up. When he holds his hands close to the iron, he can already feel the heat. Also, when he comes close to the iron he can hear the gushing sounds of the water expanding into steam.

Most of the happenings in the prior paragraph explain something about multisensory-understanding. People sense, understand and act constantly, and sometimes such interactions have to be performed multiple times in order to understand what is going on (predicting) (figure 26). In product design terms this can probably be best called the learning curve of a product. Through continued use you understand more about the product, and eventually you can predict what will happen if you perform a certain action. According to Jens Rasmussens paper (1983), there are three distinctive announcers of information. Signals, Signs and Symbols.

So how does this information about sensing, acting and understanding relate back to my design decision? When designing for the Intensive Care, it is important that the multisensory-understanding happens as soon as possible. In other words, when the understanding comes faster, the reaction time to change the action (in this case the auditory behaviour) decreases. Thus, designing something with a simple and short learning curve, like a plug and play mouse on a computer, was the ideal to aim for.

During this test was looked at how fast an initial encounter leads to an action, and by performing the test 5 times was also recorded whether participants started to predict faster. This could give an indication of the learning curve of the test.

Method

To test what senses was acted upon quickest, a set up was created in which participants would be placed in front of a Lenovo touch screen tablet, and asked to touch one of the three-on screen buttons. Before the test commenced, a stressful situation was created, where participants were asked to fill in a math-test (Appendix A12) in only 60 seconds. Immediately afterwards, without time to rebrief, the second part of the test would start, in which the actual multisensory-understanding would be tested.

This test was performed with a total of 12 Industrial Design students, of which 5 male and 7 female. A test would take between 10 to 12 minutes. Each participant would test one of the four different information conveyors: A written notification, a sequence of buzzes, a sequence of flashing lights, or a change of on-screen color. An example of a test-screen with a written message can be seen in figure 28, and the test setup itself in figure 27.

Figure 27
Test setup research 2

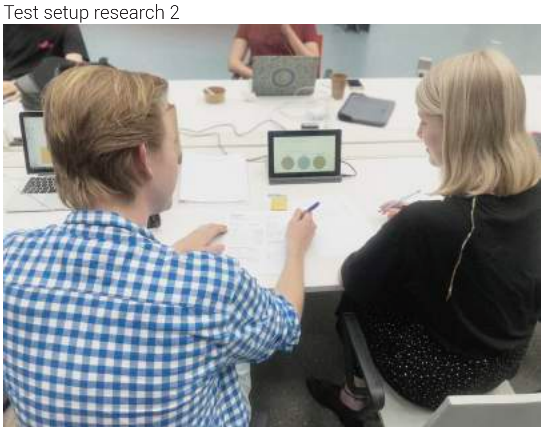


Figure 28
Screenshot from test - written message.

Figure 29
Like on the MIDI-board of a music composer, lights are simple indicators to show whether a track is turned on or off. For real important data, like the dB of a track, sliders with written information are used.

Procedure

Participants would be invited to join a test on improving the working environment in the Intensive Care. An audiotape playing regular IC noises was already playing on the background continuously in which murmuring people, alarms, and trolleys passing by could be heard.

To create a more accurate representation of the mental state of a nurse, the participants had to feel a bit stressed. This stressful feeling would be created through a little start-up exercise in which participants had to fill in an impossible math test in only 60 seconds, while random numbers were being read by the voice function of Google Translate. When the 60 stressful seconds were over, the test would proceed to displaying one of the four information conveyors, and asking what button the participant would press.

A written message, a change in color, a sequence of vibrations or lights all tried to communicate whether either alarms, speech, or incidents caused the most noise. Time was recorded for how long it took the participant to press one of the three buttons, and whether they responded correctly. To find an indication of a learning curve, this test was performed five times.

When the test was finished, participants would be asked whether they felt more stressed by the mathematics test and whether participants enjoyed and understood the way was being communicated to them. They could answer these questions on a 1 to 7 likert scale, as seen in figure 30.

Lastly all four different designs would be quickly discussed and the participant would be asked which design they would like most, without actually having tested them all. Also would be asked how the participant would include the design in the IC environment, they would be thanked and lastly given a treat.

Results

All participants answered correctly when they received information via a written message (15 of 15 correct), zero mistakes were made. During the three other tests multiple mistakes were made. For a change in color 13 of 15 were answered correctly, for a sequence of vibrations 9 of 15 were answered correctly, and for a sequence of lights only 8 of 15 were answered correctly. Some participants kept waiting until an auditive hint was given. This happened 5 times during the color-test, 7 times during the flash-test and 9 times during the vibration-test. Only with the Written messages, a learning curve could be found through the response time (see the blue line in figure 31). The three other variables showed fluctuating results, and gave no indication of participants becoming faster.

Concluding

Through the questions afterwards it became clear that participants did not understand the sequences of either vibrations or lights. The results of the test also prove this.

What most participants said (10 of the 12), is that they would like to get their attention pulled by either a light or something, as long as it would not be too obtrusive but also something that can not be missed. A vibration or a flash (especially in a sequence) can easily be missed and the object to get your attention should give a more permanent view.

Most participants (8 of 12) said that they thought that a sequence of lights or vibrations would be easy to misinterpret. Only missing one of the three flashes or vibrations could imply a great difference in meaning. Therefore the most comfortable way of being notified was a change in color (8 of 12 participants). The easiest way was thought to be using a written message (6 of 12 participants). (for inspiration, figure 29)

Implications for the design

According to this research, the design should be a stationary design that can be 'read' in the glimpse of an eye, but also being something that can not be missed. A lamp that would be permanently on and changing color would be a good archetype to make something known about the auditory quality of the environment.

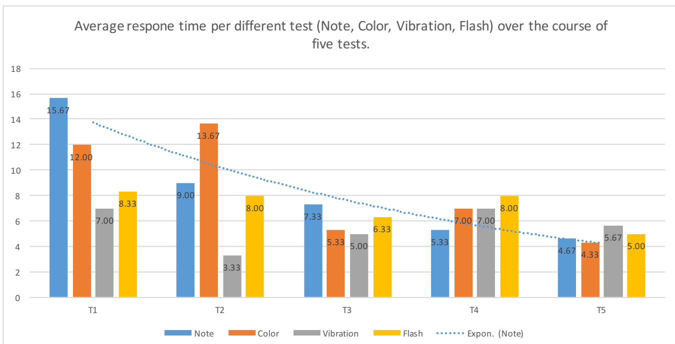
Furthermore, similar to how a notification on a phone can easily be missed, the idea of having a sequence of (portable) lights or vibrations was dismissed.

When a nurse would want to have more information on the 'why' the current state is the way it is, then they should be able to in some way obtain a written message with explanation.

Figure 30-31
Likert scale questions as asked during the research (left), and the results graph showing that only a written message showed a clear learning curve (right).

Questions afterwards

I enjoyed this way of being notified								
Totally disagree	1	2	3	4	5	6	7	Totally agree
I understood what was communicated to me								
Totally disagree	1	2	3	4	5	6	7	Totally agree
The way how was communicated to me was effective								
Totally disagree	1	2	3	4	5	6	7	Totally agree
A comminucation in the way I experienced is unpleasant								
Totally disagree	1	2	3	4	5	6	7	Totally agree
I had difficulty understanding what the design was trying to say to me								
Totally disagree	1	2	3	4	5	6	7	Totally agree
The experience was not enjoyable								
Totally disagree	1	2	3	4	5	6	7	Totally agree



Chapter 4: design continued

In this chapter will become clear why it was decided that the concept to continue with was the changing painting. Displaying content that was relevant was the next step to be determined. A video or images can have different meanings and interpretations depending on who is looking at them. Therefore it was important to have a strict set of guidelines of which visualisations are being experienced quiet, and which visualisations are experienced 'loud'.

Having mindfully chosen a concept which would display videos relating to the environment (the changing painting), it was deemed necessary to test what sorts of movies people relate to, and which visual aspects of videos cause this relation. In the end, the displayed videos should cause an emotion and create an intention to act upon the auditory environment (if necessary).

As will also be explained further in this chapter, the main determinant of a video being experienced loud or quiet is the hostility of a video, the more hostile a video, the louder it seems. To add clearer differentiation to a set of videos it is also possible to alter the color (darker is louder), alter the speed (faster is louder), or make changes in the clarity (more unclear/abstract is louder). All take-aways of this chapter are:

- Apart from being considered most interesting from the multisensory-understanding research, the changing painting also offers the biggest possibility of displaying multiple layers of information.
- Auditory display designs were translated into visual display designs, resulting in symbolic visuals to represent the auditory environment.
- Whether or not should be acted in the auditory environment is dependent on the environmental quality, and whether an emergency happened in the environment. A framework of four possibilities formed the alarm philosophy.
- Hostility of a visualization can be used to show the difference between a loud and quiet environment, color, speed and clarity can be used additionally to create stronger differences.
- Visualisations need to be semantically close to the auditory environment to be understood more easily.
- An HD screen offered the most advantages above other possibilities, and will therefore be used in the final concept.

Section 4.1

Concept choice: Layers of information

Each idea that has been elaborated upon so far, had something to do with an exchange of information. The way how information can conveyed best was found during research 2: visualisations with, when deemed necessary, a written explanation. In this section the concept that was continued with will be chosen.

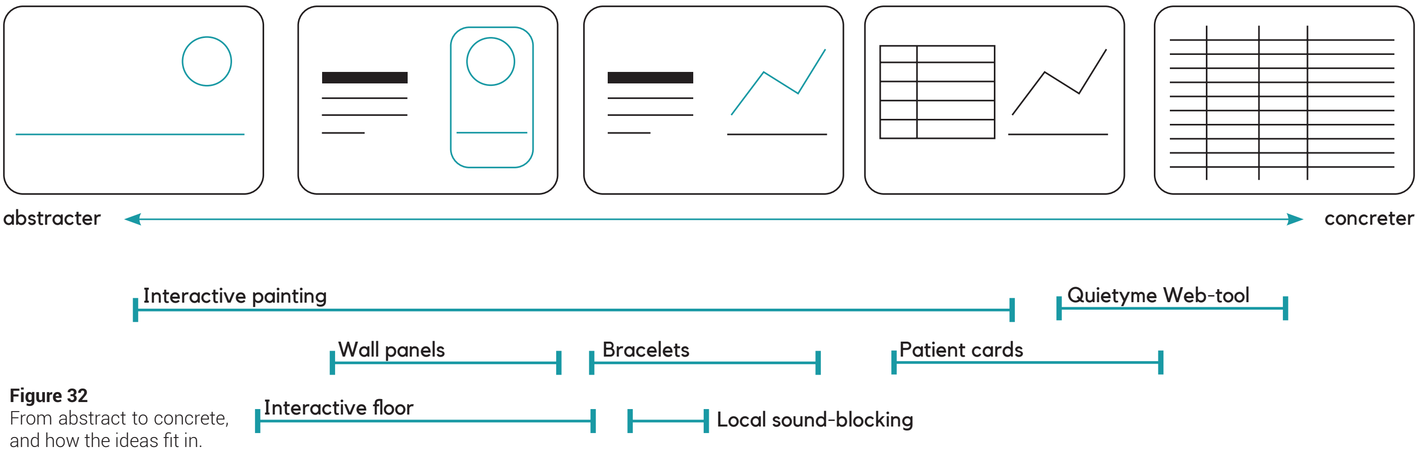


Figure 32
From abstract to concrete, and how the ideas fit in.

Understanding environmental information

Having to understand a lot of data, does not per definition have to be very complicated, but it should remain limited to prevent visual strain from occurring[26]. In this chapter will be explained what the different layers of information mean, and how they are found back in previous ideas. The most versatile concept is the picture frame, and the least versatile concepts are the local sound blocker and the bracelets.

If information is structured in different layers, it could become more explanatory[27]. A graph was made to show the layers of information that each idea conveys, with on the far edges the key-words 'abstract' and 'concrete (figure 32).

Abstract means that the difficult information, being graphs, tables and raw data, are being hidden from the user. Just a nice visual or video showing an analogy or metaphor of the current situation. For example, when a lot of people are coming by then an image of a busy street or a lot of birds could communicate that the environment is crowded.

Intermediate is somewhere in the middle between abstract and concrete. It is more informative than a picture of birds, but is nowhere near as informative as pure raw data. Lately a lot of simplification of data can be found in infographics and similar visualisations of data that are otherwise non-understandable data. Stating 1,5% of the population is difficult to interpret, but when it is stated as 'three people in a completely filled theatre', then all of a sudden the data is understandable.

Concrete is the pure data side. Facts and numbers directly derived from measurements is all there is, often showed in tables related back to a certain time. This information is the most factual, but also difficult to understand if you know nothing about the context. If over a certain time the SPO2 rises from 95 to 99 and then drops to 92, for nurses it is very clear that the oxygenation of blood is quite unstable. But to someone who has never heard about the term SPO2, these values are meaningless and difficult to grasp.

Concept choice

Onwards from the ideation phase, a selection into concepts was made (figure 33). Depending on the amount of information they could convey compared to what sort information the design should convey.

As found in the first user research, it is necessary to have a direct feedback. Whereas first was tested with only a change of color to gain attention, this could be taken a step further. Therefore the interactive painting and padded wall panels seem like potential concepts. Both are, after a bit of learning, clearly explaining everything there is to know about the sound environment.

The patient cards are a too direct approach, and is probably too close to the original problem with not much of Industrial Design to them. Not looking very inviting and still showing very static information, it is probably best to not pursue with this idea. Similar goes for the local sound blocker. This idea is not suited within the scope of this project as it is not aimed at altering the nurses behaviour. The idea only takes the unwanted sounds away, which could make nurses even noisier or more careless. The interactive floor has only one layer of information, and with being such a big surface it is difficult to create an individual experience or interaction with it. Furthermore would this design have rather extensive consequences for the environment which has only newly been built and opened. That is why also will not be continued with the Interactive Floor idea.

[26] Woods, 2005. *Musculoskeletal disorders and visual strain in intensive data processing workers*

[27] Dunlop & Reid, 1998. *Exploring the layers of information retrieval evaluation.*

Even though bracelets would not be accepted within the Intensive Care context due to hygiene and cleanability, the idea itself of always carrying a notification system with you seems pleasant and interesting. Nurses carry around their pagers almost everywhere they go. Having an add-on to such a device seems more feasible and might make nurses more mindful whenever they look at their pager. With the goal of quieting down as a team, however, this idea was dismissed.

The final decision was to continue with the changing painting. It offers proper visual feedback and has the possibility of displaying multiple layers of information. The different designs were also discussed with a group of nurses during a presentation, which resulted in a similar outcome. The main reason why nurses liked it so much because it has direct feedback, you do not have to go to a website anymore to see how you did, from everywhere you are in the IC you can now understand the sonic environment (personal contact with nurses, 2018).

Patient cards placed next to the door of each box are rather concrete. Even though a smiley face expresses the current situation, the most important aspect is the very direct feedback about the three factors contributing to sound pollution. Via three bars is explained how loud the different factors have been. When a bar is full it means that for that factor people should definitely be more mindful.

The interactive painting normally shows videos of sceneries depending on the auditive environment. This makes the concept in itself abstract. However, as the display changes upon approach to more detailed information, this idea also has a more concrete information layer.

The nurse bracelets always stay a bit on the abstract side by using colors, icons and facial expressions (emoji's) to explain the current situation. With a screen around the wrist being quite small, there will never be displayed a lot of raw data or graphs.

The LED wall panels show one consistent layer of information, the one that is constantly visible. Three waves divide a 'glass bar' into compartments. The total amount of filling shows how loud the environment was and the thickness of each layer shows how much they contributed. If a section is showing heavy waves, that means that it is measured a lot at the moment.

The interactive floor consists our of screen-blocks like a disco floor, and shows softly illuminating where more sound was produced over a past specified amount of time. This one-layer design shows information in an intermediate way. There are no hard numbers displayed, but the coloured glowing blocks are more direct than a changing painting.

A local sound blocking device delivers virtually no information, it actually takes it more or less away. Apart from the uncertainty if this design would actually work, is also conveys very little information. It could display bars similar to the patient card, but it is questionable whether these would show accurate data as some sound is taken away.

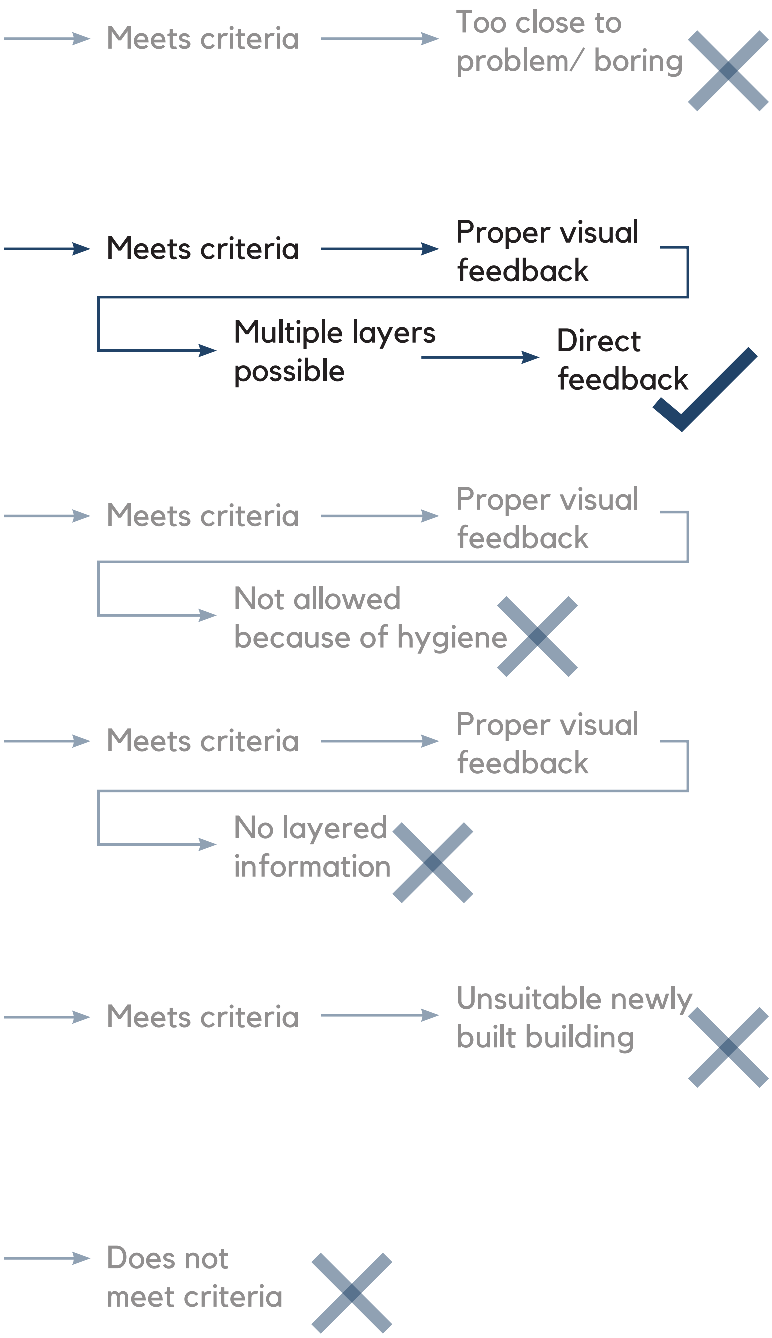


Figure 33 Rating ideas to lead to a concept choice.

Section 4.2

Alarm philosophy

As described by Özcan, van Egmond and Favarts study[28], there are three different Auditory Display Designs: Speech, Abstract Sounds and Auditory Icons. Auditory Display Designs can be translated into Visual Display Designs. These self-imagined translations show how something auditive can be used as a visual.

Speech, abstract sounds, and auditory icons explained and translated.

Pleasure in the concept
The previously mentioned pleasure needs to be light and airy, so that nurses want to keep using Doplor. Awaring nurses of their loud behaviour is a negative loaded task and therefore the Doplor needed to feel light, optimistic, and friendly. This implied that the design should be both responsive and informative, but that it also should be fun to look at and create a certain holiday feeling.

[28] Özcan, E., van Egmond, R.,Gentner, A., & Favart, C. (in press).

[29] Backes, Erdman & Büscher (2015). *The Living, Dynamic and Complex Environment Care in Intensive Care Unit.*

Speech can best be translated as a video tape of what you did, shown back to you. The term speech, in an auditory way, is the most intuitive and direct way of communicating a message, with little ambiguity[28]. Other sorts of Abstracts sounds (also called ear cons) do not refer to any existing event with their acoustical construction, they need to be learnt in context[28]. An alarm provided by a microwave or clock are examples of such abstract sounds. When translated to Visual Display aspects, these could be a colour change, flashing lights, vibrations or a temperature shock.

Auditory Icons are sound between speech and abstract sounds. They are representational sounds that refer to real events in both their acoustical structure, but also through their semantic associations[28]. The 'whooshing' sound when you send an e-mail (like a paper plane), or the sound of crumbling paper when you empty the trash bin on your computer are examples of auditory icons.

If Auditory icons are translated to Visual icons (figure 34), a lot of resemblance can be found with the vision and goal. Metaphors, forecasts, symbolic video's or photos, changes in shapes and a trophy or ranking system are all examples for a Visual Display Design. Due to the great resemblance between the responses from the how-to booklets ("how to visualise sound levels?") and the translated Visual Icons, it was chosen to continue within this field.

Visual pleasure[28] has been proved to be an positive stimuli on the utilitarian function of a human-product interaction[28]. Keeping in mind that nurses want to belong to their team[16] and that the IC is too hectic the way it is now[29], it shows that it makes sense that the design should be visually pleasurable. Like going with a team of colleagues to a museum, Doplor will provide a part of the daily art in a nurses hectic workflow, for all nurses to be informed.

auditory display	visual display
speech	candid camera
	gestures
	written message
abstract sounds	color change
	flashing lights
	vibrations
auditory icons	metaphors
	symbolic photos
	changing shape

With symbolic visualisations, Doplor will resemble the visual brother of auditory icons the most. It could very well be possible that metaphors or a change in shape would be added as well, but this would have to be tested further.

Figure 34 Continuing with a 'translation' of auditory icons, as these get the closest to actually showing an artwork.

The alarm philosophy.

Whether or not should be acted by nurses and whether the design thinks the auditory environment is suitable enough for the IC can be called the Alarm philosophy. This philosophy, as also can be seen in Figure 35, consists out a total of four states.

The first question of the philosophy is whether there should be acted (on the noise production) or not. The second question is about the (sound) environment's quality, whether it is good or bad.

If the environmental quality is good, and there should not be acted, that means that everything is okay (upper-left square). The sound levels in the environment are sufficient and it seems that in the near future the forecast will not change (there are not much noises at the moment).

If the measured environmental quality is good, but a lot of noises are currently appearing, then it becomes key to worry a bit about the sound (upper-right square). This is the case when for a longer time the environment was fine, but for example a lot of noises appeared the past few minutes.

When there are a lot of noises, but also the environment was monitored being bad for the past time, then nurses should worry a lot about the sound (lower-right square). This could be the case when alarms have been going of for a longer time, and nurses were still talking loud in the corridors.

Lastly there is the case of an emergency. The Intensive Care is the area where patients are moved in when they are in a critical state. It comes as no wonder that, when a patient is rolled into the IC, nurses rush towards the patient trying to help the best as they can. This makes sound, and that is okay. Saving a patient's life is obviously prioritised over the sound environment. That is the fourth state. The environment is being measured badly, but there is no need to act, hence there should not be worried about the sound (lower-left square).

The first tests that were performed were only about the two extremities (where the sound is all okay, or where a lot should be worried). By first looking at these extremities, it would be easier to test as big differences could be made between visualisations.

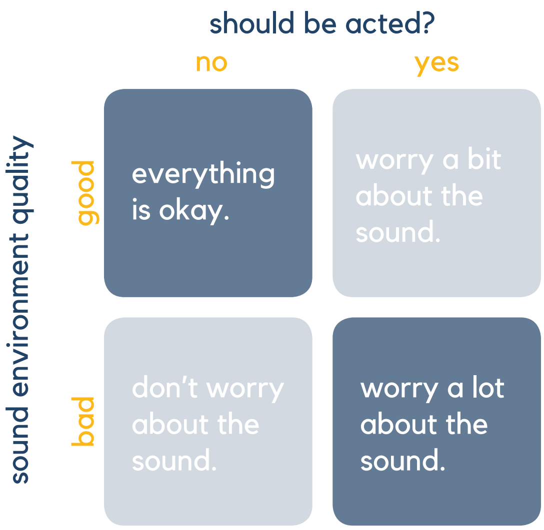


Figure 35 The alarm philosophy consisting out of a total of 4 states.

Section 4.3

Research 3: Visual characteristics

The third test was to understand what visual characteristics can be used to make a visualisation be perceived either loud or quiet. Hostility is the major determinant making a video being perceived 'loud' or 'quiet'. Clarity, Color and Speed can be used to enhance the differences.

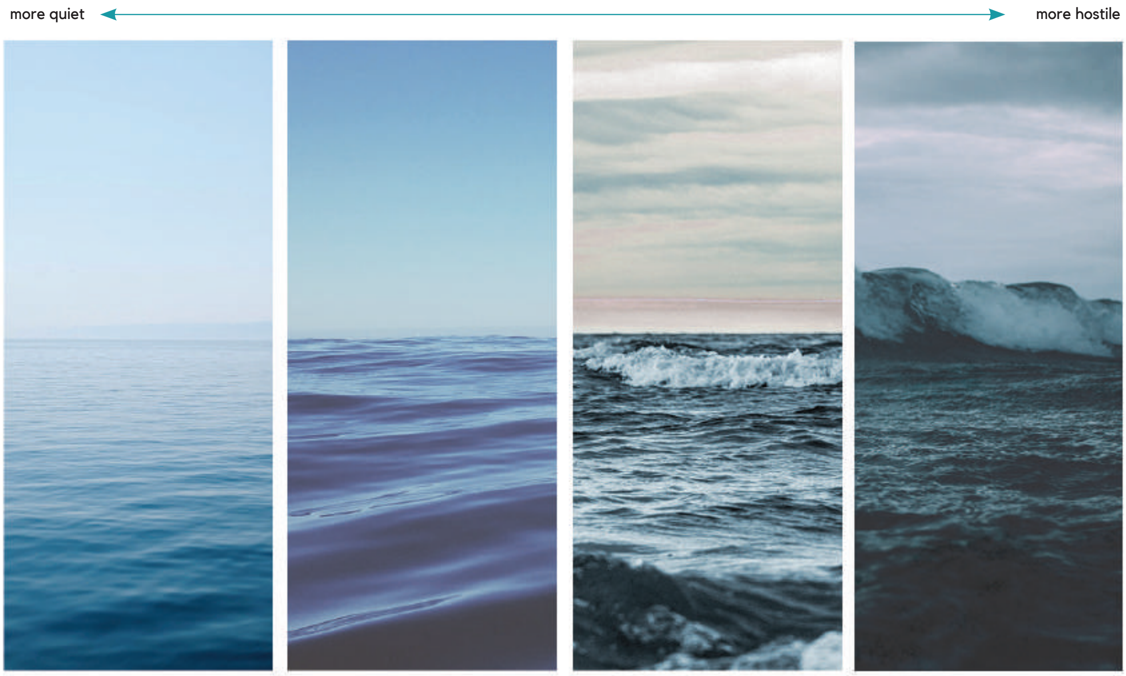


Figure 36 The most apparent hypothesis that was made was that the hostility of the sea would be directly related to waves (and thus sound waves), meaning that more waves would be presented in a louder environment.

Test set-up

The changing painting will show visualisations to nurses to give them collectively information about the auditory environment. However, if the nurses perceive a visualisation as a 'quiet' environment while the painting actually tries to say that it has been loud over the past time, then there has been a miscommunication. To prevent such miscommunications from happening, this test was performed, and a list with visual characteristics was created on which visualisations could be tested.

All visualisations are a combination of visual characteristics (figure 37), some are always there, others can be implemented. Color, shape, form, context, style and subject matter were characteristics found through Ozcan, van Egmond, and Favarts study[28], but there were more. Distinctiveness was found in McDougall, Curry and de Bruijn, 2000. Concreteness, Complexity, Semantic distance and Familiarity were found through Isherwood, McDougall, and Curry, 2007. Apart from all these terms there are also more general characteristics: Contrast, Visibility, Sharpness, Light Intensity, Speed and Atmosphere.

Not all variables are equally easy to manipulate in visualisations, therefore was chosen to continue with only six visual characteristics that have a clear definition and are easier to manipulate in readily available royalty free visualisations. These characteristics were: Style, Context, Speed, Color, Clarity, and Subject Matter. Definitions of these characteristics can be found in the sidebar on this page.

Independent variables	Dependent variables
Style	Meaningfulness
Context	Activation
Speed	Awareness of change
Color	Enjoyment
Clarity	
Subject Matter	

Figure 37 The independent and dependent variables

Style is defined in this study as the amount of abstractness of a video. Some videos are very clear (e.g. cars in a street), but other videos are further from reality (e.g. lines and dots)

Context is defined as the hostility of a movie (figure 36). In the original example of the sea, this hostility is reflected in the size and fizziness of the waves.

Speed is referred to as how slow or fast an animation is played. It is assumed that a slower video reflects a tranquil environment and a hasty video reflects a noisy environment.

Color is defined as being either easing or urging. Darker colours express feelings of anger, hostility and aggression (Valdez & Mehrabian, 1994), thus being expected to be urging to act. High brightness combined with low saturation colours, or simply lighter colours show lower levels of arousal and dominance (Valdez & Mehrabian, 1994). These lighter colours are hence expected to be less quickly acted upon.

Clarity means how visible a video is, relating to the amount of understanding what is being communicated. The clarity of a video is determined by how blurred (or fuzzy) a video is presented. Heavily blurred videos show a very easing image, while very sharp videos can be perceived as being demanding and obtrusive (depending on the content and hostility).

Subject Matter relates back to the environment that is created and presented by a video. Cute or subtle videos lack urgency and are probably less likely to be acted upon. Explicit or violent movies are more urgent and discomforting, making people more likely to become more aggressive and active (Leyens & Dunand, 1991)

Method

Meaningfulness is defined in this study as whether nurses/participants understood the relation between the video-set and the auditory environment.

Activation is whether participants expect themselves to want and act in the environment.

Awareness of change is whether participants saw a clear difference between two visualisations, and also whether they expect themselves to notice the difference with ten minutes in between.

Enjoyment is purely for informational purposes, asking whether participants enjoyed the videosets.

Two tests of ten video-sets each were made. Each video set would show a differentiation in one of the six visual characteristics. The complete scheme can be found in Figure 38, some sample images in Figure 39, and to see snapshots of all accompanying videos, please visit Appendix 15.

After each set of videos (one presumed 'looking loud' and one presumed 'looking quiet') the choice would be given to the participant asking which one is perceived representing a loud/hostile environment. Then the following questions would be asked, expecting an answer between 1 and 7 (Likert scale), how much the participants agreed with the statements:

» I quickly understood the relation between the video and the environment
» This transition in videos made me want to act in the environment
» I properly noticed a change between the two videos
» I expect I would notice this change in videos if I would not watch the screen for 10 minutes
» I enjoyed watching this videoset

These questions followed the dependent variables closely: Meaningfulness, Activation, Awareness of change, and Enjoyment. The baseline in the responses was the grade 4 (not agreeing, not disagreeing), a 1 represented *I totally disagree* and a 7 represented *I totally agree*. All answers were put into an SPSS datasheet for conducting an one-way ANOVA. The ANOVA was used to test whether the different visual characteristics were differing in means, meaning that they would have a different impact on the perception of the participants. The following hypotheses were set up:

H0: The different visual characteristics do not differ from each other.

H1: The different visual characteristics do differ from each other.

	Test A	Test B
Style	Land	Ripples
Style	Paint	Sheep
-		
Context	Clouds	Coffee
Context	Sea	Traffic
-		
Speed	Fire	Cherries
-		
Color	Aerial	Bokeh
Color	Traffic	Leaves
-		
Clarity	Ducks	People
Clarity	Leaves	Sea
-		
Subject Matter	Animals	Kaleidoscope

Figure 38 Table showing which group of participants got shown which visualisation.

Results

Color is in itself not a strong enough characteristic to explain auditory quality, but it can help in understanding speed better. Deeper darker colours are experienced with a loud feeling, making object movements more hostile. Bright and light colours are contrasting. These gave movements a more quiet and serene appearance. This conclusion is strengthened by the findings of Valdez & Mehrabian[30], where similar results in color studies were found. The results have also been visualised in Figure 40.

[30] Valdez & Mehrabian (1994). *Effects of Color on Emotions.*

When a change in speed and color are presented simultaneously, most participants (7 of 8) focussed initially on recognising the speed of movement, in which the color only played a minor influence.

Perspective was not taken up in the visual characteristics in prior research, but multiple participants (3 of 8) explained that they thought that a dramatic (flight) perspective was perceived more negative (loud) than an eye-height perspective (being perceived quiet/manageable).

Unclear images, and especially pixelated images, were often found negative, discerning and disturbing. Multiple participants indicated that they would gladly start acting to get rid of the pixelated and blurred movies.

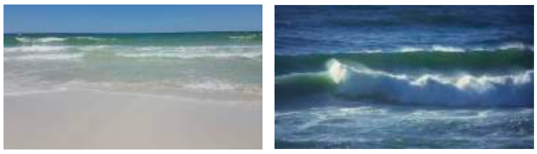
A difference in content (hostility) and a bit less strong in style (abstractness) have the greatest influence on understanding the relation between a set of videos and the 'loudness' of an environment they express.

The hostility is the preferred characteristics in a movie leading to action, whereas speed, color and abstractness are added factors helping users distinguish between a 'loud' and 'quiet' visualisation.

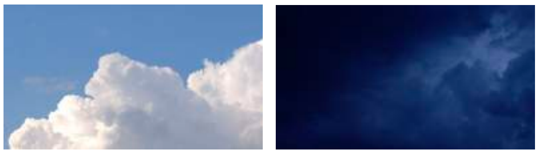
Subject matter has very little influence, as none of the visualisations were rated on the content by the participants. When asked, all participants indicated that they only looked at the hostility of a video, whereas for example the difference between a cat and lion did not matter to them. (In this videoset the cat made rougher movements than the lion.)

Quiet visualisation | **Loud visualisation**

Videoset A-8 A difference in clarity



Videoset A-4 A difference in hostility



Videoset A-3 A difference in speed and color

Videoset B-7 A difference in color

Videoset B-4 A difference in hostility (and untested perspective)

Figure 39 - right Screenshots of different videosets used in the research.

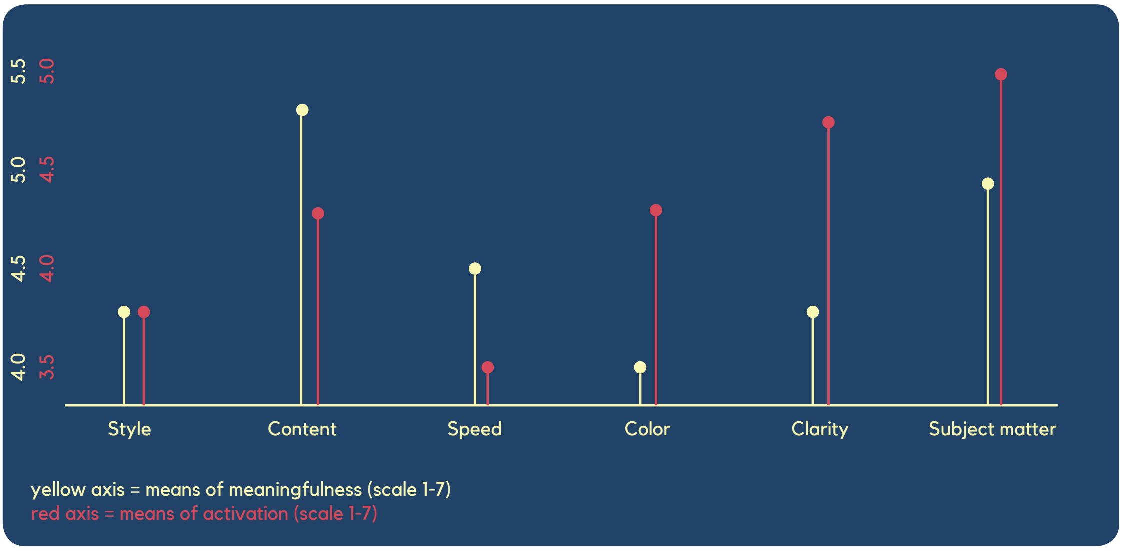


Figure 40 Results of the means of meaningfulness and activation on a 1-7 scale for the six different dependent variables.

Semantic distance

Simultaneously tested with research 3, was how semantic distance altered the means of understanding a set of visualisations. This resulted in an understanding that visualisations are better understood when the semantic distance is small (close to the auditory environment) than when the semantic distance is far off from reality.

Semantic distance can make a difference in understandability and functionality of a set of visualisations. Similar to music having different genres, a video can have many different styles. It can be photorealistic, drawn, animated and so on. One visualisation might be much easier to understand than the other, and that might be very dependent on the style in which a video is presented. As also can be seen in figure 42.2 and 42.3, both a abstract and a realistic visualisation can show a clear relation to the sonic environment. However, when a videoset as displayed in figure 41.1 is shown, the distinction is less clear.

When the experiment took place, one part of the test was to see how people reacted with the two videos as once again can also be seen in figure 42.1. When shown, participants did not really know or see what the difference was and they started looking for indications which weren't there. Answers to the question 'which one do you think was louder?' had with every participant a different redenation.

Whereas one participant concluded that it might be the perspective, the other said it was a difference in the color, and a third participant would think it is how close the camera to the coffee machine was. It seemed that visualisations should remain rather close to the auditory environment to be still understandable to users (as can also be seen in figure 41).

Conclusion

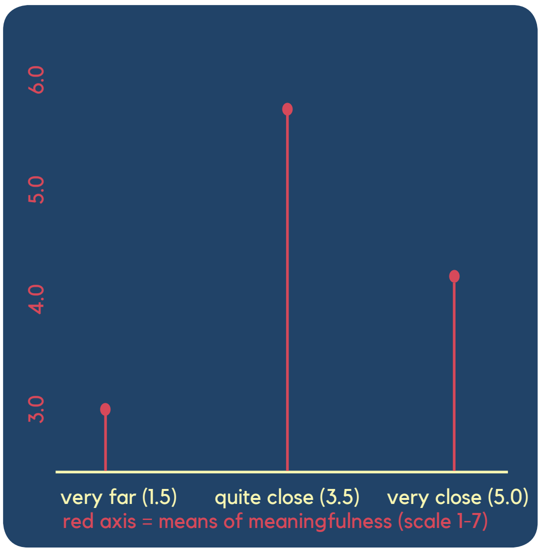
How far a videoset is semantically from a sonic environment is mainly dependent on the visual characteristics that are further included in a visualisation. It is those characteristics that create a certain level of relation to audio. When the distance is far, people can not relate videos to audio, whereas close videos are easily understood.

The most important determinants of whether a video is perceived loud are the visual characteristics. The major determinant is the hostility of a visualisation, where color, clarity, and speed can be used to create enhanced differences.

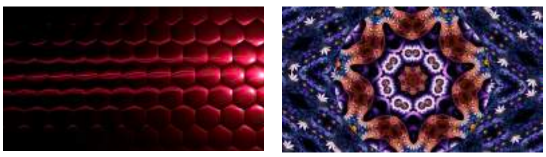
No clear relation to differentiation in subject matter was found, but effects might be found in the distance from a camera to an object, and the perspective. Further testing is advised to see whether these contributors also create a significant effect.

Figure 41 - left Visualisation sets with a closer semantic distance are rated being more meaningful, than ones being considered distant.

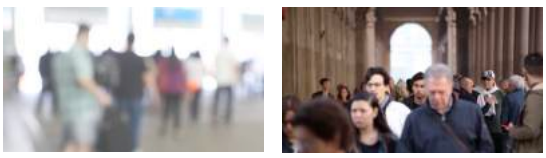
Figure 42 - right Video-sets with a difference in their semantic distance to the auditory environment.



Videoset 1 A very distant semantic distance (SD = 1.5)



Videoset 2 A closer semantic distance (SD = 3.5)



Videoset 3 A very close semantic distance (SD = 5.0)

Section 4.4

Choice of Screen

An HD screen is best suited to show all necessary information as desired in an interactive painting. A clarity in visual characteristics was made, so then the next question that arose was: 'on what sort of screen should these visualisations be displayed?' Results of this study can be found in figure 43.

Initially it was expected to test once again the meaningfulness of videos when they would be displayed on different screens, but this was later on considered to be too time-intensive for the final result. A conclusion on the question was therefore derived from the pros and cons for the different possibilities, and some logical reasoning.

An LED-matrix inevitably shows very low resolution images, as were also tested in the previous test. Having such 8-bit style images either make people reminiscent of The Sims, and made most people anxious (due to the flickering of colors) and agitated/disturbed because it remains unknown what really is displayed and what it means.

The way how a low resolution image worked was when it was contrasted with a high resolution image. People want to get rid of the pixelation as they like the high resolution images better (6 of 9 participants). As displaying high resolution images with an RGB-LED matrix is not possible, it was chosen to continue with an HD screen.

Figure 43 Table describing the pros and cons of different methods of displaying video. An HD panel was found to be most suitable.

	HD/IPS panel	LED matrix	Screen behind art	Beamer
Pros:	Looks pretty and realistic Proper explanation through text possible Endless possibilities of what videos/ visualisations to show	Retro style Much cheaper that HD panels Easy to assemble	A unique and very artistic look, can be an actual painting Within the limits of having a still immovable image, still a lot of possibilities	Easily scalable A bit cheaper than a HD panel (of very high quality)
Cons:	Photorealistic rendering is difficult and tech intensive Energy consumption	Unsuitable for showing detailed graphs, or anything detailed at all. Not possible to display text White can become headachy as it is made up of three not very well blended colors	Print is always there, could become less exciting over time Impossible to show main contribuants of sound pollution in ghraphs or text.	Not dimmable Difficult to see in light areas Too bright at night Low resolution (or very expensive) People in front create a shadow Buzzing noise due to fans

Chapter 5: Doplor

The interactive painting will be called Doplor, reminiscent of the Doppler effect. It is a design that reminds you of a picture frame, but it has much more possibilities of interacting with.

The beginning of Doplor started at the phase of a changing painting. Through the research about multi-sensory understanding, it turned out that this painting should also be interactive. More functionalities were added, so that Doplor included quietyme sensors and showed visualisations based on the environmental quality, and in the end became a comprehensive product. As all information was scattered over different chapters, this chapter is solely going through all functionalities and characteristics of Doplor once again. All of the following characteristics will be discussed:

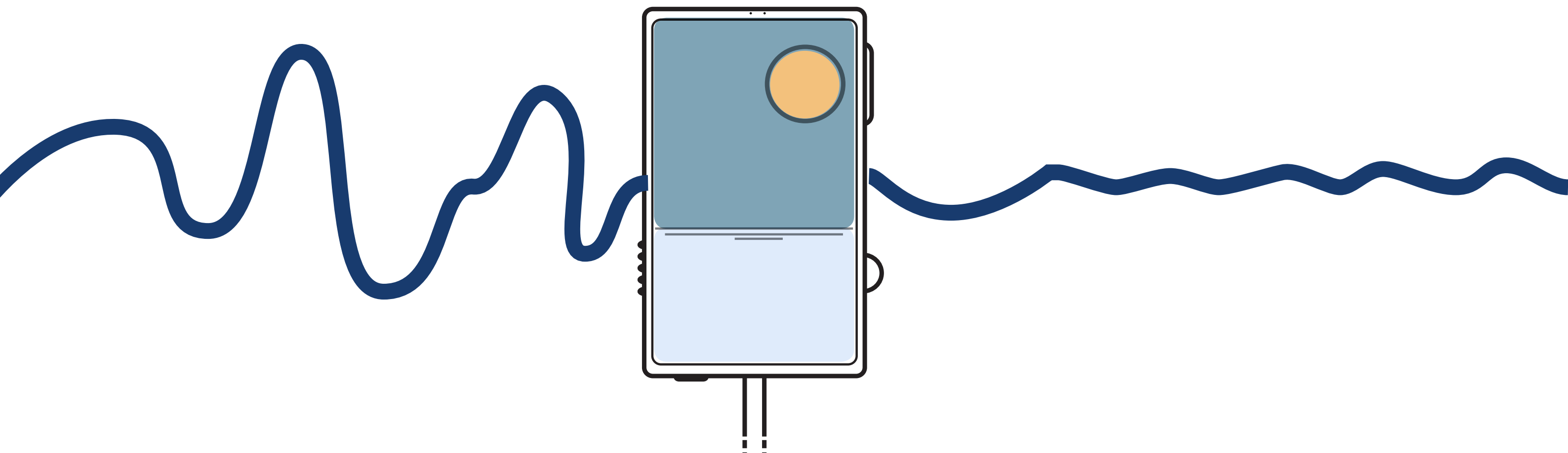
- The name Doplor comes from the similar sounding Doppler effect.
- Doplor goes through a closed system (flowchart) to continuously display relevant information.
- Doplor reminds you of a picture frame, and yet it has much more functionalities.
- Doplor listens to the environment and displays it as a symbolic visualisation.
- Doplor is envisioned to silence the Intensive Care.
- Doplor recognises when you walk up to him.
- Doplor is secretly still painting, that is why interaction with it is like repositioning a real painting.
- Doplor understands what the causes of sound pollution are and helps thinking with the user how to solve the noise.
- Doplor prioritizes patient safety over sound quality.
- Doplor has especially designed visualisations.

Section 5.1

Doplor. Where does the name come from?

The name Doplor might sound familiar, and it is not strange that it does! The name Doplor comes from the Doppler-effect, where a sound from an ambulance is perceived pitched higher and faster when an ambulance approaches you, while the sound becomes slower and softer when it has passed.

It was chosen to use the name Doplor as a similar result after the usage of this device was envisioned. Whereas now nurses are trying to be more silent, the IC environment is still quite loud and hostile. As Doplor is introduced, I believe and envision that slowly all loud sounds will fade away, just like when the ambulance passes by.



Section 5.2

Doplor his way of working

Design flowchart

A lot of (electronic) designs have a flowchart that they follow. This basically means that a product measures, and flowingly evaluates what the measurement implies and how should be acted depending on a certain variable. Different measurements can imply different results. For example, an oven is set to 200 degrees. If the heat sensor measures 140 degrees, the heating element is kept on heating. If the measurement is somewhere between 195 and 205, the heating element will be stopped.

The same goes for Doplor. The design will measure the surrounding sounds and will evaluate whether these are within the limits, given the time of the day and what the sound quality has been like for the past time. Either way, the result will be communicated to the users. Then, if the system notices that someone is close, it will indicate what the different key-players in the contributions to the sound quality are. The system will always return to it's zero-state, measuring sound in the environment. See figure 44 for a complete overview of the system.

Doplor always communicates something, no matter at what point of the flowchart. The information being displayed however continuously changes 'shape'. As introduced before: when in a loud environment Doplor shows a more hostile visualisation than when in a quiet environment.

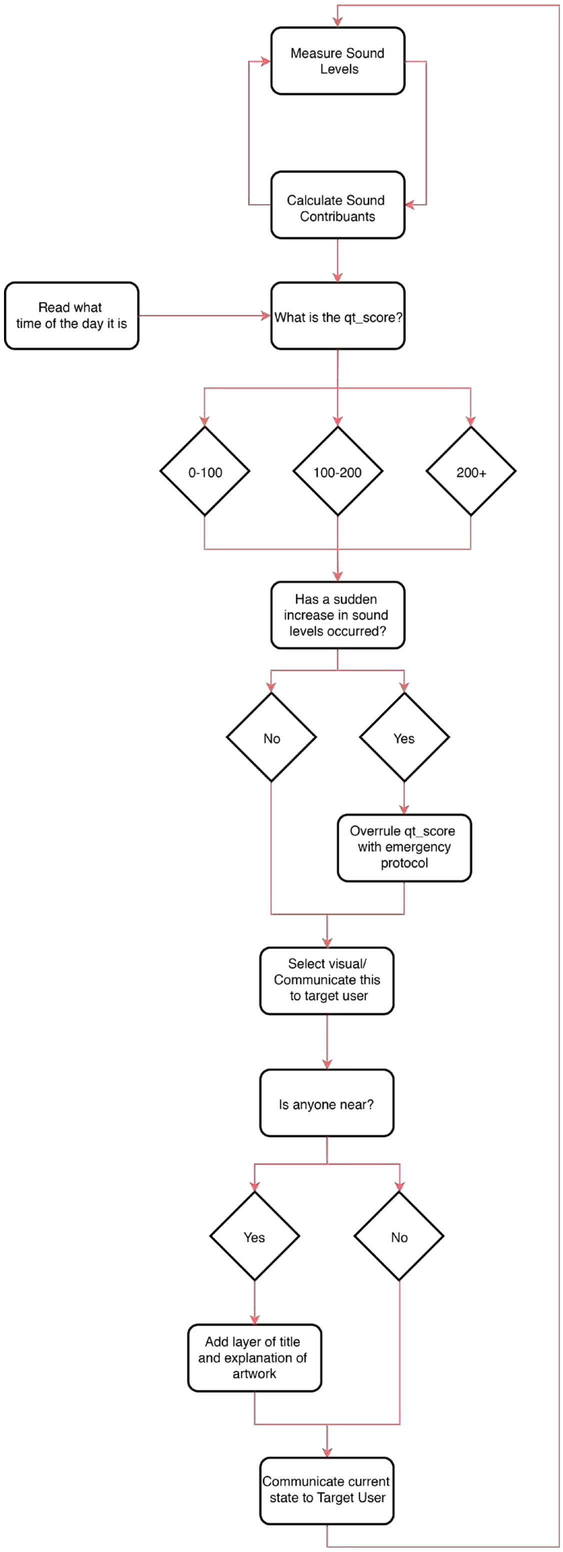


Figure 44 The flowchart that describes all functionalities of Doplor.

Section 5.3

Understanding Doplor's appearance

Doplor is a device that will be hung on the wall, like a picture frame. And even though Doplor might look a bit futuristic and advanced, Doplor still tries to resemble a picture frame. Interacting with him feels like repositioning a real picture frame, and Doplor mainly shows art, but then related to the auditory environment.

Different functionalities of Doplor have come by, but in this chapter will all of them come together in one design.

Doplor started as the drawing in figure 45, a screen which offered the opportunity to be interacted with. Slightly reminiscent of a painting, but then with a few extras.

The screen was intentionally envisioned to become 17.3 inch, as these could easily be gained from refurbished laptops, which could give Doplor an environmental friendly approach. However, when prototyping started, a 17.3 inch screen seemed to be a bit small to be used in the Intensive Care, as the new IC was quite spacious.

Luckily the opportunity of using refurbished screens remained, but then with 21.5 inch monitors as used in our faculty. A lot of these monitors have either a defect LCD panel, or a broken electronic circuit, but combining them easily creates a fully functional screen again.

When taking a closer look at Doplor, four clearly different but related functions can be found: Doplor listens[31], Doplor responds[32], Doplor understands[33], and Doplor prioritizes[34].

The main components facilitating the use of Doplor (as also shown in figure 46 and 47) are:
1 - The on and off button
2 - The scroll wheel
3 - The quietyme sensors located within Doplor
4 - The proximity sensor
5 - The button at the side

Doplors total size is 500 mm high, 300 mm in width and approximately 35 mm in depth. Figure 47 gives a general overview of the concept.

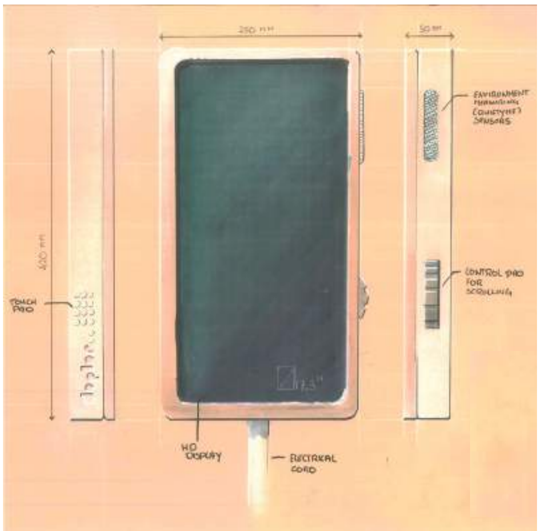
As will also be explained in chapter 6, a prototype of Doplor was made to test it;s functionality and appearance. This would initially run on Max MSP (a visual type of coding and prototyping) and was later coded in Processing (Javascript based coding program) to be more representative of an actual coded product.

[31]**Doplor listens**
Doplor listens to the environment using Quietyme sensors. Environmental factors being measured are light intensity, temperature, humidity and decibels. Every second a packet is sent to the router connected to all Doplors.

[32]**Doplor responds**
When you walk up to Doplor, Doplor responds in showing you the tile of the visualisation currently shown, and also tells in a positive way what the visualisation communicates.

[33]**Doplor understands**
Doplor receives streams of data as calculated by Quietyme's algorithm. Depending on the different results, Doplor displays an animation representing the measurements, and thus the auditory quality of the past 60 minutes. When Doplor displays a loud visualisation, the user can touch the button and scroll wheel at the side, making an infographic appear.

[34]**Doplor prioritizes**
Doplor prioritizes patient safety over auditory quality, that is why the alarm philosophy was introduced. When Doplor all of a sudden notices a lot of sound, 'loud but okay' visualisation will be displayed.



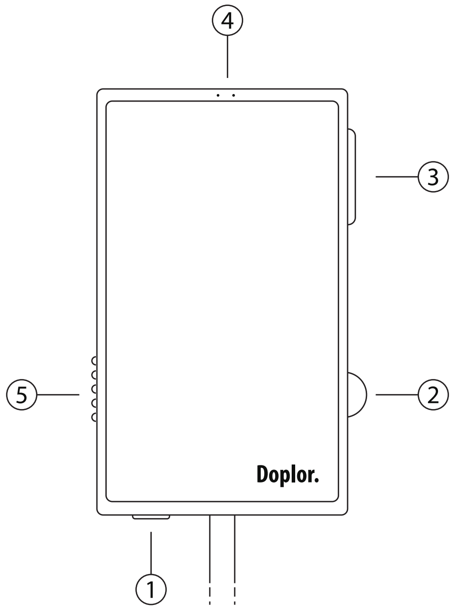


Figure 45-46 Doplors first appearance in an ideation drawing, and an illustration showing all main parts of which Doplor consists.

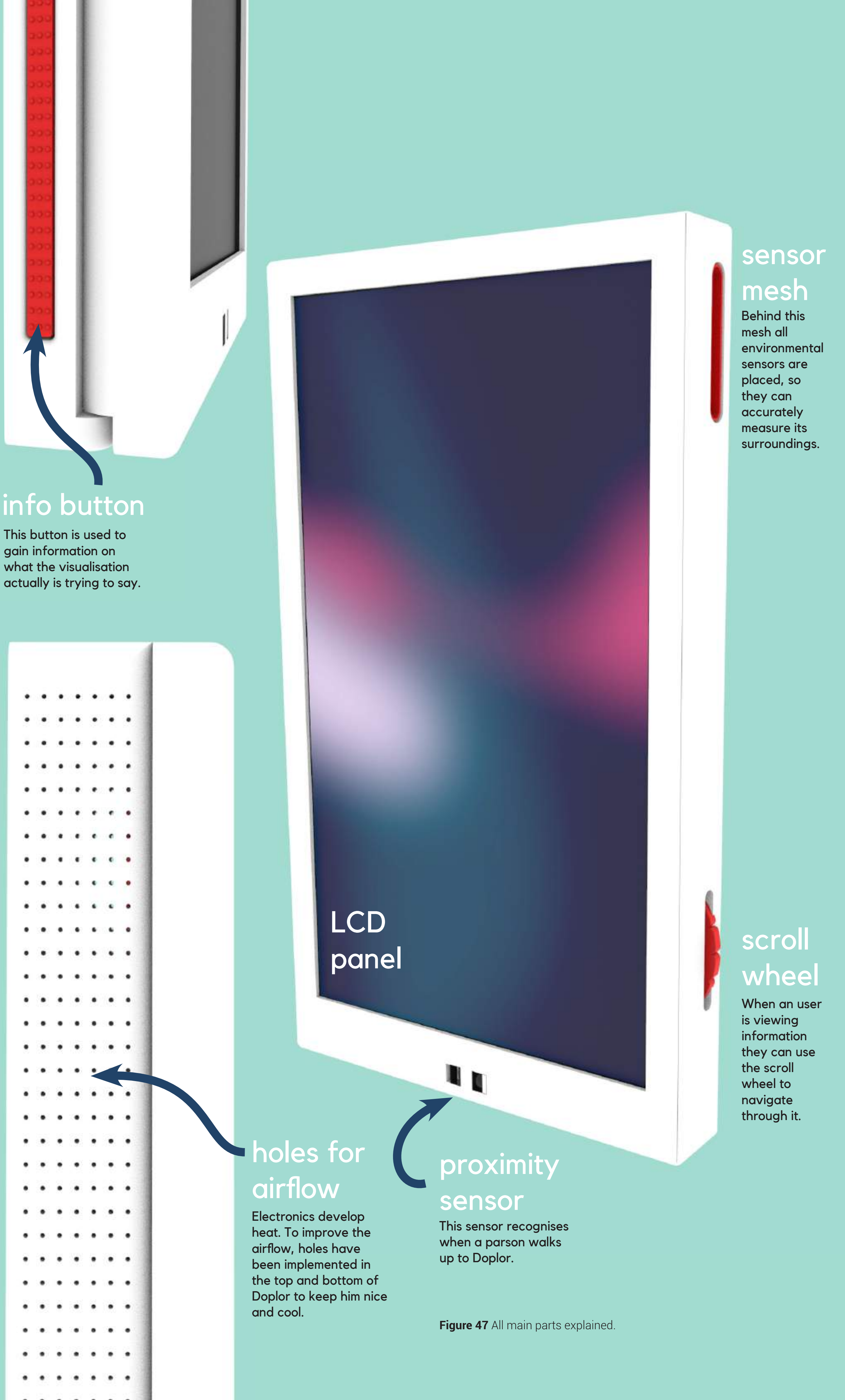


Figure 47 All main parts explained.

Section 5.4

Doplor listens

The first and foremost functionality of Doplor is that it listens, it measures decibels, sends them for calculations to Quietyme, and keeps track of the trend of all noise over time.

[35]**Quietyme Sensor**
Quietyme sensors have a lot of sensors, but the three most important ones are indicated underneath. The microphone measuring dB, the humidity sensor and the light intensity sensor.

Quietyme sensors as currently found in Quietyme's own devices[35] are implemented at the side of Doplor, behind the sensor mesh. Doplor will receive an almost continuous stream of data with all sorts of different meanings (as described in table 2), which has to be placed in the right place in the software.

This data stream has among others the qt_score in it. This Quietyme score is a numerical representation of the loudness of the environment. In silent areas it often floats somewhere between 0 and 200, and when environments get louder, the scores rise higher up to 600 or sometimes even higher. Doplor recognises the QT-score and decides which visualisation to display directly on this score. All visualisations that are being used for Doplor have been self-designed. They will be highlighted later this chapter in section 5.8.

All values that are sent through, were decided by Quietyme and the way they process data, apart from time, proximity, and target_level. These three are locally generated and calculated by sensors directly attached to Doplor.

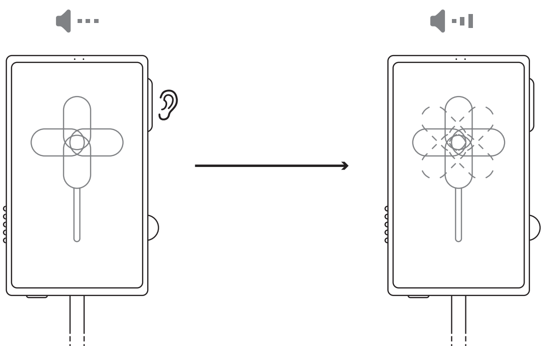
After the values are received, Doplor calculates them to decide what visualisation to display (figure 48). The decision in the prototype for what visualisation to display is based on the height of the qt_score. The qt-score is represented as a slider, this takes directly the value of it's input. Then, dependent on the qt_score it is decided whether the quiet or loud visualisation is displayed.

If the qt_score is below 200, the quiet visualisation will start playing. If the qt_score is above 200 then the loud visualisation will starts playing. This prevents Max MSP from running two videos simultaneously.

Each output is then connected to a 'start-stop' system which makes it possible to either start or stop a video (figure 49). The metro 50 acts as a setting for the framerate, making sure that a video refreshes every 50 ms, thus creating a 20 fps framerate.. The output of this list of functions goes to a visualiser, creating the visualisation on the LCD panel.

hour	the hour of the day of which the measurement is summarised.
qt_score	the quietyme score. An abstract number that is an calculation of the different lengths and amounts of auditory disturbances.
max_level	the highest measured value in dB
min_level	the lowest measured value in dB
nt_alarms	the cumulative amount of alarms rang
nt_alarms_duration	the cumulative length of alarms in seconds
nt_talking	the amount of conversations held
nt_talking_duration	the cumulative length of conversations in seconds
nt_spike	the amount of auditory interruptions (interaction sounds)
nt_spike_duration	the cumulative length of alarms in seconds
time	the current time of the day
proximity	the proximity of a user to Doplor
target_level	the target level wich is desired at the current moment of the day (average of qt_score of the past week)

Table 2
All different values that are being received by the main processing unit of Doplor.



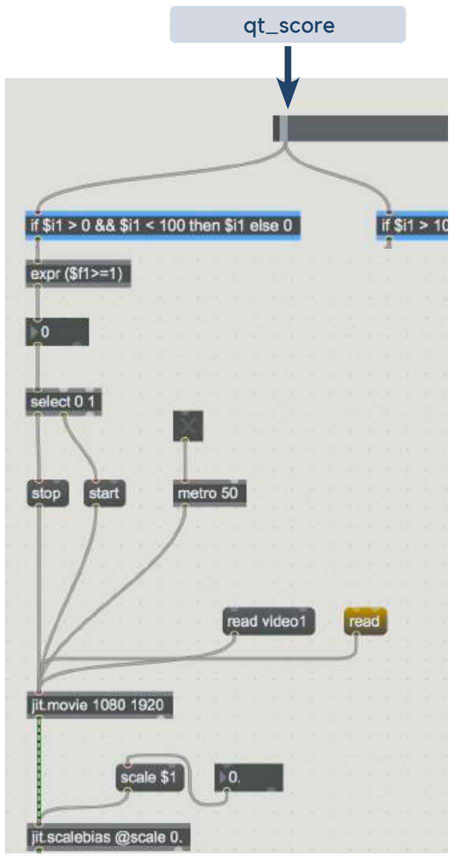


Figure 48 - left
The louder the environment gets, the more hostile the visualisation that Doplor displays gets.

Figure 49 - right
A part of the Max MSP file showing where the qt_score is used to decide which visualisation to display.

```
void loop() {

loudnessState = analogRead(loudnessPin);
Serial.print(loudnessState);
Serial.print('\t');

infoButState = analogRead(infoButton);
Serial.print(infoButState);
Serial.print('\t');

infoSlideState = analogRead(infoSlider);
Serial.print(infoSlideState);
Serial.print('\t');

proxState = analogRead(proxPin);
Serial.print(proxState);
Serial.print('\t');
```

Figure 50
The arduino code determining the proximity, button and slider state, and loudness (representing the qt_score for prototyping practicalities), and printing them to the serial monitor.

```
void readArduino() {
  while (mySerial.available() > 0) {
    String myString = mySerial.readStringUntil(nl);

    if (myString != null) {
      myString = trim(myString);
      int mysensors[] = int(split(myString, '\t'));
      count = mysensors.length;

      if(count == 5){
      LoudVal= mysensors [0];
      InfoButton = mysensors [1];
      InfoSlider = mysensors [2];
      DistVal = mysensors [3];
      VisChoice = mysensors [4];
      println(LoudVal, '\t',
              InfoButton, '\t',
              InfoSlider, '\t',
              DistVal, '\t',
              VisChoice);
      }
```

Figure 51
The Processing code used for Arduino's string of text from the serial monitor, and assigning each value to the corresponding sensor.

```
void draw() {
      readArduino();
      videoChoice();
        if (LoudVal<=255) {
          displayedMovie = movieQuietOkay[videostate];
          displayedTitle = titleQuietOkay[videostate];
          displayedMovie.loop();
        } else if (LoudVal > 255 && LoudVal < 511) {
          displayedMovie = movieLoudOkay[videostate];
          displayedTitle = titleLoudOkay[videostate];
          displayedMovie.loop();
        } else if (LoudVal > 512 && LoudVal < 730) {
          displayedMovie = movieQuietNotOkay[videostate];
          displayedTitle = titleQuietNotOkay[videostate];
          displayedMovie.loop();
        } else if (LoudVal > 731 && LoudVal < 1050) {
          displayedMovie = movieLoudNotOkay[videostate];
          displayedTitle = titleLoudNotOkay[videostate];
          displayedMovie.loop();
        }
    image(displayedMovie, 0, 0);
```

Figure 52
The Processing code that evaluates the value of the Loudness, and relates it back to displaying an animation with a certain loudness.

Arduino reads sensors

Due to the nature and way Max MSP has been developed, layering more than two videos being alternated between is not advised. It was noticed that the processing power of even newer computers was still lacking to properly create a shift between multiple videos. Therefore a Javascript based program called Processing was used to create a new structure determining all Doplor's calculations.

Firstly in Arduino (code in figure 50) is being read what the loudness is, representing the qt_score. As during this graduation it was not found possible to create a direct link to Quietyme's servers in America. Sample data from room H307 as described in section 2.5 was used to represent the auditory quality. Also is being measured whether the button at the side is being pushed, and if so, what the position of the scroll wheel (slider) is. Lastly the proximity of the user to the device is measured.

The serial monitor forms a bridge

Arduino writes all values to the serial monitor of the computing device (during prototyping a macbook pro). The serial monitor is a digital space where different programs and components can write and read text. In this case Arduino writes the different values, and Processing reads the text again (as seen in figure 51). A long string of text is interpreted as a total of five, and then converted to the values belonging to LoudVal (loudness), InfoButton (whether button is pressed), InfoSlider (the position of the slider), and DistVal (the proximity of user to device).

Processing determines

From all read values of the serial monitor, Processing picks up the LoudVal (the value of loudness, previously mentioned as qt_score), and checks what the value is. When the value is 255 or lower, a QuietOkay movie is loaded and looped. When the value is between 255 and 511, a LoudOkay movie is loaded and looped. This structure is used for a total of four different loudness animations (figure 52).

Section 5.5

Doplor responds

Doplor causes a different environment in the complete Intensive Care, or at least, that is how its presence is envisioned.

Renewed and envisioned patient journey (figure 53)

In this new scenario, Doplor was implemented for some time and the nursers understand its presence and functionality. The different actors in the Intensive Care see Doplor and understand that he is trying to tell something.

It has been loud for the past hour in the Intensive Care, but Anna did not notice. She does not quite understand why Doplor states that the environment has been loud, and therefore walks up to him to get more information. What exactly happens is described on the next page.

Cleaner Ferdy also makes use of Doplor, while he thought it was a good idea to clean the IC, Doplor thought otherwise. The visualisation makes Ferdy think twice, and he decides to come back a later time so that patient Desie can have a proper sleep for one or two hours.

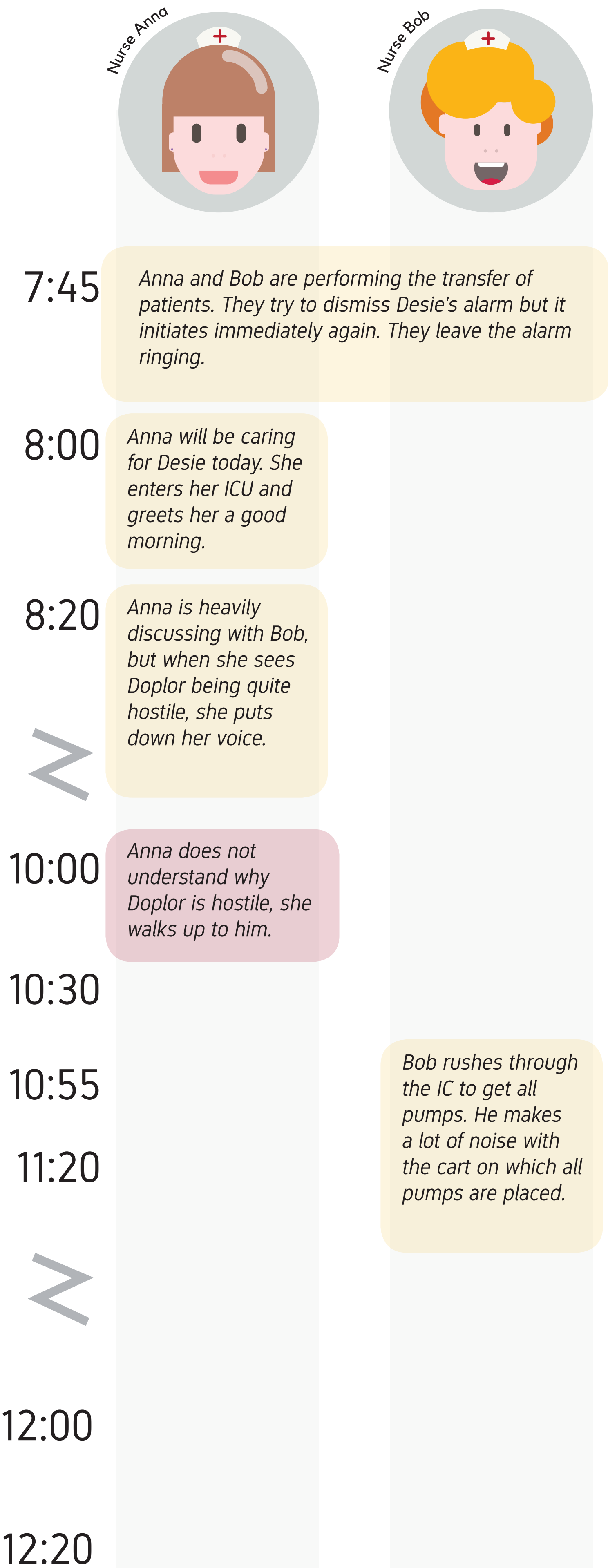
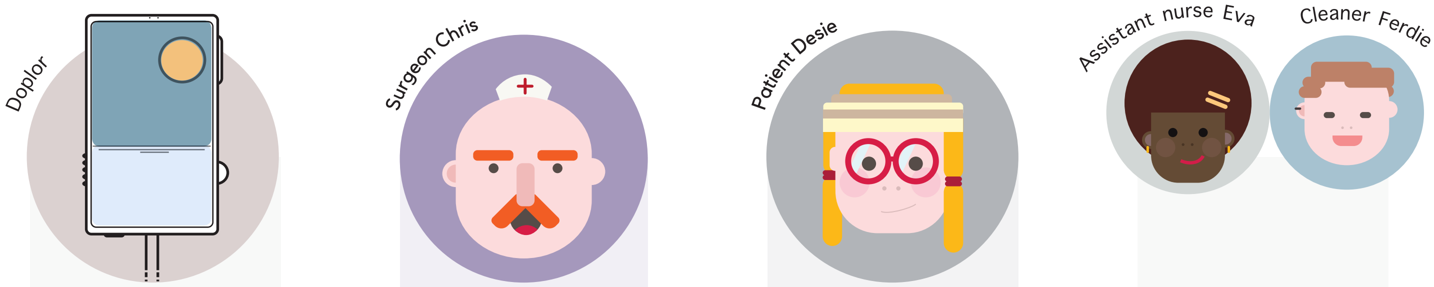


Figure 53
The new envisioned patient journey after Doplor is introduced.



Measures disturbances, adds score to 'alarms'. Scene still quiet.

Desie awakens and moves in her bed. Her SPO_2 clip falls of her finger and the first alarm initiates.

Eva is talking with the other nurses about her weekend. All laugh rigorously.

Measures multiple disturbances, adds score to 'speech'. Scene becomes hostile.

The loud bang increase Desie's heartrate. An alarm starts ringing.

Eva walks by with a cart full with crates. Ten of them fall giving a loud bang.

Doplor adds score to 'incidental'.

Doplor recognises someone and displays more.
See the next page to exactly see what happens

Chris starts with the inturbation of Desie but forgets to turn off the alarms. When he unplugs a tube all pagers get emergency notifications. Having seen Doplor, he is aware of the alarms and turns them down.

Desie is undergoing the treatment performed by Chris.

Doplor hears all noises but understands it's an emergency. Tranquil videos are displayed.

The inturbation is finished. Chris alters the alarm intensive limits and leaves Desie to rest.

The emergency is over, but as the environment has been loud, hostile videos are displayed.

Desie is exhausted but with the environment now being better controlled (and Ferdy not disturbing at the moment) she can find her peace and sleep for a bit.

Ferdy walks into the IC and sees that a lot of disturbances occured lately. He decides to come back later today.

The IC becomes silent, Doplor displays quiet videos again.

Understanding the environment

Nurse Anna does not quite understand why already at 10 o'clock in the morning Doplor displays quite an 'agitated' image. She want to act on the situation, but to do so she needs to know what actually happened so far that was loud. That is why she walks up to Doplor and gets a closer look, and sees what actually is going on (figure 56 schematically shows her interaction.).

Figure 54 - right
Code in Processing determining the proximity.

```
image(displayedMovie, 0, 0);

if (DistVal >= 300){
image(displayedTitle, 0, moveY);
```

1 When someone approaches Doplor, it's proximity sensors on top of the screen understand that somebody is coming up to him (figure 54 briefly shows how this is determined in Processing). In return, Doplor shows the title of the artwork that is currently showing, including a small descriptive text of what is shown and what it means. Some examples of different texts masked over the visualisations can be found in Appendix A16.

2 Sometimes a small explanation is not enough to understand every small detail about the sound in the IC. Therefore nurses can touch the ribbled side, bringing up a page showing a detailed graph of the cumulation of sound over time, comparing it to how much sound is regularly measured.

When the scroll wheel on the other side of the screen is turned, even more information about the sources of sound can be found. In an infographic style de different contributors are explained and visualised. It will quickly become clear where the focus of attention should be to make the IC silent again.

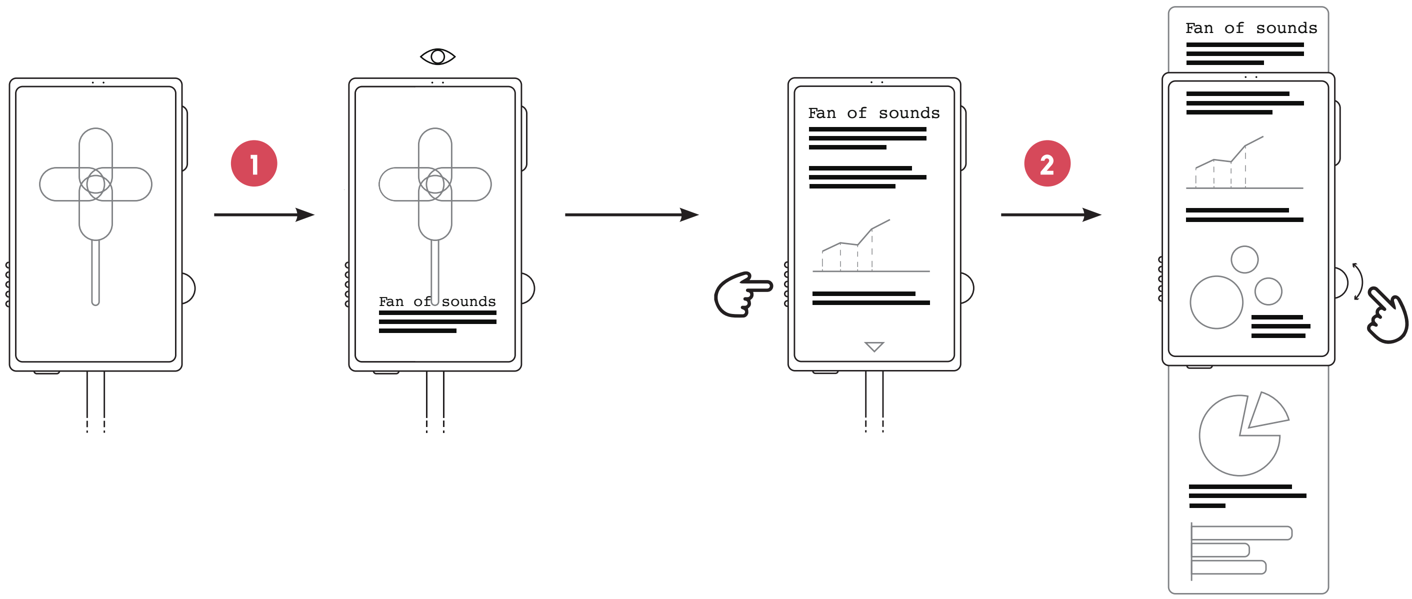
Figure 55 - right
The interaction with Doplor is like a real picture frame.

Figure 56 - below
By walking up to Doplor, you will get a bit of information what Doplor is trying to say. Still not convinced? Press the button at the side and see an infographic will all information that you need.

Interacting as if it were a real painting

The interaction with Doplor was designed as natural as possible. Doplor is a bit futuristic, but with a known touch to it, it might be a bit less scary to use.

That is why the both the button and the scroll wheel have been placed at the side of the encasing. It almost feels as if you are repositioning a real painting (figure 55), while in fact you are asking for a bit more information about the environment.



Section 5.6

Doplor understands

When the environment has been noisy, you do not just want to be alarmed, you also want to know what to do to make it better again. Doplor understands that as well.

Figure 57
When only the button at the left side is pushed, the average amount of decibels can be found.

Figure 58
When also the slider at the side is used, more elaborate information can be found about the amount of conversations, alarms and incidents that occured.

The infographic shows it all

With the use of the datasets being received from Quietyme (as seen in table 2 in section 5.4) of speech, incidents and alarms an infographic is made to help nurses understand what has caused the most noise the past hours.

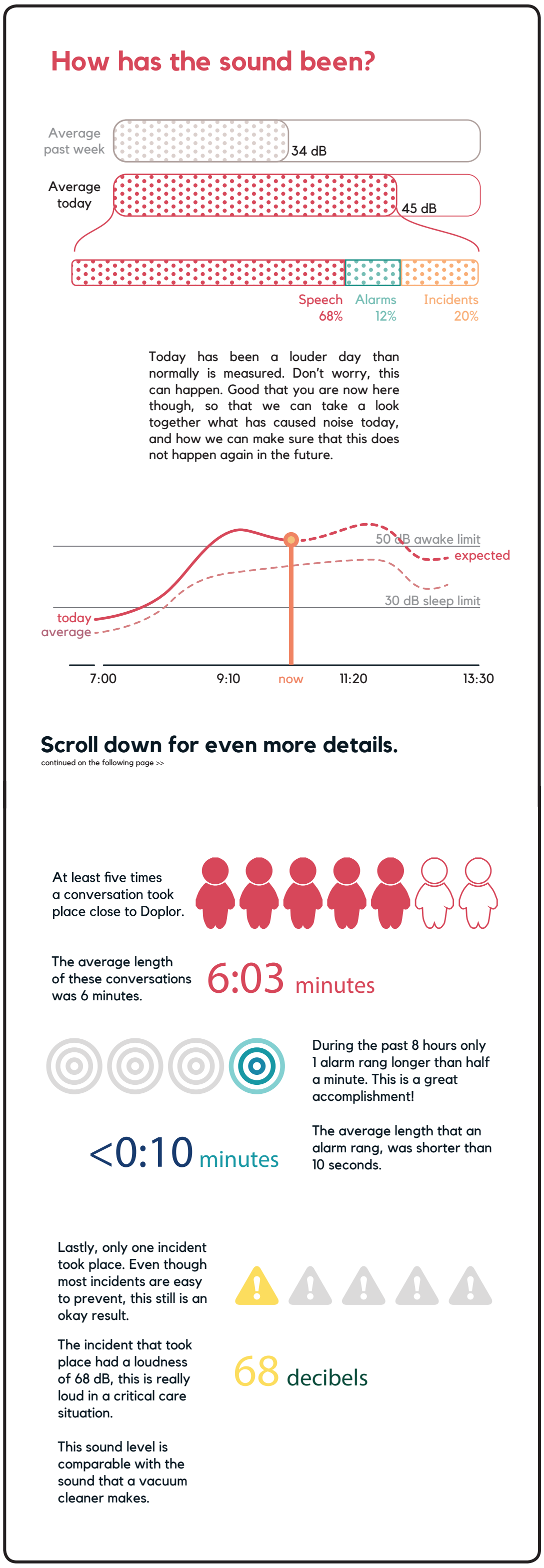
When only the button at the side is pressed (figure 57), this shows the graph and information as seen in figure 59. Nurses (or other users) can directly see how loud it has been averagely the past day, and how it compares to the average of the week.

When users use the scroll wheel at the side (figure 58), then it also becomes possible to view all contributions to the noise culture. Three different sound factors have three different colours (inspired by the book 'infographic guide to life, the universe and everything' by Eaton, 2014), making it easier to indicate which one belongs to which noise-contributor. Other findings inspired by Eaton are:

» Icons that are easily recognised as people are used to indicate the size of a group of people, as well as the severety of an effect.
» Icons and elements within the infographic show just enough detail to understand what is being communicated, without overloading the visuals with elements
» Only one typeface is used, in three different styles to limit the amount of change, creating a nicer overview.

Being able to see which contributor was the loudest over the past time could make it easier to get the environment more silent in a short period of time. That is why this function was added.

Figure 59
An example of what the infographic will look like.



Section 5.7

Doplor prioritizes

If directly (through a PID-controller[37]) a lot of sound is measured over a longer time, the standard protocol will be overruled and a visualisation will be used indicating 'don't worry about the sound but worry about the patient'.

[37]**PID-controller**
A PID-controller is a piece of code that does not only look at the present values, but also predicts the future and averages the past. In this case, an average sound level is created by summarizing the last 15 minutes, and when a drastic change happens for three minutes, the program understands that this loudness was not just a coincidence.

When Doplor notices that indeed the sound levels have risen rapidly and this takes place for longer that 3 minutes, this most probably means that an emergency is occurring/has occurred. A slow transition in visualisations will take place to a visualisation that is trying to say: 'it is okay that it is loud, you are doing your work and sometimes that makes noise, don't worry.' (figure 61)

To facilitate this gradual transition between visualisations, a functionality pack was added between the 'visualisation choice' and 'display visualisation' elements in the Max MSP file (figure 60).

The 500 is used to indicate the amount of milliseconds that a transition between two videos. This way, a video can be displayed 'on top of' another video, making sure that once again only one video is actually displayed.

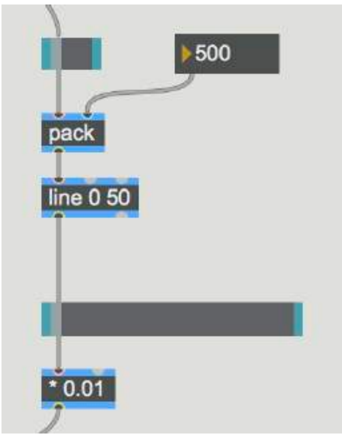


Figure 60
A part of the Max MSP patch showing how a fade between videos is created.

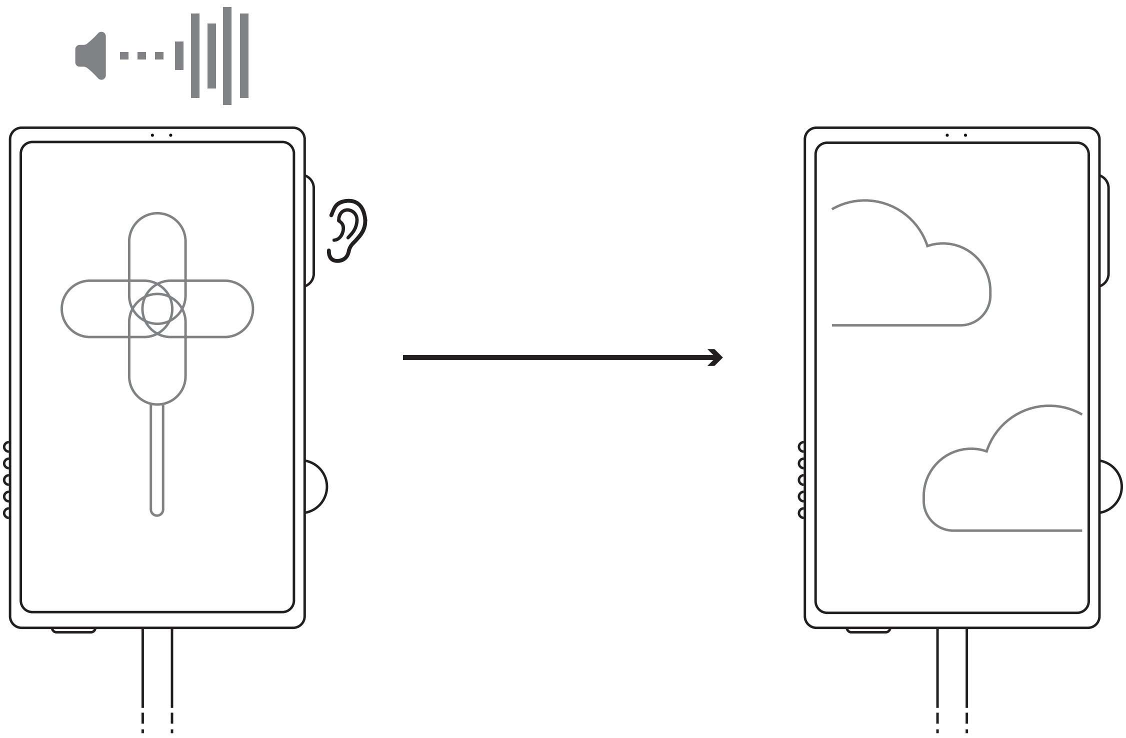


Figure 61
When sound levels increase severely all of a sudden, probably an emergency happened. Visualisations change accordingly by showing visualisations that communicate: 'don't worry about the sound, but worry about the patient.'

Section 5.8

Designed visualisations

As explained in chapter 4, creating a shift in hostility was a useful way for displaying a difference in the perceived loudness of a visualisation. Color, speed, and clarity were additional factor that could be used to create more distinction between the visualisations.

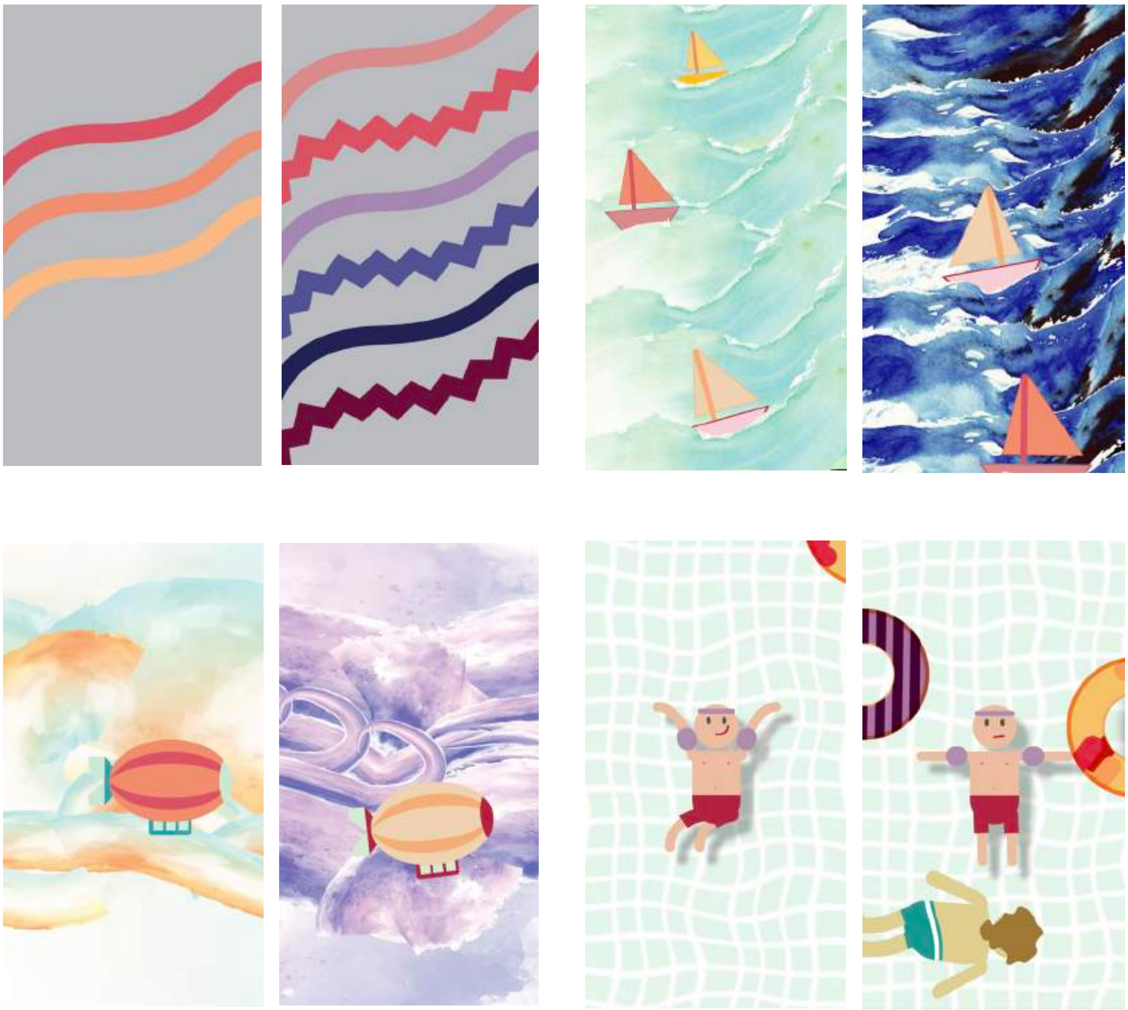
Multiple styles of visualisations were designed with the results of research 3 in mind (figure 62). Even though visualisations can not be displayed while moving in a report, some screen caps were added to show the general distinction between quiet and loud.

In figure 62, all left screenshots display a quiet visualisation, as all visuals have brighter and lighter colors, overalll less components, more fluent movements and generally are clearer.

The visualisations on the right are on their turn on these aspects the opposite. They have darker, gloomier colors, move more hostile and have more components.

Even more visualisations than shown on these pages were created, and can be found in Appendix A17. Furthermore, for now only two states are shown, Quiet and Loud. This was done intentionally as having two opposites was more suitable for the test with Max MSP, as explained in section 6.2. In the following section 5.9 additional visualisations showing the complete alarm philosophy can be found.

Figure 62
Different designed visualisations, all showing a quiet (left) and loud (right) environment. These were designed with results from research 3 in mind.



Section 5.9

Adding the alarm philosophy

For testing with students, initially only a quiet and a loud visualisation were made, this seemed the most time efficient, and yet enough in-depth to understand whether the visualisations were perceived the way they were intended. However, to create the full scope of 'QuietOkay' to 'LoudNotOkay', for each set of visualisations two more visualisations had to be made.

These visualisations had either to become 'even more silent' or 'even louder', to create the overall flow (figure 64-65). In the set of mountain-visualisations, the 'loud but okay' visualisation shows a big crane carrying a heavy crate. This is the visualisation that shows that there is being worked, and that it is normal that such work makes sound. With the sound-waves a similar effect is created, as the text that comes up (figure 63) shows that the 'sailors know how to handle the situation'.

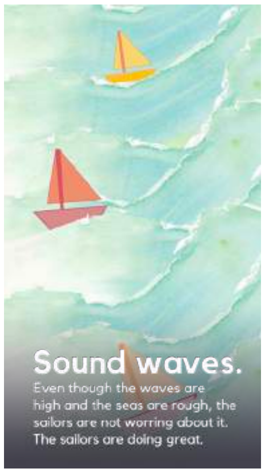


Figure 63
One of the four titles that could come up when a person approaches. Shown is 'LoudButOkay'. Others can be found in Appendix A16.

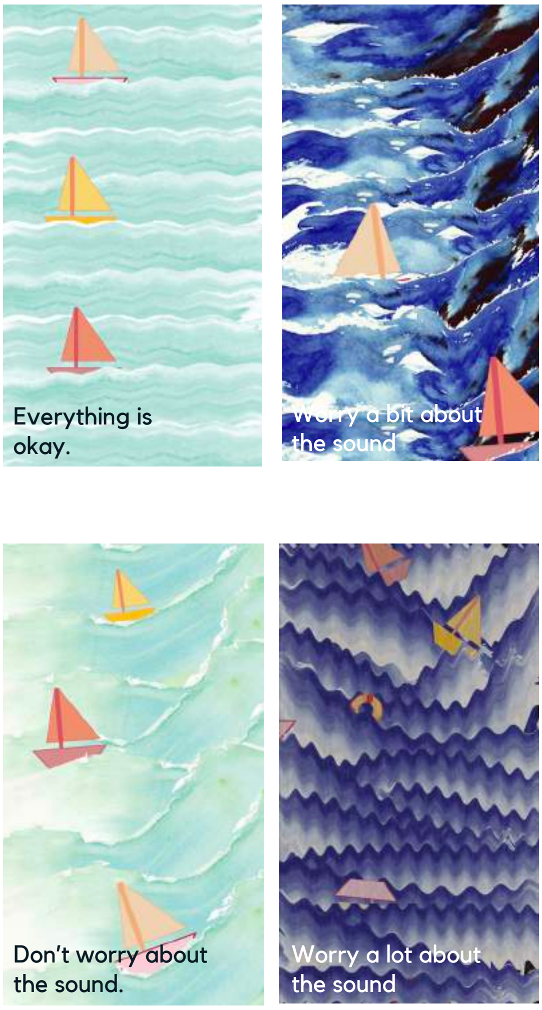


Figure 64 - Left
The four different states as described by the alarm philosophy, in a watercolor sea style.

Silent visualisations have brighter colors and have less hostile waves. Louder visualisations feature higher and more waves, more components , more hostility and darker colors.

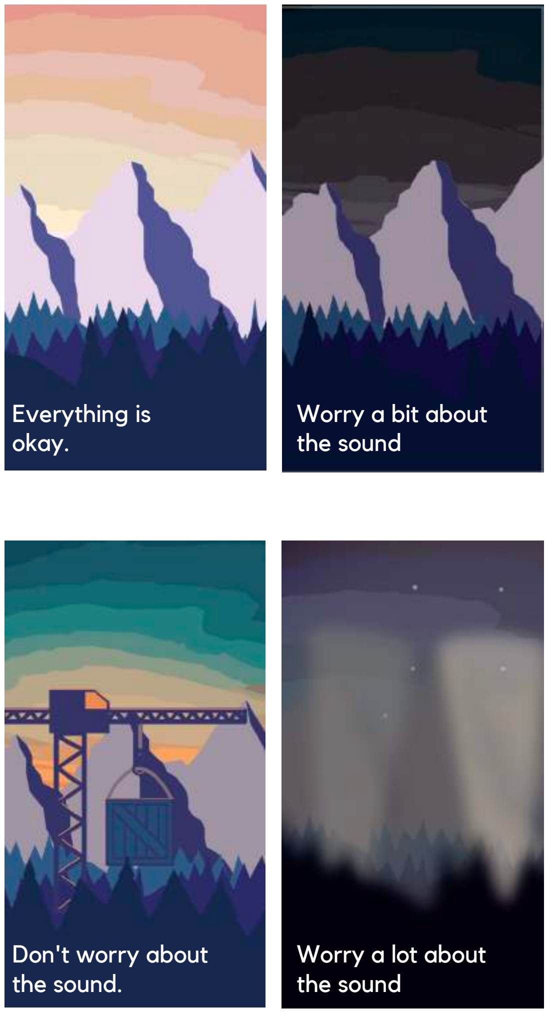


Figure 65 - Right
The four different states as described by the alarm philosophy, but then in a flat-art mountain style.

Pastel like colors are used to show silent environments, whereas darker and gloomier visualisations are used to communicate that the environment has been loud.

Chapter 6: understandability and optimisation

With all designs on paper being practically ready, it was time to start prototyping and test with students and the end-users (nurses) again, to see if the results were the same as designed. Both nurses and students responded enthusiastic.

During the tests also some interesting remarks came up. In the prototype for example was the proximity sensor clearly visible, something that made students think that they were being monitored still. How to solve this and all other findings in this chapter are:

- A prototype of Doplor was made, running on Arduino and Max MSP
- Participants of a functionality test were enthusiastic and would love to work in an environment with Doplor in it.
- A similar test with nurses shows that also within the critical care context Doplor has a possibility of changing the sonic environment.

Section 6.1

A working prototype running Max MSP

Functionality could best be tested when a fully functional prototype would be at hand. Therefore multiple weeks of prototyping were planned to create a prototype that could display visualisations, encase al needed electronics, was suitable and sturdy enough to test with, and look somewhat like the digital model. To see some pictures of prototyping, please visit Appendix A18.

Figure 66
The working prototype when turned on for the very first time. The prototype now still displayed a regular background.

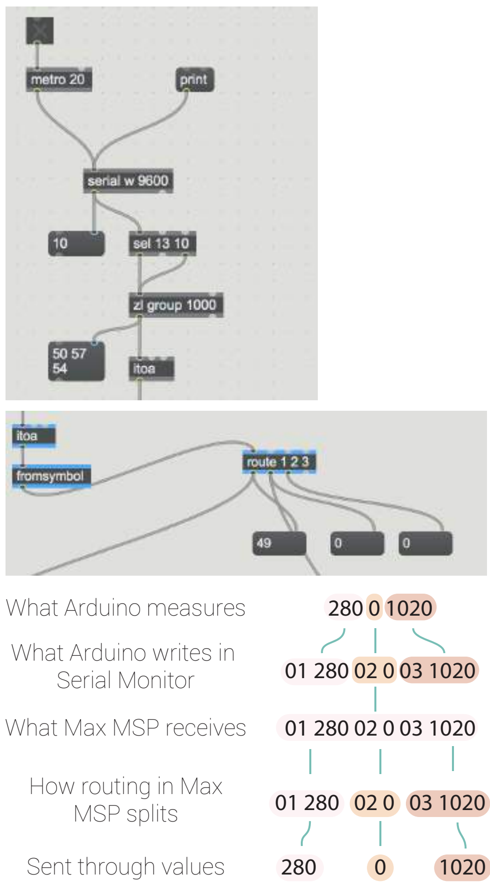
Figure 67 - Right
Max MSP code that reads Arduino's output in the Serial Monitor, and then translates to be used in the Max MSP patch.

This prototype (figure 66) was used to see whether users understood the way of interacting, to get to know their general feeling when using Doplor, and whether users would expect themselves being more quiet when being around Doplor.

The main functionalities in Max MSP and Processing have already been discussed, there occured one more challenge before the complete connection between a computer and Doplor could be made. As noticed before, the serial monitor is a digital space where applications can read and write strings of data. However, Arduino and Max MSP speak a different language, meaning that Max MSP (the receiver) needed to have an extra translation functionality.

What exactly happens is a bit difficult to explain in words, but the way how it has been set up is that Arduino writes each analog value with a numerical value (01, 02, and 03) in front of it. Max receives one big string of numbers in which all values are attached to each other.

In Max MSP, using the 'itoa' function all values are translated to Max-language and via a routing, the numbers are being split again, ready for Max to be used (figure 67). The electrical flowchart of cables and attachments can be found in Appendix A19, also the complete code of Max MSP and Processing can be found in this Appendix.



Section 6.2

Research 4: Usability test among students

The fourth test was to see whether Doplor actually fulfills the purpose that it was designed for, getting people to understand the consequences of their auditory behaviour - and communicating the causes of the disturbances when the auditory environment has been taken care of poorly. The different designed visualisations were shown to eight participants, of which all 8 responded in a positive way.

Only two of the four states were tested

Initially, the main difference between a quiet and a loud environment was tested. Differences between visualisations could this way easily be tested, and Max MSP showed enough versatility to hands-on change visualisations while performing a test.

Testing whether Dolor could create the envisioned 5 minutes extra without auditory disturbances could not yet be tested, as this would be part of a much more elaborate test after multiple months of Doplor's introduction to the Intensive Care (more about this in Chapter 7, 'closing the circle').

For understanding whether the visualisations showed proper differences, and whether participants could relate the visualisations to the sonic environment, the following questions were the main research questions:

» Do participants relate the designed visualisations to the auditory environment?
» Show participants a certain willingness, or do they expect that they would change their auditory behaviour when exposed to an (envisioned) 'loud' visualisation?

Abstract

All eight participants were enthusiastic about the design and thought that the whole experience was kind and friendly (4.75 out of a 1-5 scale). Doplor would add great intention to work more quiet (4.25 out of 5) and participants rated the understandability of visualisations to the environment also very positive with a score 4,11 out of 5.

6 out of 8 participants understood the first visualisation (without seeing the title and explanation), and when these were added 7 out of 8 participants understood the visualisation correctly the first time. When participants were shown the counter-visualisation the non-loud and non-quiet ones, each participant understood all states correctly immediately.

Method

This study was conducted with a total of eight participants, all Industrial Design Master students, none of which had elaborate prior knowledge about the intensive care. Each test took about 15 minutes, excluding conversations afterwards. Participants were introduced to the environment in which the product would normally be located (the IC) through images and a small story about past experiences.

The participants would then be showed the prototype and they would be asked what they thought the design would be and what they generally thought of the visualisations.

This test consisted of two parts. The first part included solely the visualisations (one quiet, one loud) observing from 2 meters distance. The second part a different set of visualisations (one quiet, one loud) would be shown, but then with the added functionality of walking towards Doplor, reading the description and being able to manually show the infographic.

Steps during the first part: When shown the first visualisation, the participant would be asked whether they thought the visualisation showed either a quiet or a loud environment. The visualisation displaying the opposite environment would then be shown, and the participant would be asked the same question.

Steps during the second part: A similar setup was used, only this time it was also allowed for the participant to walk up to Doplor, making the title with a small description appear, and also to interact with it to show the infographic.

Afterwards the participants would be asked what they thought of the design and the interaction, and also if the participant felt like changing one or more aspects of the design. Answers on these questions were gained with the following questions using an answer possibility on a 1 to 5 scale (1 = totally disagree, 5 = totally agree) (the full respondent form can be found in Appendix A20):

» I think that the visualisations shown were friendly and kind.
» The design would help me understand the auditory environment easier.
» The way of interacting with this design was intuitive.
» I would act more quiet with this design being around.
» I did not gain enough information about the different sound-disturbing factors
» The design would easily get me bored
» The visualisations showed no clear relation to the sonic environment
» I would feel monitored with this design in my workspace.

Results

Out of the 8 participants, all (8) participants thought that the design was informing properly about the auditory environment and participants thought that Doplor informed in a friendly way (4.75 out of 5). All results are also in table 3.

A participant (P2) said "I would never have thought of using such a device, uhh..., as a device to show how the sound is, eh..., sounding! I think this could really help people understanding noise."

Participant 2 and 3 also indicated that they are able to understand the device without too much effort but that they would like explanation better. P3: "I, uh, really think that having (rigorously pulls slider) some more indication on how exactly, oh...! (finds out to slide slider), I really

Figure 68 - Right
1 Participant 7 is re-reading the text of the visualisation carefully again before answering to the question: do you think this is a loud or a quiet visualisation?

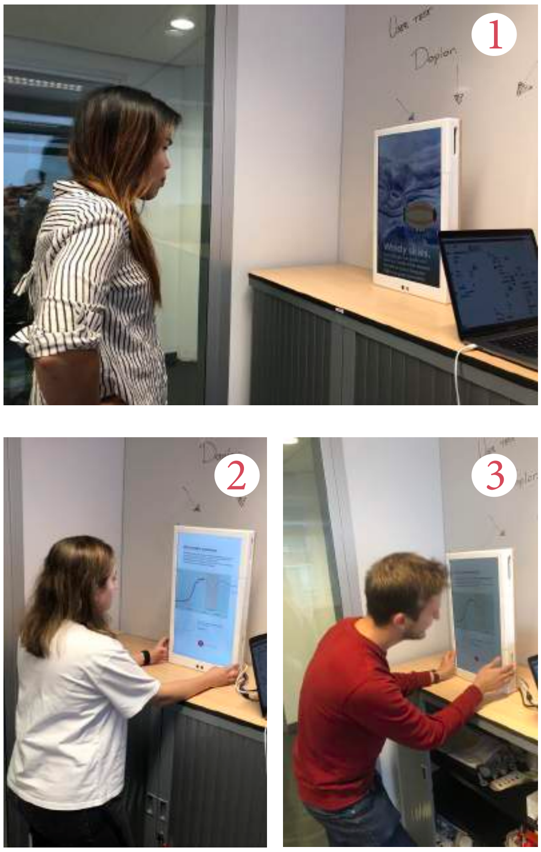
2 Participant 3 is here trying to understand what the graph means and is also trying to figure out how the slider exactly works (followed by the comment that its usage should be clearer instructed).

3 Participant 8 was trying to blindly find the slider, but in the end had to look before he could interact properly.

think.. that having an explanation would help me greatly with directly understanding this."

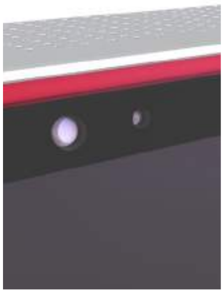
One participant (P7) said that she would like to see a time-slider, "so you can go back in time and ... basically see ... (the visualisation took her attention for a moment) how everybody did over time.. and that you can also see whether you have done better if you looked earlier that day."

Participants thought that they could obtain enough information (3.75 out of 5), but that the style of the infographic could be improved more to be easier readable. It was also noticed that the typeface and spacing were too big in size when interacting with Doplor, as people had to fully stretch their arms and step a bit backward to be able to read from the screen comfortably.



Concluding

The proximity sensor was too obvious in the sight of participants, even though the design itself did not make participants feel monitored at all (1.38 out of 5), the aspect still feeling to be monitored was the proximity sensor. This could be changed by making it less apparent, like for example hiding it behind the screen (figure 68).



The button and slider were too difficult to notice making that participants did not think the usage of the design was intuitive enough (2,88 out of 5). When elaborated upon, it was rather that participants would like to see better use-cues indicating where to push rather than to have the buttons on the front. Buttons on the front were expected to distract from the most important part of the design, the visualisations. When explained and experienced, participants started getting used to the button and the slider.

The design is perceived friendly and approachable, and also felt helping all participants in understanding better whether the auditory quality was good (4.11 out of 5) and to most (7 out of 8) participants also made it clearer what were the main contributors to the perceived noise.

Table 3
Results of research 4. The blue column shows the averages per question.

Questions	#	P1	P2	P3	P4	P5	P6	P7	P8	Averages
visualisation 1										
Understand relation to auditory environment	1	yes	no	yes	no	yes	yes	yes	yes	6 out of 8
Indicated correct state (Quiet or loud)	2	quiet	loud	quiet	quiet	loud	quiet	quiet	loud	6 out of 8
visualisation 2										
Understand relation to auditory environment	1	yes	no	yes	yes	yes	yes	yes	yes	7 out of 8
Indicated correct state (Quiet or loud)	2	loud	loud	loud	loud	loud	quiet	loud	loud	7 out of 8
Main contributor to sound pollution	3	speech	speech	speech	speech	speech	speech	-	speech	7 out of 8
Average length of this contributor (speech)	4	6.03	6.03	6.03	6	6.03	5x 6.03	6.03	6.03	8 out of 8
about Doplor										
Friendly		5	5	5	5	4	5	5	4	4,75
Help understand		5	4 (X1)	4 (X1)	4	5	5	5	5	4,11
Intuitive		5	2	4	2	2	3	2 (X1)	3	2,88
Would act more quiet		5	3	4	4	4	5	4	5	4,25
Not enough information		1	1	2	2	1	1	4	2 (X3)	1,75
Would bore easily		1	1	2	1	2	2	2	1	1,50
No clear relation		1	3	2	1	2	1	1	1	1,50
Would feel monitored		1	2	1	1	2	1	2	1	1,38
What to change?		infograph	infograph (X2)	usecues	button	scrolling	infograph	infograph	button	

X1 : Respondents indicated they would understand when would get explanation on using Doplor
X2 : Respondent would like to see a timeslider which could be set by user
X3 : Respondent had difficulties in clearly distinguishing between different factors in infographic

Section 6.3

Research 5: Usability test with nurses

The overalll goal of this last research was to evaluate whether Doplor and its visualisations fulfilled their function; did nurses understand why Doplor was designed and what it is trying to say? The result of research 4 seemed promising, but it was even more interesting to understand what the intended end-users (nurses) thought of Doplor.

It was tried to understand whether Doplor increased the awareness of the sonic environment among nurses, and whether they thought Doplor would help them with confronting each other when they think it is a bit too loud. This test was not about the long term effects on the nurses behaviour, or whether they would show a clear difference in their own awareness when they make noise. Instead, this test was about introducing the final design, and get response on Doplor. Did the nurses see themselves working with Doplor around, and would they understand the interaction?

Method

Doplor was taken to the Intensive Care on the fourth floor of the Erasmus MC Nieuwbouw hospital, where a total of 10 nurses participated in a 15 minute-during test (figure 70). All nurses would get an introductory talk about Dolor, explaining its main functionalities and they were shown some visualisations to familiarise. Then some questions would be asked regarding appearance of my design to understand whether nurses defined visualisations relatable to the auditory environment, and how they perceived[38] the visualisations.

For two sets of visualisations would be asked whether nurses understood the relation with the auditory environment, and how they would rate the videos on hostility, business, etc.

To finish off the test, some general questions about Doplor would be asked, all to be rated on a 1 to 5 scale (completely disagree to completely agree):

» This design would help me understand the auditory environment easier.
» Doplor could help me to make other nurses aware when they are a bit loud
» I would act more quiet with this design being around
» I did not gain enough information about the different sound disturbing factors.
» This design would easily get me bored
» I would feel monitored with this design in my workspace.

Lastly would be asked if nurses saw Doplor more as an alarming device or a helper. The complete research form that was filled in can be found in Appendix A21. Treats were available as a 'thank you' for participating. All results would be filled in Excel, and average scores would be calculated for each sub-question.

[38]**Perception of visuals**
Nurses were asked define how relatable they thought the visuals were to the auditory environment on a 1 to 7 scale. Then they could elaborate with a more in depth 1 to 7 scale perception on how *hostile, busy, friendly, soothing, approachable, peaceful, and activating,* they thought the set of visualisations were.

Figure 69-70 Performing research 5 with Intensive Care Nurses.

Results

A total of 10 nurses participated in the test. The nurses showed interest and acknowledged the fact that it can sometimes be loud in the Intensive Care, through verbal contact a common response was found that nurses liked Doplor and the way of having more art in the IC while still being informative. Nurses understood the link to the auditory environment (scored 4.85 out of 7). Two nurses told, after seeing the visualisations, that they would like to have a bit more humour in the artwork, like the scream of 'the scream' becoming bigger.

Following the results (figure 71 and 72) of the questionnaire, 9 out of the 10 nurses thought that Doplor was a helper rather than an alarming device. Even though not completely similar, with average scores of visualisation-set 1: *5,1 out of 7* and visualisation-set 2: *4,6 out of 7*, nurses understood the link between the designed visualisations and the auditory environment. The nurses thought that the visualisations were non hostile (v1: 2,1 and v2: 3,2) and not busy either (v1: 2,4 and v2: 2,9). Nurses expect to act more silent with Doplor implemented (3,7 out of 5) and they saw Doplor as a help to approach other nurses when they are loud (4,1 out of 5). Doplor was perceived very slightly activating (v1: 4,3 and v2: 4,2), and when in an environment where Doplor would be used, nurses would not feel monitored at all (1,7 out of 5) Nurses also did not expect Doplor to be boring after a longer period of time (2,1 out of 5).

Discussion

Nurses understood the cause and reason of Doplors existence and enjoyed its company when displayed in the Intensive Care. The observed effect is however smaller than could be found with Industrial Design Students. Average age and work-experience could be of influence, and also the amount of experienced stress during the day (it was a busy day during the tests) could have had an influence. Whereas the link between Doplor and the auditory environment was there, the evidence of its activation and change in behaviour is still small. Four participants indicated that the availability of the link to the environment was neutral (score 4 out of 7), which shows that visualisations should be more explicit than the way they are now. This was also found in a comment of participant 5 who said 'explicietere verschillen', and participant 3 'misschien iets hardere kleuren in luide omgeving' meaning that more explicit differences (in hostility and color) were desired to better understand the link.

Participant 1 indicated that it might be nicer, in the new situation of the Erasmus MC, that every patient box would have a smaller indicator so that the state within a patient box could also be monitored. In most cases, where there is less auditive blocking between the corridor and ICU's, this would be less of an issue. For the Erasmus MC though, now this proper isolation is realised, it could be interesting to also offer the opportunity to get data per patient room.

Conclusion

Even though the visualisations were designed with hostility being the most prevalent change between states, these changes were still experienced too subtle for nurses to directly be activating. Nurses understand the link between Doplor and the auditory environment, and this could be the reason why nurses expect themselves to act more quiet in their working environment. Having different visualisations is why Doplor was not perceived boring, even after longer periods of time. Doplor was expected to help nurses with approaching others when a bit too loud, giving a common place that it insightful for everybody.

Direct implications for Doplor are that visualisations need to be rethought and newly designed or updated, a difference in hostility needs to be implemented even more thoroughly so they are noticed almost instantaneously. It was also considered to create a little brother for Doplor.

Figure 71
Initial questions per visualisation set on how hostile, busy, etc. they were perceived.

	I can see a clear link with the auditory environment	Hostile	Busy	Friendly	Soothing	Approachable	Peaceful	Activating
V1	5,1	2,1	2,4	5,8	55	4,8	6	4,3
V2	4,6	3,2	2,9	4,7	4,3	4,6	4,7	4,2

Figure 72
Averages for general questions how nurses liked and understood Doplor.

Question	Average
Doplor would help understanding the aud. Env.	3,6
Help with approaching other nurses	4,1
I would act more silent with Doplor	3,7
Did not understand biggest cause	2,3
Doplor would bore me easily	2,1
I would feel monitored	1,7

Chapter 7: recommendations

Even though both literature and field research show that Doplor could create an impact in a Critical Care context, it still is a concept that could become even better when researched and designed upon more. Within the limited time of graduation, I could not yet completely get to the bottom of every aspect, but I have made an attempt in showing what else also could be implemented in this design.

In this last chapter of my thesis I will take a look at other possibilities that could make my design even better. Subjects which I have thought of, but not completely thought through yet. Firstly will be discussed how an actual behaviour change could be tested, some other possibilities of continuation with this design are discussed, and lastly I will finish this thesis with a critical reflection.

- 'Closing the circle': An effectivity test that shows whether people are actually more silent when Doplor displays 'loud', has still to be tested. A research proposal has been set up.
- Bringing Doplor to the market gets an interesting twist when including upcoming graphic designers.
- It is estimated possible to make Doplor a viable product when a monthly subscription fee of 35 euros is paid, for at least a year.
- Visualisations could get even more informative when specific visual components are used to display the cause of an auditory disturbance.
- Not taking into account the prototypability within IDE, a more futuristic design made out of an aluminum encasing could be made

Section 7.1

'Closing the circle': Research 6

The long term effects of Doplor have not yet been tested, and this introduces uncertainty about the actual effectivity of the design. From the beginning of my graduation, the aim was to increase the time between auditory disturbances so that ICU patients just starting to dose off would not be woken up just before they reached stage 3 sleep.

The real question whether this actually would happen remains unanswered until further testing has been performed (figure 71). But until then, I expect it would. Doplor introduces an artful way of informing nurses about the auditory consequences of their behaviour. Sooner or later, after multiple times of use, I believe the awareness of loud behaviour returns to the nurses, meaning they hear the noise again, and try to reduce it themselves, as a team.

Method

To properly test the changes, Doplor would have to be implemented and explained properly within the Intensive Care. A test would have to be performed now, and in 2 to 3 years, to see a change in behaviour, as such a change takes time to happen.

The average amount of decibels, and the amount of auditory disturbances per hour should be measured. Also should nurses fill in a questionnaire with how likely they are to find a common ground with a colleague nurses when found to be a bit loud. Quietymes sensors and their obtained data will be used for benchmarking the amounts of alarms, conversations and auditory disturbances that actually happened. These values can be averaged per week of testing and could show an indication if Doplor indeed decreases the amount of auditory disturbances..

As different shifts work on different days, disturbances and overalll loudness will be measured in blocks of two hours over a total of 14 days. In later analysis, all found values could be filled in Excel, and the average of each day could then be calculated, and compared to previous years. A questionnaire will also be handed out each year, asking on a 1-7 scale whether nurses feel monitored, whether they feel that the IC has become more silent, and if nurses feel more aware and consious about their auditory behaviour.

Research questions

The research questions are, with previous method in mind:

» Has the average amount of decibels in the Intensive Care dropped?
» Are there overalll less auditory disturbances than currently occurring?
» Do nurses feel monitored with Doplor in their surrounding?
» Has the overalll recovery time of patients dropped?
» Has the overalll sleeping time of patients during the lunch break increased?
» Has there been an increase in average time between auditory disturbances?

When this test would be performed, there could be seen whether there has occured a change in the auditory behaviour of the nurses, whether time between auditory disturbances increased, and in the end, if patient sleep time has improved.

Figure 71 Placement of Doplor in the IC. Would the auditory behaviour of nurses change when direct feedback on the sound quality is given?

Section 7.2

Doplor to Market

Doplor is envisioned to be brought to the market in a lease model. Against a standard fee, it is possible to rent Doplor and display the auditory environment symbolically. Having a lease model has its advantages, namely to have continuous updates of the different visualisations.

Renting graphic designers can be costly, so it was envisioned also a collaboration with an educational institute like Willem de Kooning or the Haagse Hogeschool. This gives the graphic designers of the future a nice step up to the real world, being able to display their work in a busy environment out of the school doors. After talking with some students doing a design study at Hogeschool Rotterdam on 23-8-2018, I understood that such assignments are not uncommon and that the students like doing such assignments. An similar assignment that was assigned a few months ago had a similar theme, designing a new poster for Het Prinsenhof in Delft of which the winner's poster would also be distributed everywhere in the Netherlands. A great opportunity for these Graphic Design students, showing that similar results could be gained out of Doplor.

Erasmus is keen on having a lot of art in their hallways, and even though they do this greatly, the Intensive Care is still rather empty and isolated from the outside world. To fight against this isolation it might be good to have an opportunity from upcoming designers to showcase their work in the hallways of the hospital.

Not every design is suitable to display of course, that is why I still envision a small office where also some designs are made, and where submissions from other designers are checked according to the standards of distinction between a quiet and loud environment, and whether the visualisation in general is suitable to display in a critical care environment.

Even though Doplor was designed with the Erasmus MC in the back of mind, this does not mean that it cannot be used outside this hospital. Instead, Doplor can be used in various medical instances where patients are eager to sleep and where care takers could use some assistance with their auditory behaviour.

With a total of alone 315 hospitals (zorgkaartnederland, 2018) there is quite a big field that can be sold to. With this given, it seems like a fair assumption that the first batch of Doplors would consist out of 500 pieces.

The cost for a Doplor is estimated to be 305 euro. Screenshots of used components and their prices can be found in Appendix A22. When an subscription of at least a year is proposed, then the monthly costs would be around 35 euro each month (see table 4). When the subscription period of a year would have passed, this could imply a drop in subscription cost to around 20 euros per Doplor per Month. This would add great opportunities to collaborate with also greater graphic designers to create more visualisations.

Piece - Object - Work	Price calculation	Price/ piece
3 people working one day (8 hrs) each week to design and check submitted visualisations and eventually design some visualisations themselves	3 persons x 15 eur/hr x 7 hrs a day = 315 eur a per week	€0,65 per week
Two mould for major case front panel and encasing	16180+ 19040= 35220	70,45
Injection moulding + plastic	4.42*0.9 5.02*0.9	8,50
Sensors Quietyme Sensors Proximity Other actuators and small parts		40
22 inch LCD panel		70
Wifi module		6
Assembly and Quality control	4 hours * 15 eur/hr	60
PCB	Approx 3* 13.03	50
TOTAL		305
Per month		28
Add in some spare - monthly price		35

Table 4
Cost calculation that could be tried for implementing Doplor into the market.

Section 7.3

More informative visualisations

The visualisations as they have been designed so far, all give an indication of how the auditory quality has been over the past time. They show when it has been qiuet or loud, and generally if nurses have done well. This could however be optimized, as for now the visualisations give no clarity yet in what of the three main disturbants actually was the loudest.

This could be optimized by having visualisations that also have the possibility of showing the causes, as also sketched in Figure 72. The image on the left shows a quiet state, where a nice field with mountains in a chinese style can be seen. When however a lot of alarms (honking busses) and speech (clouds in the form of text balloons), this could immediately show nurses that those were the main disturbants.

Having such visualisations would mean that it is not necessary for nurses anymore to always walk up to Doplor, interact through the infographic and then finally know what the main cause of the noise was. Instead, by just giving a look to the visualisation, it is already clear what the cause was. The possibility of interacting would obviously remain, as times of the disturbances are not included in the visualisations (yet) either.

As was learnt in Research 5, nurses liked a bit of humor in the visualisations. Including something like a touring car in suche a serene scene adds the possibility of also sometimes getting a smile on the face of the nurse, while still being informed properly.

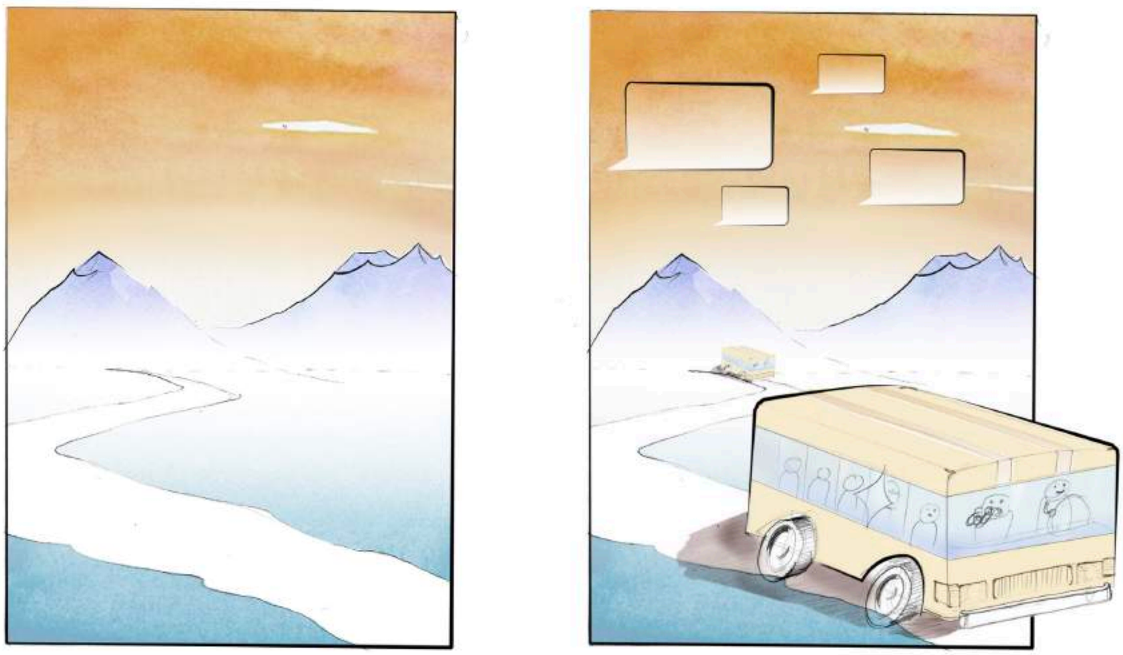


Figure 72 A visualisation showing a direct link to the source of the auditory disturbance (right), in this case being speech and incidents.

Section 7.4

A futuristic design

The design presented so far was designed so that prototyping would be possible with the available resources within the faculty. The design as is, and as was prototyped, offered the opportunity to research the initial remarks by students and nurses. For a real world product however, the design needed to be a bit more realistic, so that it would look as advanced and technological as the Intensive Care is.

The final appearance (figure 73) is far from set in stone. A design can take all sorts of shapes and still look aesthetically pleasing. Doplor has become a design that shows an advancement in technology and would catch the eye of nurses, doctors and visitors.

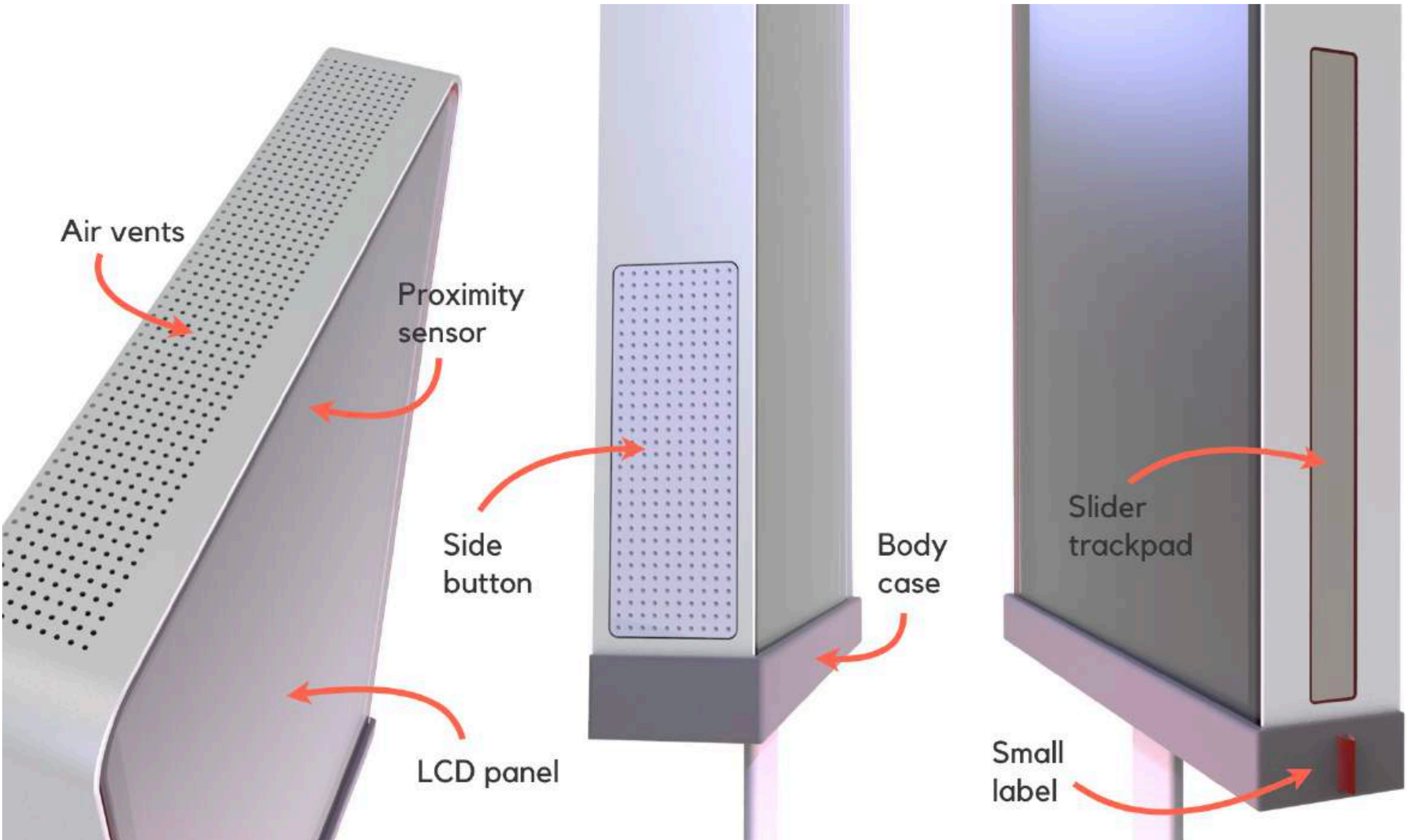
The scroll wheel at the side has been replaced with a touchpad for easier operation (as was decided upon with research 4), the screen is now surrounded by a merely bezelless brushed aluminum encasing and the proximity sensor is integrated behind the high gloss glass panel (as also could be concluded out of research 4).

Part of the design is about being shiny, catching people's eye. When that has happened, the real purpose of Doplor happens. People see the visualisation and they will idealistically understand the meaning of it, relating it to the auditory environment.

The parts are the same as in the prototype, but now they are all updated to be similar to each other. To create the redesign, first a minimalist collage was made (figure 74), and then Doplor was redesigned. The collage helped with determining the small bezelles encasing and a similarity in patterns. The size has remained the same as the prototoype (500x300x35 mm).

Figure 74 A minimalist collage was made to gain inspiration for the final design.

Figure 73 - below The redesign of Doplor. An almost bezelless design with similar patterns and almost no visible gaps.



The future design consists of multiple parts, of which mainly the encasing, motherboard and screen are the most important (figure 75). Around Doplor an accent color was used for all rubbers around different components.

The motherboard has all different components combined, such as the CPU (processing power), GPU (visualisation power), RAM (loading in all visualisations), but also an integrated wifi-chip so that visualisations can easily be downloaded and Doplor becomes a design that only has one cable. This gives a clean and uncluttered appearance when implemented in the Intensive Care,

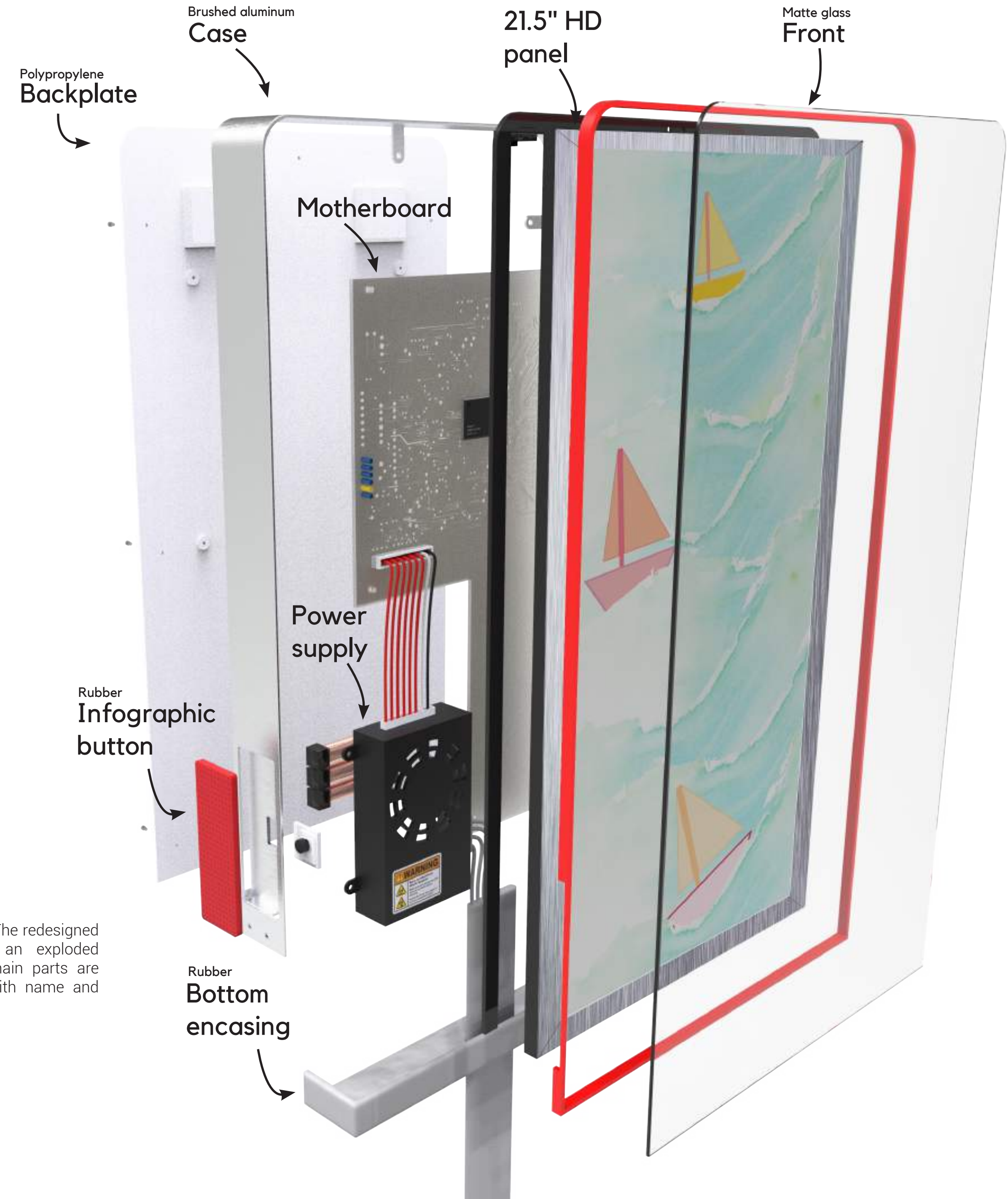


Figure 75 The redesigned Doplor as an exploded view, the main parts are indicated with name and material.

Section 7.5

Conclusion

Apart from a reflection, this thesis and my graduation have come to an end. In this last section I will go through the design once more, why Doplor has been designed, and why it would benefit the end user.

The critical care environment has been witnessed to be one that is unsuitable for sleeping in during day time. Auditory disturbances happen approximately every 12 to 15 minutes, and this is preventing patients to get into their deep sleep during the nurse's lunch break. Being able to get into deep sleep has been proven to be very useful for recovery, and obtaining it is possible. Five minutes extra between auditory disturbances could already make all the difference.

From all different auditive sources of the disturbances, it turned out that the main contributors were speech, incidents and alarms. These contributors mainly seemed to be induced by nurses. When questioning why actually these disturbances were present, it was not the case that nurses deliberately were very loud. On the contrary, they love their job and caring and curing patients. It turned out that the loudness of the nurse could be related back to the same phenomena as alarm fatigue. As nurses are working in a loud environment continuously, they become unaware of what actions cause loud noises. Through physological theories was also found that nurses do not like to continuously be each others point of remark, and they rather not say to each other when they are loud. That is the part where I could help.

What was needed within the Intensive Care, was a device that could help you get informed yourself, or help informing others when the auditory environment has been louder over the past time.

Through multiple rounds of testing, it could be concluded that the best way of getting someone's attention was in a visual way and when you wanted more information there was the need for a written explanation. To describe the loudness of an environment, this could best be done through the hostility of a visualisation, and a more distinctive 'loudness-state' could be obtained through adding differences in clarity, color, and speed. All these findings have been included in Doplor, an interactive painting, helping you understand the auditory environment a bit better.

Through testing with both students and nurses, a proper understanding and a small expect could be found. Both parties expected themselves to be more quiet with Doplor being around, they understood better what the causes would be when Doplor showed a loud visualisation and lastly, both parties liked Doplor's appearance and would see him as a real helper in quieting down as a team.

Even though more testing should definitely be performed to understand the full effect and change of behaviour in nurses, I truly believe that Doplor could be a great addition in quieting down as a team within the critical care context.

Section 7.6

Reflection

Within (only) 100 days, I think that I have come quite far with limited prior knowledge or research about the Intensive Care and Critical Care context. The starting point was about a loud environment within the Intensive Care and the possibility of measuring sound using Quietyme sensors. From there, bringing it to an interactive painting which also works as a prototype, is something I am proud of myself.

However, there are definitely remarks to be made to this design in general, and steps that still have to be performed before I can be fully sure that Doplor has a reason of existence.

One of the most prominent hiccups that I encountered is that I am no software engineer, and apart from writing some code and learning javascript, I have not come even close to actually creating and designing the PCB. I know that a CPU, a GPU, and about a gig of 8 of RAM are needed to fluently show and load all different visualisations. But apart from that, someone really knowledged should help me out with creating the internals and proper code to completely finish Doplor's internals.

Another big influence is whether Doplor, and it's visualisations, actually cause previously mentioned change in behaviour. The results of research 4 and 5 seem promising, both show a (slight) effect where both students and nurses expect themselves to act a bit more quiet with Doplor's presence. To me this seems logical. Noises occur all the time on the IC as nurses get tired of and deaf by them. But having a painting that continuously moves, and which has the possibility to show endless sorts and styles of visualisations, really seems like a design that you cannot just forget about or miss. The real test is to see whether this effect indeed happens when Doplor would be implemented for some time.

During this graduation, time was limited continuously, and I tried my best to get the most out of it. This implies that the research phase was solid and well thought through, but the ideation phase has been rather short and might come over as being limited. The research with the how-to booklets and the multisensory understanding both concluded into an idea that I already had on paper, and made it easy for me to continue with. But would I have gone further, went through multiple phases of ideation, and then analysed again, probably a different design would have come up. Obviously now I do not have a real clue what shape the design would have become, but it might have been even better.

Lastly there was my planning and approach to this whole graduation when I started early in April 2018. During that time I was determined to use the Design Thinking approach. Afterwards, now my graduation is nearly finished, I can conclude that I managed to perform this design method so-so. I have indeed managed to sympathise with the target group, but they remained a bit closed and distant from the design-work, and I still was at the IC too little to probably fully gain the nurses' trusts. I am not sure whether being at the IC even more often would have benefited my design process, as trying to generate findings is a full-time task, and transcribing everything makes it double the time. So having chosen to perform more tests with students has in the end benefited my workflow, but it for example has resulted in nurses wanting more humor in the paintings (as found in Research 5) - I simply did not know as I did not perform Research 3 with them as well.

Concluding, I dare to say that that I am satisfied with the result. Doplor has over the weeks become my 'design-baby', which I raised through different steps of designing. With the flaws which I have noticed during my process, I generated advice for myself, as a professional designer in the future, with which I will end this thesis:

» Do not be afraid to step up to people. Not only nurses, but everybody around you is a person, and they are not willingly trying to harm you. A question is really just a question away. Trying to get out of this comfort zone of thinking - "I can do this by myself" - has really helped you with generating findings.
» Your planning is there with a reason, but it remains a guide. Some phases require more time than the others. Plan accordingly and know when it is okay to take a bit more time to for example perform some research, and know when to stop to continue with the next step.
» Be the designer by remaining yourself. Remember how much fun you had by just explaining what you were working on? That is why you are becoming a designer, and that is why you actually already are a designer. You know how to find inspiration in aspects seemingly unrelated to eachother, and combining them in something that all of a sudden makes sense.
» Take more time for yourself when you feel you have to - and go easy on the coffee.

Section 7.7

References

Ajzen, I., & Fishbein, M. (1980). Understanding attitudes and predicting social behavior. Englewood Cliffs, NJ: Prentice-Hall.

Aminoff, M. J., Boller, F., Swaab, D. F. (2011).We spend about one-third of our life either sleeping or trying to do so. Handbook Clinical Neurology, 98(vii). doi: 10.1016/B978-0-444-52006-7.00047-2.

Backes, M. T. S., Erdmann, A. L., & Büscher, A. (2015). The Living, Dynamic and Complex Environment Care in Intensive Care Unit. Rev. Latino-Am. Enfarmagem, 23(3), 411-418. doi: 10.1590/0104-1169.0568.2570

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84(2), 191-215. doi:10.1037/0033-295X.84.2.191

Bandura, A., (1986). Social foundations of thought and action: A social cognitive theory.

Boogers, K., (2018). CareTunes: Music as Nurses' monitoring tool. Retrieved from TU Delft repository.

Daffurn, K., Bishop, G. F., Hillman, K. M. & Bauman, A. (1994). Problems following discharge after intensive care. Intensive and Critical Care Nursing, 10, 244-251.

Delaney, L. J., Haren, F. van, Lopez, V. (2015) Sleeping on a problem: the impact of sleep disturbance on intensive care patients - a clinical review. Annuals of Intensive Care, 5(3). doi: 10.1186/s13613-015-0043-2

Dunlop, M. D., & Reid, C. W. J. J, (1998). Exploring the layers of information retrieval evaluation. Interacting with Computers, 10, 225-236. doi: 10.1016/S0953-5438(98)00014-9

Edworthy, J., Page, R., Hibbard, A., Kyle, S., Ratnage, P., Claydon, S. (2013). Learning three sets of alarms for the same medical functions: A perspective on the difficulty of learning alarms specified in an international standard. Applied Ergonomics, 45, 1291-1296. doi: 10.1016/j.apergo.2013.10.003

Erasmusmc.nl, (2018). Geschiedenis van het ziekenhuis. Retrieved from https://www.erasmusmc.nl/overerasmusmc/wat_doet_erasmus_mc/historie/geschiedenis_ziekenhuis/ on 01-09-2018

Erasmusmc.nl, (2018). Missie en Visie. Retrieved from https://www.erasmusmc.nl/overerasmusmc/wat_doet_erasmus_mc/missie.strategie/ on 01-09-2018.

Fishbein, M. (1967). A behavior theory approach to the relations between beliefs about an object and the attitude toward the object. In M. Fishbein (Ed.), Readings in attitude theory and measurement (pp. 389-400). New York: John Wiley & Sons.

Fishbein, M., & Ajzen, I. (1975). Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research.

Hayes-Roth, B, R., Washington, D., Ash, R., Hewett, A., Collinot, A., Vina & A., Seiver. (1992). Guardian: A Prototype Intelligent Agent for Intensive-Care Monitoring. Artificial Intelligence in Medicine, 4, 165-185. doi: 10.1016/0933-3657(92)90052-Q

Johansson, L., Bergbom, I., Waye, K. P., Tyherd, E., Lindahl, B. (2012). The sound environment in an ICU patient room - A content analysis of sound levels and patient experiences. Intensive and Critical Care Nursing, 28, 269-279. doi: 10.1016/j.iccn.2012.03.004

Jones et al (2001). Memory, delusions, and the development of acute posttraumatic stress disorder-related symptoms after intensive care. Crit Care Med, 29(3), 573-580. doi: 10.1097/00003246-200103000-00019

Kafeza, E., Dickson, K., Chiu, W., Cheung, S. C. & Kafeza, M. (2014). Alerts in Mobile Healthcare Applications: Requirements and Pilot Study. IEEE Transactions on Information Technology in Biomedicine, 8(2), 173-181. doi: 10.1109/TITB.2004.828888

Kesecioglu, J. (2014). Improving the Patient's Environment: the Ideal Intensive Care Unit. Réanimation, 24, 341-343. doi: 10.1007/s13546-014-1012-8

Koch, S. H., Weir, C., Haar, M., Staggers, N., Agutter, J., Görges, M. & Westenskow, D. (2012). Intensive care unit nurses' information needs and recommendations for integrated displays to improve nurses' situation awareness. J Am Med Inform Assoc, 19, 583-590. doi: 10.1136/amiajnl-2011-000678

Korompeli, A., Muurlink, O., Kavrochorianou, N., Katsoulas, T., Fildissis, G. & Baltopoulos, G. (2017). Circadian disruption of ICU patients: A review of pathways, expression, and interventions. Journal of Crititcal care, 38, 296-277. doi: 10.1016/j.jcrc.2016.12.006

Kristensen, M. S., Edworthy, J., & Özcan, E. (2016) Alarm fatigue in the ward. SoundEffects, 6(1), 89-104. Retrieved from: http://www.soundeffects.dk/article/view/24915

Makoul, G., Clayman, M. L., (2006). An integrative model of shared decision making in medical encounters. Patient Education and Counseling, 60, 301-312. doi: 10.1016/j.pec.2005.06.010

Martin C. M., Hill A. D., Burns K, Chen L. M. (September 2005). Characteristics and outcomes for critically ill patients with prolonged intensive care unit stays. Crit Care Med, 33(9), 1922-1927. doi: 10.1097/01.CCM.0000178184.97813.52.

McGonigal, K. S. (1986). The importance of sleep and the sensory environment to critically ill patients. Intensive Care Nursing, 2, 73-83.

Minton, C., Batten, L. (2015). Rethinking the intensive care environment: considering nature in nursing practise. Journal of Clinical Nursing, 25, 269-277. doi: 10.1111/jocn.13069

O'Sullivan, R. J. (1991). A musical road to recovery: music in intensive care. Intensive Care Nursing, 7, 160-163. doi: 10.1016/0266-612X(91)90004-B

Özcan, E., van Egmond, R.,Gentner, A., & Favart, C. (in press). Incorporating brand identity in the design of auditory displays: The case of Toyota Motors Europe. in Foundations in Sound Design (ed. Michael Filimowicz). Routledge.

Quietyme.com, 2018. The Latest in Hospital Noise Reduction Research and Articles. Retrieved from https://www.quietyme.com/learning-center-hospital-noise-research/ on 01-05-2018.

Valdez, P., Mehrabian, A., (1994). Effects of Color on Emotions. Journal of Experimental Psychology, 123(4), 394-409. doi: 10.1037/0096-3445.123.4.394

Waterhouse, J., Fukuda, Y. & Morita, T. (2012). Daily rhythms of the sleep-wake cycle. Journal of Physiological Anthropology, 31(5).

Weinhouse, G. L. & Schwab, R. J. (2006). Sleep in the critically ill patient. SLEEP, 29(5), 707-716. doi: 10.1093/sleep/29.5.707

Woods, V., (2005). Musculoskeletal disorders and visual strain in intensive data processing workers. Occupational Medicine, Volume 55(2), 121–127. doi: 10.1093/occmed/kqi029

Zorgkaartnederland.nl, (2018). 315 ziekenhuizen in Nederland. Retrieved from https://www.zorgkaartnederland.nl/ziekenhuis on 8 - 8 - 2018.

Reference-links for cost calculate:

LCD:
https://www.alibaba.com/product-detail/22-Industrial-LCD-Panel-M220Z1-L03_1972325519.html?spm=a2700.7724857.normalList.1.23de33f1KqMAiO&s=p

Mold price calculation
http://www.icocity.com:8060/cost/CostCalculation.jsp

Wifi module:
https://www.tme.eu/nl/details/esp-wroom-32/iot-modules-wifibluetooth/espressif/?brutto=1&gclid=CjwKCAjw-8nbBRBnEiwAqWt1zSJ69eLACP96teRyc1tyKXG8e-L1gRTPx9gw0a8b0wGHms6OOg3pFxoC-m8QAvD_BwE

PCB circuit boards
https://portal.multi-circuit-boards.eu/?aspxerrorpath=/Customer/

Proximity sensor
https://nl.mouser.com/Sensors/Proximity-Sensors/_/N-7h7mq