Care Tunes

Music as a nurses' monitoring tool

Colophon

Care Tunes: A musical sonification for critical care

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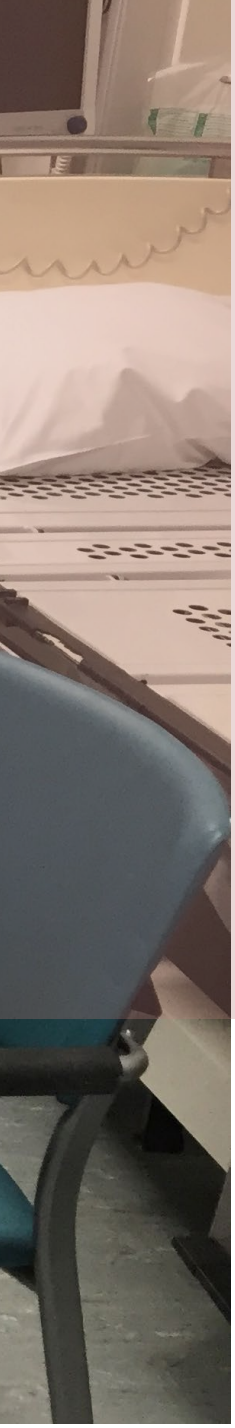


Executive summary

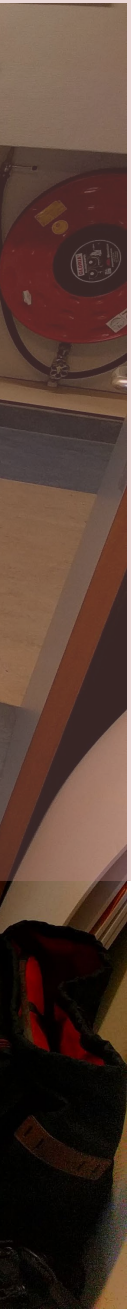
Nurses working in the ICU of the Erasmus Medical Center in Rotterdam are exposed to a vast amount of sounds from medical equipment. The amount of alarms nurses cope with causes alarms fatigue, which causes nurses to become desensitised to alarms. Not only is this a threat to patient safety, it also causes stress.

Care Tunes is a product design that allows nurses to listen to music to monitor their patients. By wearing an earpiece that plays the music, nurses can constantly be aware of their patients health without having to listen to the cacophony that is caused by alarms.

In an iterative design process several versions of this concept were designed, tested and evaluated. Simultaneously, research was conducted into the experiences nurses of the Erasmus MC have regarding sounds.

This research into the ICU context reveals insights into the experience and underlying mechanisms of alarm fatigue. Among them are the low level of information that alarms carry and the range of personal preferences nurses have when it comes to setting boundaries for their alarms. Alarms also tend to be used as a reaffirmation by using narrow alarm limits, causing more alarms to sound.

Care Tunes attempts to offer much more information in the sonification of patient data. This lets nurses listen to a pleasant musical stream to get all the information they need about their patient.



Acknowledgements

As a designer, I enjoy bringing a range of disciplines together in a project to come to a novel and surprising design, suited to the users needs. I like to incorporate new technologies, or at least technologies that are new to me, in my designs, while keeping a firm grip on the application of the design in the context of use. Mostly, I really like to make things.

This project has given me the opportunity to do exactly that, even more so than I could have anticipated when I started it. Not only have I been able to work on an important topic and on what I think is a very original idea, I have gotten to know many people along the way, without whom this project would not have been possible.

I want to express my gratitude to Design United for funding this project and to Elif, for her trust and support throughout the project. Her enthusiasm and passion for this topic has been a big motivation.

I would also like to thank Aadjan for nudging me into the right direction with his always honest and constructive feedback on my work and the design process.

I want to also thank Joe and Yoko, for being so involved in this project despite the distance and time differences. Their input never failed to be exactly what I needed to broaden my view on the issue at hand.

I'm very grateful to Rosel from whom I learnt a lot during the great collaboration we had in researching the ICU.

I want to thank Caryll, whose hospitality made our stay in the USA extremely pleasant, and all the others taking the time to meet with us during our visit.

Lastly, I would like to thank Ruben for collaborating with me and Lisanne and all my friends and family who have supported me throughout this process, by checking in with me, discussing the project with me and by reading and editing my work.

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Chapter 1
Introduction

Ever since my first lessons on the mandoline, music has played a role in my life. I've always enjoyed attempting to teach myself to play different instruments (with different amounts of success) and experimenting with recording and sound effects. Making music has often been a lower priority as other activities predominated. It has however always been able to regain my interest at some point in time.

One of these occasions has been the graduation assignment that is described in this report. This project gave me the opportunity to combine my interest in music with my master Design for Interaction. A very interesting combination, as it has often occurred to me that the (quite chaotic) creative process that I go through with my band when writing a song, has many parallels to the design methodologies I have learnt over the past few years.

This report will take you through the iterative process of the design of a musical sonification of patient data for the intensive care unit (ICU) of the Erasmus Medical Center in Rotterdam. Through five design cycles of research, designing and testing a product was designed that allows nurses to monitor a patient's vitals just through listening to music. Care Tunes, the idea that this project is based on, provides nurses with a much more harmonic and informative soundscape in their work environment then the vast amount of alarms they are currently exposed to every day.

The master Design for Interaction focuses on understanding users' needs in a certain context to design products that are relevant to the user. As a designer graduating from this master programme, in this project I will attempt to understand what nurses who work in the ICU go through and what challenges they face. By getting to know the environment that Care Tunes will eventually be used in, I can design a product that suits the everyday routine of the ICU. This understanding of the ICU will come from first hand experiences of the context, the involvement of nurses in research and testing design ideas with users in context.

1.1 Problem Definition

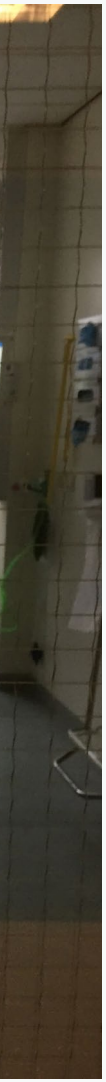
The Intensive Care Unit (ICU) in the Erasmus M.C. (EMC), where patients with severe illness or injuries are treated and/or monitored, relies in part on specialized equipment that helps ensure a normal functioning of the patient's' body. Critical events that are measured by equipment may require action from hospital staff. To notify clinicians (nurses, physicians) of such events, auditory alarms are an important part of monitoring equipment.

The EMC is currently building a new ICU that decentralises the nursing station. Nurse will be stationed close to the patient room that they are responsible for. There is a desire to be more patient-focussed and to create a quieter ICU. The redesigned layout is one of the ways the Erasmus MC tries to achieve this. The modernised ICU offers possibilities to think about innovative solutions regarding the ICU soundscape.

Alarm fatigue

Once introduced as a safety tool amidst an ever expanding amount of medical devices, alarms have now turned into a danger to patients and medical staff. In their annual top ten health technology hazards for 2017, the Emergency Care Research Institute (ECRI) states that "missed ventilator alarms can lead to patient harm". In their additional concerns regarding this topic, they describe alarm fatigue as a phenomenon "in which staff become overwhelmed by, distracted by, or desensitized to the number of alarms that activate." (ECRI, 2017)

Image 1: An empty patient room with different types of medical equipment



Several theories exist regarding the causes of this behaviour by people who are expected to respond to alarms from equipment. Some of the symptoms of alarms fatigue suggest that an excess of false alarms causes the issue. The fact that clinicians may purposefully ignore alarms of even switch them off altogether suggests that alarm fatigue is the result of the amount of non-actionable alarms. When the majority of the alarms that are perceived as unimportant or do not require any action, the alarm will lose its perceived urgency to the recipient (Ozcan et al., 2017).

It seems the desensitisation to alarms due to too many false alarms, often refered to as the cry wolf-effect, is not the only cause of alarm fatigue. Clinicians in certain cases miss alarms completely (Cvach, 2012). This would not leave them the choice to ignore or act upon them based on whether or not they assume the alarm to be false.

The design of the medical environment and the acoustic design of the alarms that are used have been recognised as a cause for the alarm fatigue (Edworthy and Hellier, 2005). Auditory warnings are used by a large range of equipment manufacturers. The alarms mostly cary very little information and the combination of sounds designed by different companies causes a cacophony in the ward.

Current use of alarms

Systems that are used on the ICU give alarms based on thresholds set by staff. When a value exceeds one of those thresholds, an alarm will sound (Siebig et. al., 2010). This way of alarming and the thresholds that are being used, are based on the tendency towards a high sensitivity that exists in an ICU environment. Staff at the ICU cannot afford a passive attitude due to the often life-threatening circumstances that patients are in (Blum & Tremper, 2010). This is combined with a low specificity, meaning the exact cause of an alarm is not reflected in what the alarm sounds like. The current use of alarms is further elaborated on in literature research.

1.2 Care Tunes

Care Tunes, entails the musical sonification of the data that nurses need to be aware of to ensure patient safety. This means that clinicians would listen to a stream of music that contains the information they need to be aware of the state of their patient. The musical stream would contain information about the patient's vitals and possibly other information that may be communicated through alarms in the current situation.

The use of music instead of alarms in has the potential to create a much more pleasant soundscape at the ICU. A musical piece can contain many different parts or instruments while still producing a coherent and pleasant soundscape, as opposed to the current cacophony of alarms.

Music may also be able to greatly reduce stress levels among people working in the ICU. Khalfa et. al. (2003)even show that listening to relaxing music can stop the increase of cortisol levels after a physiologically stressful task.

Another advantage of music is that it is possible for music to be present on the background while clinicians are working on one of many other tasks they need to attend to during their day. When music carries all the information nurses need about their patient, they can leave the nursing station while still listening and thus being aware of the patients health.

The team

The Care Tunes project, funded by **Design United**, is supported by several people. The project was initiated by **Dr. Elif Ozcan Vieira**, assistant professor at the TU Delft, and researcher at the **Erasmus MC** where she works on the Silent ICU project. **Joseph Schlesinger M.D**., assistant professor anesthesiology at the Vanderbilt Medical Center is involved in this graduation project as an external supervisor, advising on the medical aspect of the topic. **Yoko K. Sen** is a musician based in Washington D.C. in the USA. Recently she has been involved in several projects that aim to improve the soundscape of the ICU, motivated by her own experiences of being on the ICU. Part of her work was done in the innovation hub of the Sibley Memorial Hospital in Washington D.C.. Yoko is involved in the Care Tunes project to offer advice on the musical aspect of the design.

In the process of researching the experiences of nurses in the ICU, a collaboaration with **Rosel van den Berg** was initiated. Rosel is a UX designer and design researcher at Van Berlo. She had allready been working on research into the ICU for some time, commisioned by Elif Ozcan Vieira.

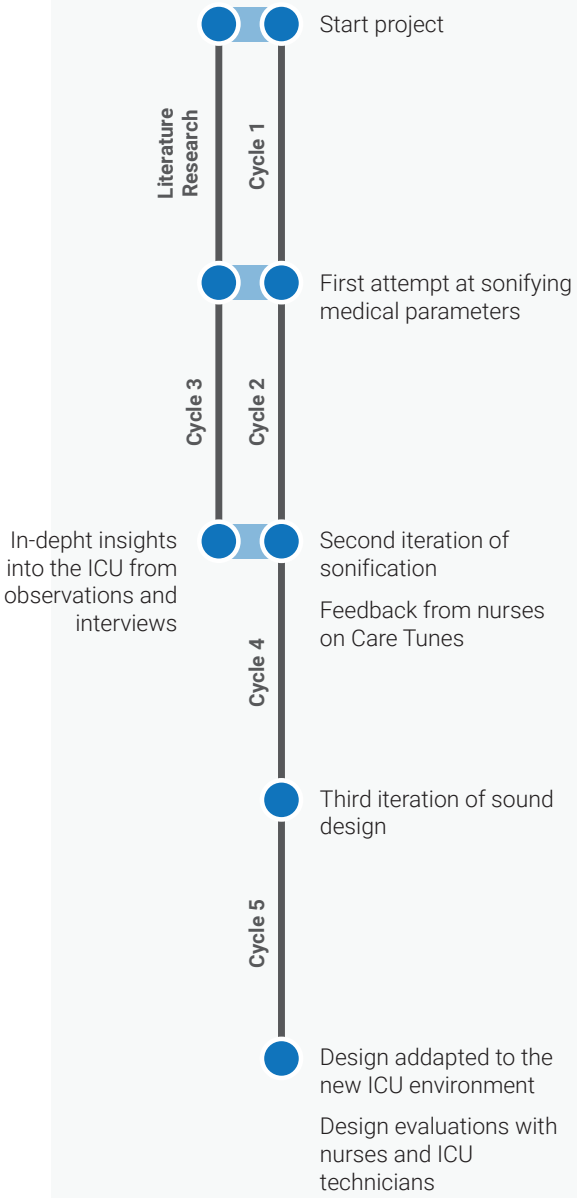


Image 2: An iterative approach is taken in the design process.

1.3 Assignment and process

The goal of this graduation assignment is to design and prototype a way of musically sonifying patient information for use by medical staff.

The assignment will include several activities.

The context that the personnel of the ICU at the EMC work in and the challenges they face regarding alarms and alarm fatigue is mostly unknown. The design will be based upon research into this context. This research will be performed with the help of contextmapping methods.

The assignment of the will focus on the design of Care Tunes to fit in the context of the ICU of the EMC with the work of nurses in mind.

Prototypes that allow for the evaluation of the design will be produced. Nurses and other clinical staff of the EMC ICU will be asked to participate in this evaluation.

Design process

As described earlier, the problem of alarm fatigue in the ICU is influenced by many different factors. It is difficult to create an overview of everything that is involved in this problem through a traditional design approach in which the problem is analysed, ideas are formulated and the best solution to the problem is selected. The unpredictability of the problem and the novelty of the Care Tunes idea can benefit from a more iterative approach.

In their 2001 article “Decision making: it’s not what you think”, Mintzberg and Westley suggest a doing-first approach for making certain decisions. They state that by doing something, by experimenting, insights can be gained about the problem at hand.

Doing-first is a suitable approach for situations that are novel and confusing. The situation that this projects aims to design for can be seen as such because of the many different medical disciplines involved.

The iterative design process (image 2) taken in this project will involve formulating a possible solution quickly, which can then be prototyped and tested with the target group. The insights gained from this first design will then be used to form the next attempt. This will be repeated several times as shown in the image. Producing prototypes as quickly as possible will not only help in exposing the factors involved in sonifying patient data, it will also serve as an effective communication tool to discuss concepts with medical staff. Care Tunes is an idea that not many medical professionals will be familiar with. Prototypes can help them understand it by giving them the possibility to experience the idea right away. This, in turn, will make it easier to ask them for their opinions of it.

Chapter 2
Literature research

Several topics that will have an influence on the project require a basic introduction. Though the iterative approach described in chapter 1 aims to gain first hand insights into these topics as quickly as possible, a basic understanding gained from literature will help ask the right questions when observing the ICU for example.

Regarding the ICU, some initial information can be found about what the purpose of the ICU is. The people who work there and what their tasks are will be briefly introduced in this chapter.

Some information about the purpose and design of traditional alarms will also be introduced. This will give an idea of where the problems with alarms may come from.

To improve the soundscape of the ICU, an understanding of the theory behind sound is necessary. This chapter will introduce some basic principles of the physics behind sound. Since Care Tunes involves the use of music, concepts like harmonics and key will also be touched upon.

2.1 The ICU

The ICU is a rather unique environment that many people don't often see. As any work environment, the ICU has its own specific challenges that clinicians face everyday. To be able to design for this context, it is important to have a good understanding of these challenges and of how people experience working on an ICU.

The Erasmus MC is currently working on a renewed ICU. This environment cannot easily be investigated as it does not exist yet. This report therefore describes findings and insights from research activities at the current ICU that have taken place throughout the project. Combining these insights with the information that is available about the new ICU gives an idea of how people will experience this new workplace. This assumes the clinicians' attitudes, values and challenges will not change greatly in the new environment.

Stakeholders

Work at the ICU involves stakeholders from a range of disciplines and backgrounds. Some of them, mainly nurses, are there for the duration of their day while others perform tasks that require them to be there for just certain moments. Among these people, a wide variety of tasks is performed. Some of them are part of the core treatment and caretaking responsibilities of the ICU, while others are related to support of the unit.

Image 3 gives an overview of the people who work at the ICU and how they work together. It also discusses the relationship different people have to each other, if they have any at all. This design project focusses on nurses as a target group for the product design.

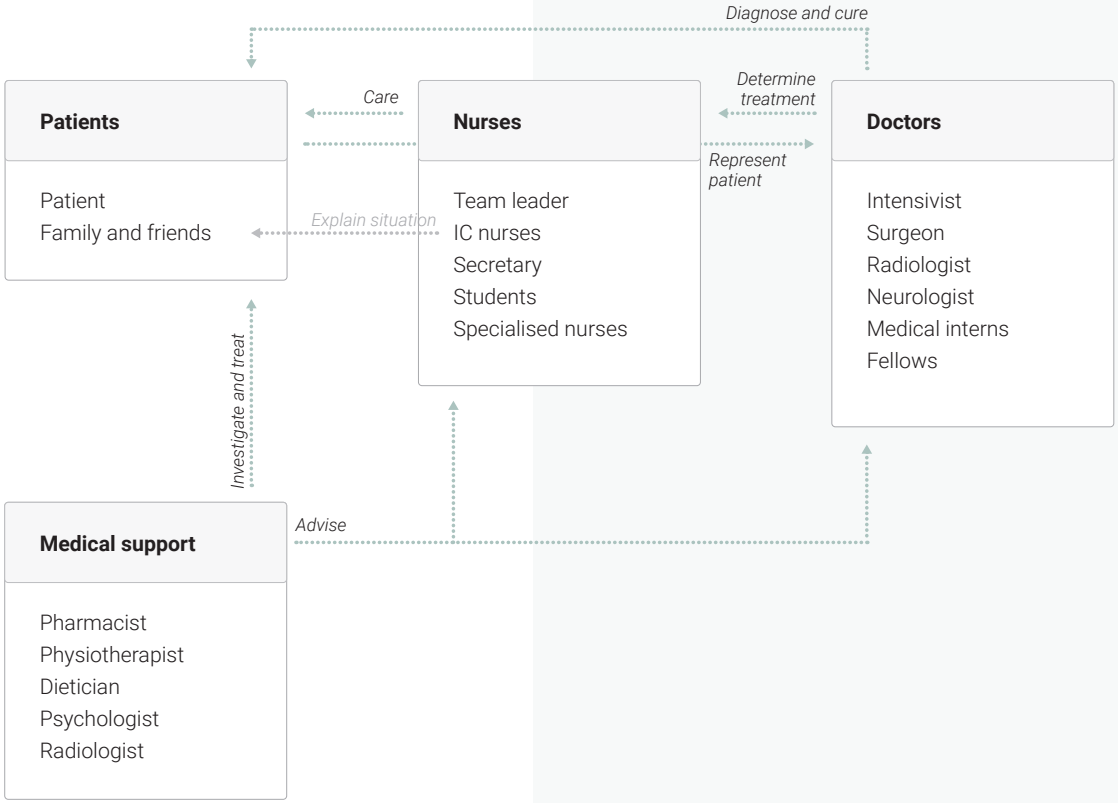


Image 3: Many different stakeholders are involved in the work at the ICU.

2.2 Alarms

Alarms, or auditory warnings can often be found in critical environments. Alarms notify people in such an environment of critical events that require their attention. Environments in which alarms are used include power plants, manufacturing facilities, cockpits of vehicles and intensive care units of hospitals.

In Fewer but better auditory alarms will improve patient safety (2005), Edworthy states that the use of auditory warnings as opposed to visual cues has the advantage that the recipient can be looking away from the event and still perceive the warning. An example of an auditory warning in everyday life is the siren of an ambulance, notifying drivers who may not have seen the vehicle approaching.

Auditory warnings can be divided into the categories of non-verbal signals, verbal messages and auditory icons (Baldwin, 2012).

Non-verbal signals are mostly non-specific siren or bell-like sounds. The ambulance is an example of a non-verbal auditory signal.

Verbal messages involve language to specify the event that needs to be communicated, like an anouncement on a train station.

Auditory icons are a relatively new development in which the auditory warning consists of a sound that represents the critical event with a metaphor (Belz et. al., 1997). An example of an auditory icon is a sound of pills rattling in a cup to represent an event related to medication.

When designing an alarm, the intensity, frequency and on- and offset of the sound can be taken into account. These are of influence on the perception of the alarm by the recipient as they determine noise penetration, allerting effectiveness, perceived urgency and annoyance (Baldwin, 2012).

Edworthy (1994) argues that in many situations determining the correct levels for alarms is considered less efficient than using very loud alarms. After all, the repercussions of not hearing an alarm are far worse than those of hearing a loud alarm. This results in alarms that use brute force to ensure the recipient hears the warning. Such alarms will have a high frequency, a high intensity or a combination of both to ensure noise penetration and allerting effectiveness.

2.3 Sound and Music

Sound plays an important role in everyday life for most people, and as has been established, it plays an instrumental role in the ICU. Apart from the qualities of alarm sounds and how they may play a role in the problem at hand, Care Tunes takes music as a solution for it. This section therefore gives a basic overview of sound and music theory which can be put to use in the design process.

Sound

Sound is made up out of waves that travel across matter. We can perceive these waves by hearing. Sound waves compress and depress air. These vibrations travel into our ear where the pressure differences excite our eardrum (entnet.org). This means we can hear things around us that cause sounds. These might include noise (a car passing by, the airconditioning), speech, man made auditory cues (a phone ringing or an ambulance) or music. So many sounds we hear are not music. For sound to be perceived as music, or even as a musical note, there are a few conditions.

From pitch to key

Every soundwave has a frequency. This is the speed at which recurrent peaks in the wave succeed each other. In noise, there are a big range of random frequencies. The spectrum of a recording of noise may look something like the one shown in image 4.

When sound is produced in just one, constant frequency, it is perceived as a tone. The sine wave in image 4 would play a clear tone when the signal is played back by a speaker.

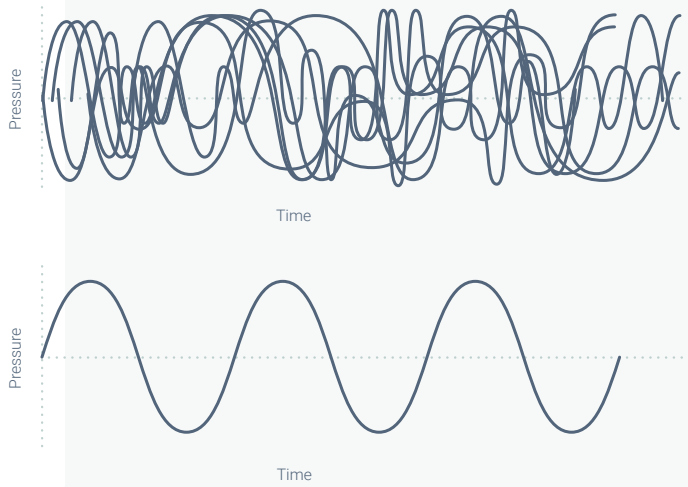


Image 4: Noise (top) consists out of a random spectrum of frequencies. A clean sine wave (bottom) is percieved as a tone.

Image 5: Each note is assigned to a frequency, based on 440 Hz

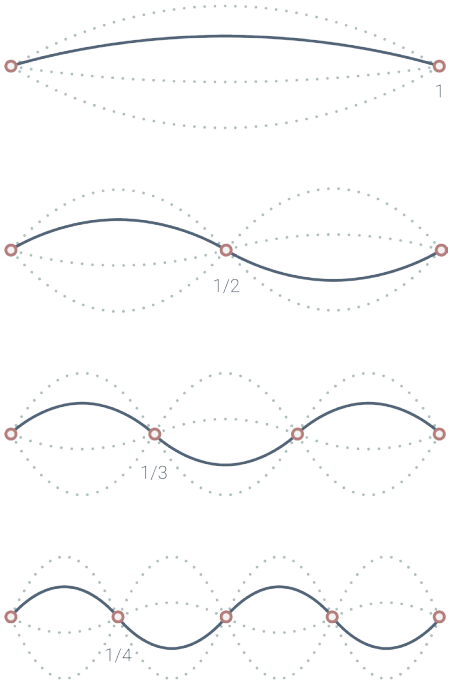


Image 6: Each partial is at half of the wavelenght of the previous one.

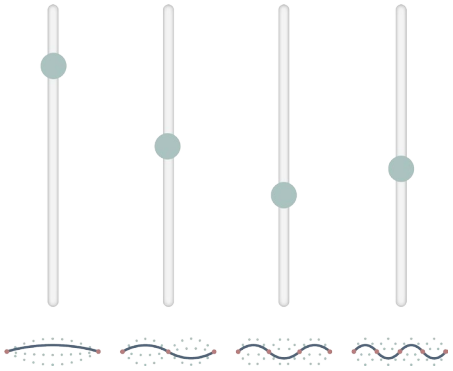


Image 7: The volumes of different partials relative to each other detemine timbre.

When a single sine wave is played, it can also be perceived as a musical note. The tone is perceived relative to other frequencies on the musical scale and therefore a note can be assigned to it (Levitin, 2006). Because frequencies have to be somehow assigned to musical notes, modern music generally uses the A440 pitch standard, which puts the middle A at 440 Hz (iso.org; Levitin, 2009). All other musical notes can then be deducted from this, as shown in image 5.

Unlike tone generators, musical instruments don't usually generate just one isolated frequency. When a guitar string is strung for example, it will vibrate in many frequencies at once. The most prominent frequency from an instrument is called the fundamental. This determines the tone that the instrument produces. The other frequencies that can be heard are called partials. Musical instruments' vibrating bodies are designed to have mostly harmonic partials, meaning they have frequencies that are subdivisions of the lowest frequency as shown in image 6.

Partials and timbre

When listening to a musical instrument, people will usually be able to hear the difference between instruments. Most people can tell the difference between a guitar and a trumpet when they hear them (even though they may play the same note). These differences in how instruments sound are called timbre. Timbre is what enables us to distinguish different instruments or one person's voice from another's. In musical instruments, timbre is determined for a large part by the relative volumes (image 7) of the different harmonic partials of the instrument.

Timbre and tempo

In a sonification of patient data, key, tempo, pitch and timbre could all be used to represent values of the different parameters involved. This same aspect of the piece should also be able to bring a part to the foreground or to the background to be able to draw the attention of the listener. An important criteria for this is whether or not listeners will likely be able to detect changes.

Timbre seems to be an aspect of sound that is quite universally recognised by people. People are able to remember the voice of someone they know and recognise it. Differences between musical instruments, especially from different families, can be heard by most untrained people. A guitar clearly sounds different than a trumpet, even when playing the same note.

In 'Remembering the melody and timbre, forgetting the key and tempo', Schellenbach and Habaschi (2015) show how people perform better at the memorisation of melodies when the timbre remains the same in both instances they heard it in. This implies timbre plays a role in recognition of melodies.

Wolpert (1990) even shows that to people without musical training, timbre has a bigger influence on the perception of a musical excerpt than harmonics. When non-musicians are asked to select the excerpt they heard earlier, 95% will select a sample in which the instrumentation is unchanged, ignoring that sample's incorrect harmonic accompaniment.

If non-musicians are indeed inclined to recognise musical samples by their timbre, this would be a useful attribute for to represent data in a sonification. It would mean users could listen to the sonification and recognise changes in the values it represents without having to identify tonal or harmonic changes. This can make the design less reliable on musical training.

Levitin and Cook (1996) show that the memory of a piece of music contains a reasonably accurate tempo for that piece. When people are asked to reproduce a song they had not hear for at least 72 hours, the majority of people are able to reproduce the tempo of the song with an error of only 8% or less. This suggests there is an absolute memory of tempo when people remember a song.

A musical sonification will inherently have a certain tempo. Because people have a reasonably accurate memory of a tempo of a musical piece they have heard before, this tempo, like timbre, seems a suitable aspect of music for the representation of data.

Auditory grouping

When people hear sounds, which may come from several different objects at the same time, they hear a broad range of frequencies. The sound they hear contains all the sounds from different sources mixed together. The frequencies perceived by the ear do not carry any information about which object it is that produced them. The listener therefore need to analyse this mixture of frequencies to recognise them as separate sounds (Darwin, 1997). This process is called auditory grouping.

This problem of interpeting sound to a level that allows us to assign them to an event is something that concerns composers. When people should recognise different instruments in a composition, they should be able to distinguish them from the mixture of sound that makes up the entire piece. Similarly, a succesful use of data comunication also depends on the listeners ability to discriminate between the different parameters they hear.

Bergman () describes several cues that listeners use to determine the source of a sound.

Onset and offset syncrony is a cue based on the fact that sounds coming from the same source will usually start at the same time.

A range of frequencies may come from the same spatial location, indicating it may come from the same source.

Sounds from the same source tends to have similar amplitude fluctuations.

Frequencies that are close together tend to indicate the same source.

Chapter 3
A first stab at sonification

Cycle 1 starts right at the start of the design project, meaning very little is know about the problem yet. The main goal of the first cycle is therefore to explore the context, stakeholders and technical challenges of the design of a musical sonification. It is not yet clear what factors will play a role in this design process. This first cycle will therefore aim to uncover these factors though a first attempt at designing a way of sonifying patient data and prototyping this design. This will also indicate how suitable different tools are for this and next prototypes.

3.1 A first hand impression of the ICU

One of the first activities undertaken in the project was to visit the ICU at the Erasmus MC to get a first impression of the context relevant to this project. A short observation of the ICU combined with a tour by Ditty van Duijn, research coordinator of the ICU, gave the following impression of the environment.

General ICU information

The ICU at the Erasmus started in the 1960's from a need to monitor patients more closely than was usually possible at the time. This started with a ward where people could be assisted by a mechanical ventilator. Possibilities for life support and monitoring have grown since then as technology has evolved.

The ICU used to be split into several departments where different types of patients were housed. This is no longer the case as all types of patients are now together. This means that nurses now need a broader set of skills and knowledge whereas they used to have more specialized skill sets. This is reflected in the affiliation some nurses still have with a certain type of patient.

Equipment

The ICU has rooms, that are called boxes, which all house one patient. Some of these boxes can have a low or high pressure relative to the surrounding spaces and can only be entered through an airlock. This helps prevent contaminations leaving or entering the box.

Medical equipment is an important part of the ICU in order to monitor and support patients. Many patients at the ICU need life support to take over functionality of one or more of their vital organs. Nurses and doctors also use medical equipment to keep track of a patient's health and to administer nutrition and medicine. Since this equipment communicates a lot of information through the alarms that currently cause alarm fatigue, an understanding of their functionality and intended use will help improve the ICU soundscape. Form the first observation of the ICU, followed by a conversation with assistant professor at the Vanderbilt Medical Centre Joseph Schlesinger, the following devices in image 8 are found to be important to be aware of.

Image 8: An overview of the most frequently used equipment in the ICU

Ventilator

Assist in breathing or takes over breathing completely. Some patients can't breath by themselves. The ventilator is connected through a tube that goes directly into the patient's airway. As the patient improves, the tube may be removed. To prevent drying out the airway, the ventilator can mix the air with water.

Drug infusion pump

These are used to administer drugs to patients. They automatically dose a precise amount over long periods of time. A drug infusion pump takes a syringe which contains the fluid that is to be injected.

Bedside monitor

The monitor shows the patient's vitals on a screen so the medical staff can track them. It will alarm staff if certain values exceed boundaries set by the nurses. It generally shows Heart rate (BPM), the level of oxygen in the blood (SPO2), blood pressure measured from an arterial line (ART) and a respiration curve.

Volumetric pump

These pumps provide liquid tube feeding to a patient. This is slowly and accurately administered through an intravenous injection over a period of 24 hours. Liquids come from a bag or a bottle. These pumps sound an alarm when a supply of fluids is almost empty or when a line is obstructed.

Alternating pressure matress

To prevent skin breakdown due to patients lying down for long periods of time, this mattress is able to put pressure on alternating areas of the body. Hence, the body is supported by alternating parts of the body.

Dialysis equipment

This equipment is not standard in each box. It is stored away in a separate space and is used only in the event of kidney failure or a risk thereof. It takes over the functions that the kidney usually performs.

3.2 Design

In the first cycle, a first attempt at musically sonifying patient data is done. Relatively little research into the context has been conducted yet, but some observations and conversations have already given some insight into what it is like to be a nurse at the ICU. These insights gave the incentives for this first design attempt.

Goals

Producing a design right away helps to answer questions that arise from the main premise of the Care Tunes idea, using music to communicate patient data.

It is not yet clear what will be involved in achieving a musical sonification. By attempting to do so right away, challenges that may be encountered during the project become clear. A big part of the work done in this cycle consists of determining which tools are best used for developing a musical sonification.

These goals lead to the following research questions for this cycle:

How can patient data be musically sonified to communicate changes in the relevant parameters?

Somehow, patient data needed to be transformed into music. A few more questions arose in trying to achieve this:

Which data should be sonified and can this data be retrieved from equipment at the EMC?

Which properties of a musical piece can be used to convey information to the listener?

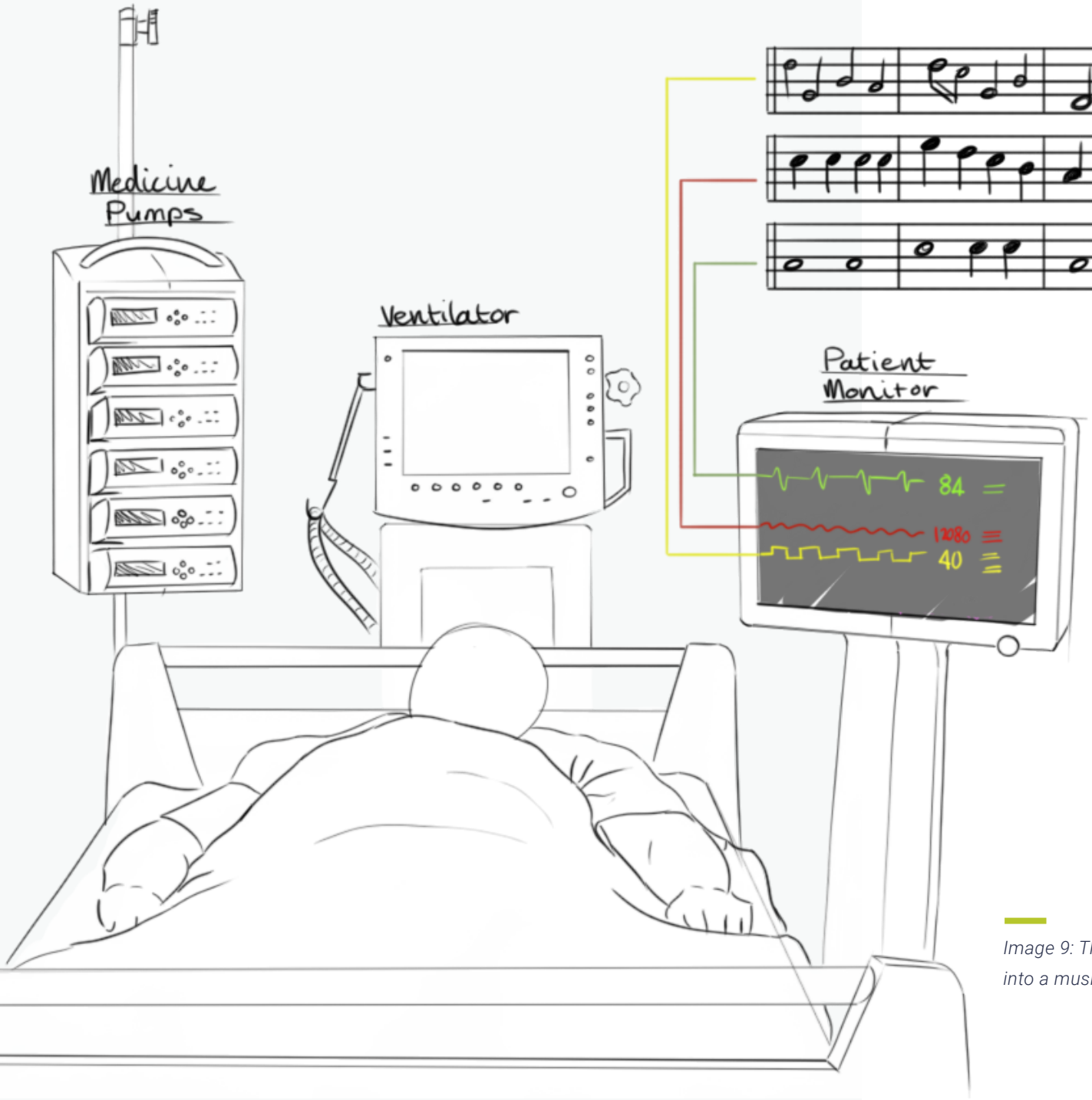
Which are most suitable for the design of a musical sonification of patient data?

Medical Data

Judging from the observation at the ICU and the conversation with Joseph Schlesinger, the patient monitor seems to be a central piece of equipment at the ICU. The vitals of every ICU patient are monitored closely. Therefore these vitals would be a good starting point for a musical sonification.

From an interview with Teus van Dam, working in technical support in the ICU, it had become clear that the equipment at the ICU is quite a complicated collection of brands, types and ages of devices. This is important to note because it makes a single datastream from all of the equipment that is being used seem difficult.

Directly retrieving the data from the equipment was found to be possible but has not yet been achieved in the duration of this cycle. The data input will therefore be simulated for demonstrational purposes.



Musical sonification concept

For the musical sonification to carry the information that nurses need to monitor their patients, a universally understandable aspect of music seems desirable. This same aspect of the piece should also be able to bring a part to the foreground or to the background. This will likely be useful in drawing the attention to one of the data points that is being sonified. Reasoning from theories regarding sound perception and musical theory, as described in literature research, timbre can be assumed to be a property that can be employed to achieve this.

Image 9: The sonification will turn each patient vital into a musical instruments part in a composition.

3.3 Prototype and evaluation

A prototype is built to demonstrate the concept of using three of a patient's vital signs to influence the way different parts of music sound. Because no real patient data is available yet, the prototype uses input from the user to change patient vitals, which then influences different software synthesisers. The prototype that is presented as a result of cycle one consists of a Max MSP program (image 10) that sonifies three patient vitals that are often monitored on the patient monitor; heart rate (HR), Oxygen levels in the blood (SpO2), and blood pressure (BP).

Max MSP

Manipulating synthesisers based on data can be done with the help of Max MSP. Max is a visual programming language that is often used for multimedia purposes. In Max, one can build a 'patcher', which consists out of objects that all have their own function and can be connected through patch cords to create the desired functionality.

Max also offers integration with Ableton Live, which will become instrumental in prototyping later design iterations. In the first design cycle, software synthesisers and audio effects that are integrated in Max are used to generate musical motives. Parameters of the software synthesisers that influence it's timbre can be manipulated based on the numbers of simulated patient vitals. Image 11 shows a state diagram of how the Max path works.

Image 10: An interface built in Max MSP allows for demonstration of the first sonification design.

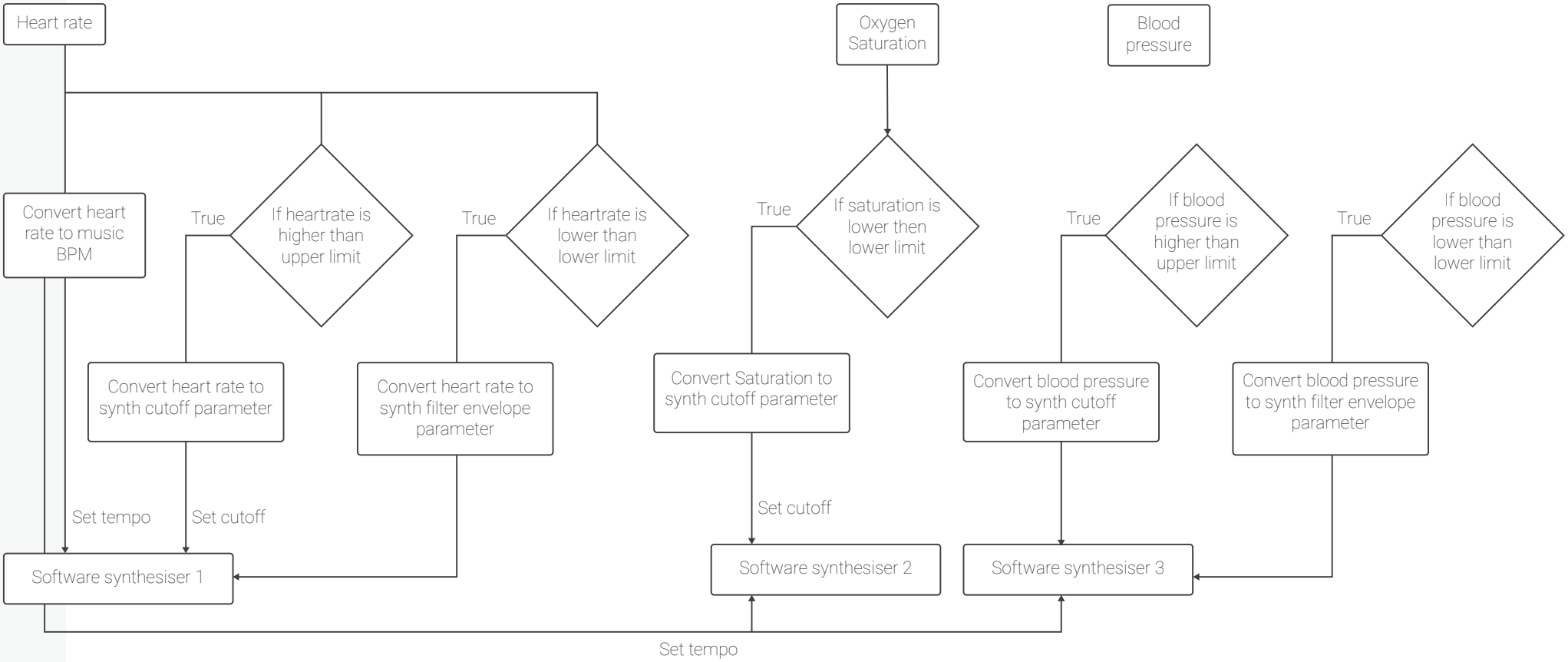


Image 11: State diagram of the Max patch that constitutes the first prototype.

3.4 Results

The first iteration of designing takes the insights that have been gathered during the first cycle by the initial observations and conversations at the ICU of the Erasmus MC into a design proposal.

The prototype helps in communicating the project to people involved and gathering their feedback. It is also a way of exploring the possibilities and the tools that are available in the realm of generative music.

The first design proposal was evaluated by demonstrating the design to experts in the Care Tunes team. This results in several insight into how the design can be improved in the next cycle. From these insights, the design goals for cycle 2 are formulated.

Feedback

This first prototype shows one of the possible ways in which events can be sonified. It uses timbre and tempo to do this. Demonstrating this prototype raises questions and comments that can be of used for the development of further concepts.

One of the clear limitations of the current design is the **lack of variation** in the melodies that are being played. A bassline, and two melodic motives are played continuously. Listening to them for a longer period of time may become just as tiring as listening to alarms for a whole shift. It seems that after about 15 minutes, the repetativeness can become bothersome.

The sound that the prototype makes has a particular atmosphere to it. This was described as soothing and subtle by people listening to it, but the **question of personal taste** also arose. How would different people appreciate the overall timbre of the sounds? In the next cycle, a composition that is a neutral and universally likable as possible could be considered.

Part of the Care Tunes project is to enable nurses to use the **design as a tool** for the work they do at the ICU. The current prototype does not yes consider their needs in the implementation of the sonification at the ICU. During the next cycles, the way in which users will listen to the sonification should be further investigated.

3.5 Design goals for cycle 2

The following design goals can be derived from the results of the evaluation of the first design cycle. They consist of goals relating to the product and goals related to insight into the context.

Design goals

3.1: The design should consider the difference between very neutral or very musical sonifications. The sonification of patient data in the current design form a melody. This unavoidably has a certain atmosphere to it. It would be good to investigate whether the sonification can benefit from this of if it would be better if it were as neutral as possible.

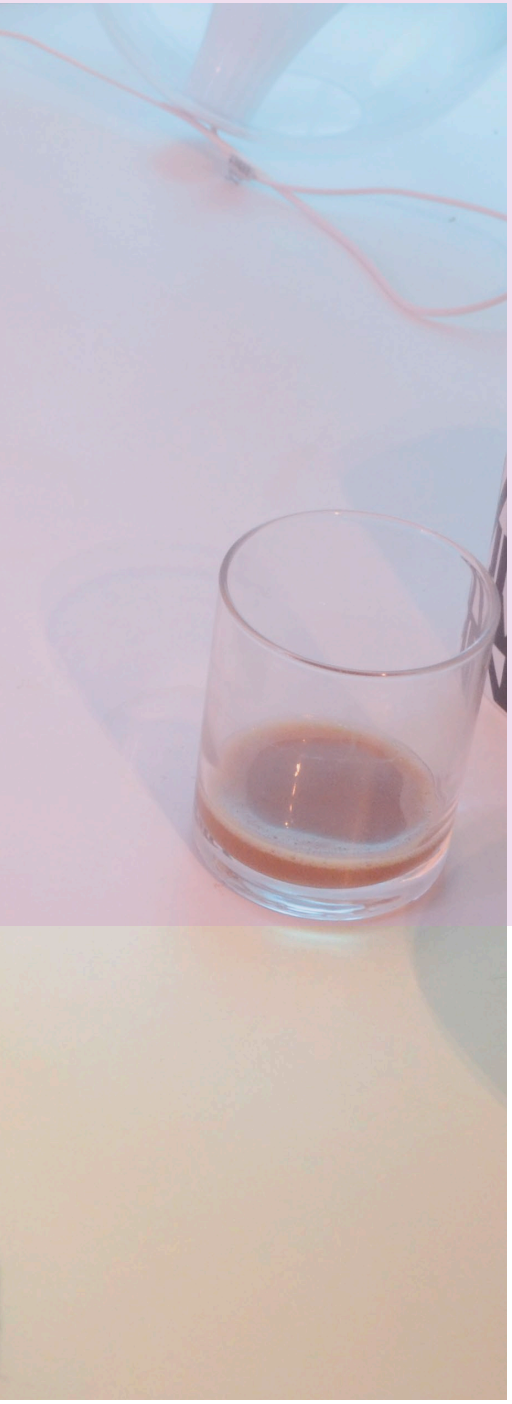
3.2: The design needs to be suitable for an entire shift of listening. As the goal of a sonification is to be able to constantly communicate medical data, nurses will listen to it during their entire shift. The relative simplicity and repetitiveness of the current design makes it unrealistic for them to do this.

Research goals

3.3: Gain insights regarding nurses' needs regarding information they receive about patients. The current assumption is that the most important data to sonify is data from the patient monitor. Research in the next cycle should point out whether this can be confirmed or if there are other information streams that also suitable for sonnification.

3.4: Define how nurses would best be able to use a sonification. The current design pays no attention to the way in which a sonification could be listened to by nurses. They should elaborate on how they imagine a sonification to be usefully implemented in their daily routine.


Intensiteit muziek
>>
Volgende huismer
Hartslag
SpO2
Bloedzuur



Chapter 4
Sonification for longer listening

In cycle 2, the development of the Care Tunes concept and the research into the context happened in parallel. The opportunity arose to make arrangements with nurses interested in participating in research, and in the meanwhile the redesigning of the concept continued. Cycle 2 and 3 describe these two simultaneous activities. The first containing the second iteration of designing and its evaluation and the latter going into context research that took place at the Erasmus MC. This chapter covers cycle 2, in which the sonification was redesigned based on design goals from cycle 1.

4.1 Goals Cycle 2

In the effort to achieve design goals 1 and 2 as formulated in chapter 3, several questions arise. In the second design iteration, these questions shape the redesign and testing.

1. Can one distinguish the changes in timbre that signify a change in physiology?

2. How can the soundscape be something that one can listen to for the duration of an entire shift?

3. How can soundscapes provide for different needs regarding the complexity of the music, as this may differ between people and situations.

4. How do nurses feel about the care tunes concept?

How do they think they would feel when listening to the soundscapes for a long time?

What are nurses suggestions for the practical side of the concept. How would they want to be listening to this in the ICU?

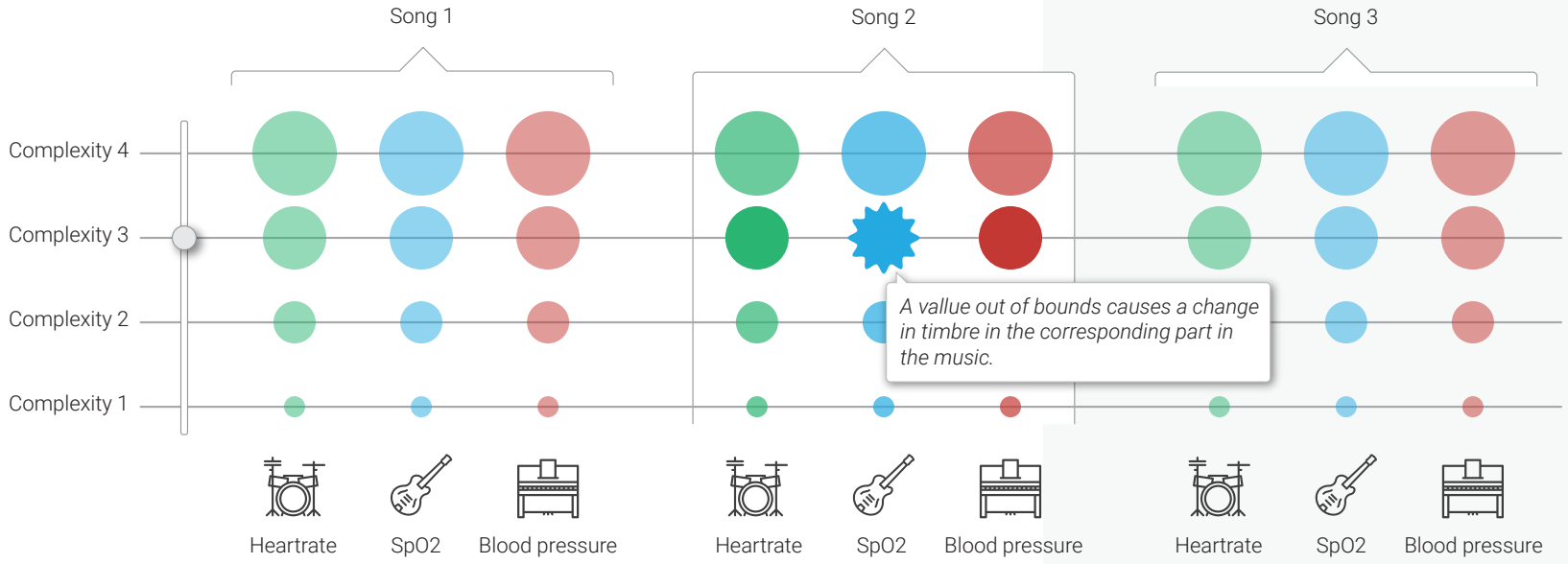


Image 12: The sonification is able to play 3 different songs, each in 4 different intensities.

4.2 Sonification redesign

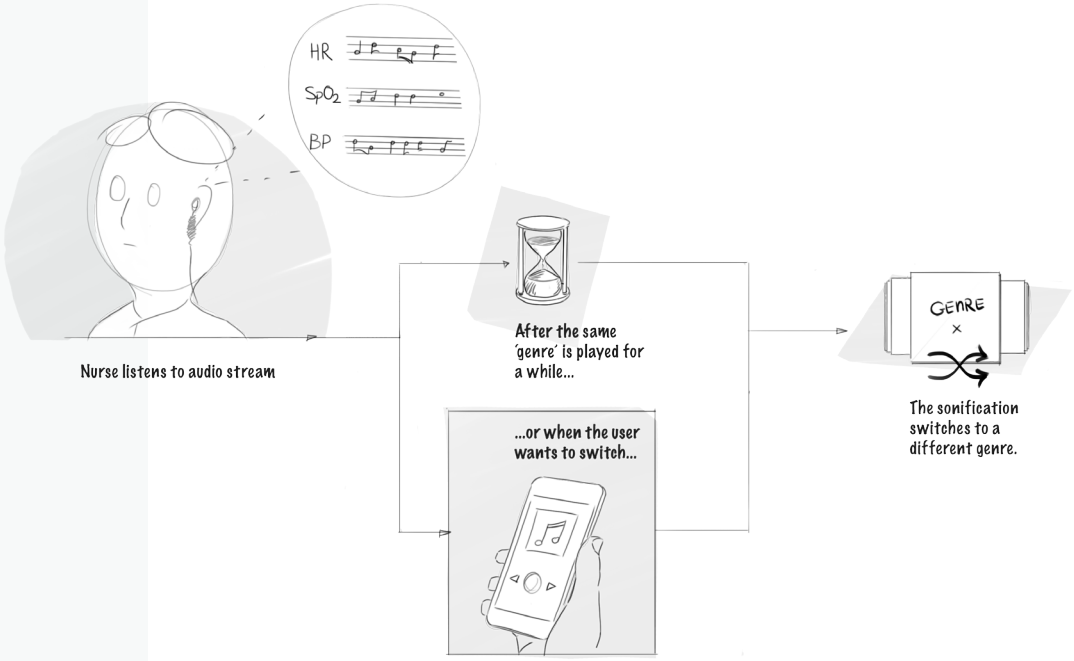


Image 13: Nurses listening to the sonification will be able to switch between songs.

The redesign, shown in images 12 and 13, was based on the results from the first cycle and the growing understanding of the context. In the redesign, the design goals from cycle 1 have been considered and changes to the design were made accordingly. The following changes were made to the design to reach the goals from cycle 1.

The design should consider the difference between very neutral or very musical sonifications.

From the expert evaluation in cycle 2, whether or not the sonification should sound very musical seems to depend on the taste of the person listening to it. It will also depend on the situation that person is in. When someone needs to concentrate a very simple sonification may work best, whereas simpler tasks may call for more stimulation from the sonification.

So, the redesign should allow the user to choose the complexity of the sonification. This way the user can decide whether they want the sonification to fade to the background as much as possible or if they may want to listen to something more interesting.

The design needs to be suitable for an entire shift of listening

Concerns in the previous cycle regarding the sonification becoming boring or irritating after a while seemed to stem from the repetitiveness of the sonification. The redesign therefore has a more song-like structure. The sonification consists of a drum part, a bassline and a chord scheme, played by a higher pitched instrument.

To try to make it more feasible that a nurse may listen to the sonification for an entire shift, several of these chord schemes are produced, each with a slightly different instrumentation. The user can choose between these different 'songs'. This way, when the user becomes bored with one of them, he or she may skip ahead to the next one.

4.3 User test

In this second iteration in the design process, a test of the current Care Tunes concept was conducted to determine the direction of the next iteration. This section describes this test and the pilot test that has been conducted to verify the methods used.

Questions

The current concept for sonification requires linking a change in timbres that occur in a soundscape to a patient's medical data. An alarm philosophy (image 14) is used to show the actions that are intended for different levels of alarms that would go of in the current situation. In the current Care Tunes concept, these actions will be evoked by a change in timbre in one of the parts of a soundscape that nurses listen to.

White alarms

Heart rate: Check functioning of Arterial line

Blood pressure: Check functioning of Arterial line

SpO2: Reconnect pulse oximeter

Respiratory rate: Check functioning of ventilator ventilator tubing

Yellow alarms

Heart rate: Be aware of heartrate vallue.

Blood pressure: Be aware of blood pressure vallue

SpO2: Be aware of oxygen level

Respiratory rate: Be aware of respiratory rate

Red alarms

In all cases: life threatening situation. Find help and take action immediately.

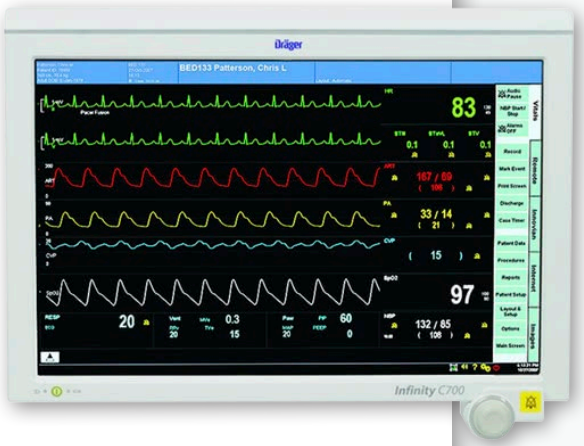


Image 14: Three levels of alarm urgency currently ask many types of action from nurses.

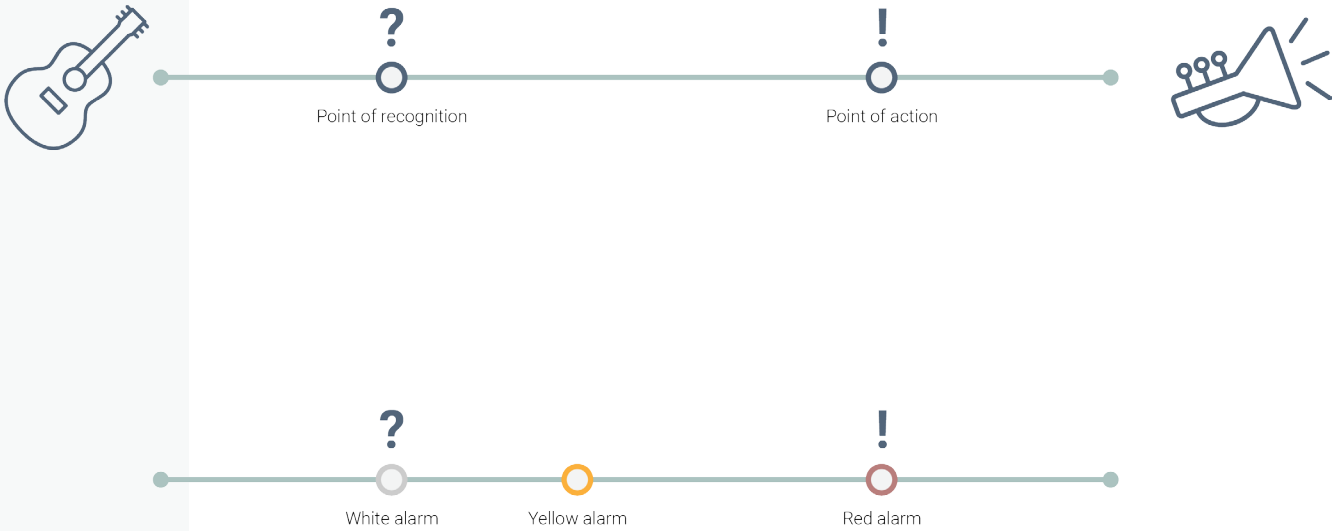


Image 15: By determining the how well people recognise differences between timbres, they can be linked to the alarms currently used.

When both a user's response to different levels of change in timbre and the desired responses to different levels of change in a patient's vital signs are known, this gives the required input to link the two together in the soundscape. Image 15 illustrates this.

Combining the alarm philosophy with the response to timbre change, different levels of urgency can be mapped to the range of timbres.

The desired response from the nurse can be extrapolated from the alarm philosophy. The actual response to changes in timbre leaves the following question for this user test:

> *How well do people succeed in recognising a change in timbre and assigning it to one of the parts of the soundscape?*

From the first iteration of the Care Tunes concept, the matter of taste across different users arose as a point of attention. Different users may prefer different kinds of soundscapes while performing different kinds of tasks. This also raises the question to which extent the soundscape should excite the user and how this may differ across a range of tasks that nurses need to perform. The following question is therefore also subject of this test.

> *How long can users listen to the sonifications produced before wanting to switch to a different soundscape?*
>
> *How distracting are different levels of excitement by the soundscape from the primary task the user needs to perform.*

4.4 Prototype

As in the previous design cycle, evaluating the design was done by building a prototype that allows users to experience parts of the design relevant for evaluation. This section explains how the prototype works. It was used in this cycle to conduct user tests, but also to demonstrate the design to nurses.

Ableton Live

Prototyping the concept of switching between different complexities in the musical composition requires the use of a tool that makes it easier to produce music than Max MSP does. Though many music production programs are available that would be suitable for this task, Ableton Live (image 16) is selected as the most suitable tool for this prototype. Ableton Live is prefered mostly because of its integration with Max, which makes it possible to automate parameters in audio effects from Max.

Ableton Live is a program for music sequencing and arranging, first released in 2001 (Ableton.com). Though ableton is used for recording or arranging music, many users also use it in live performance. In the 'session view' in Live, one can record audio or midi 'tracks' that all contain 'clips'. These clips can be triggered, either in the interface itself or from external hardware, allowing the user to create a composition out of pre-recorded samples or midi sequences.

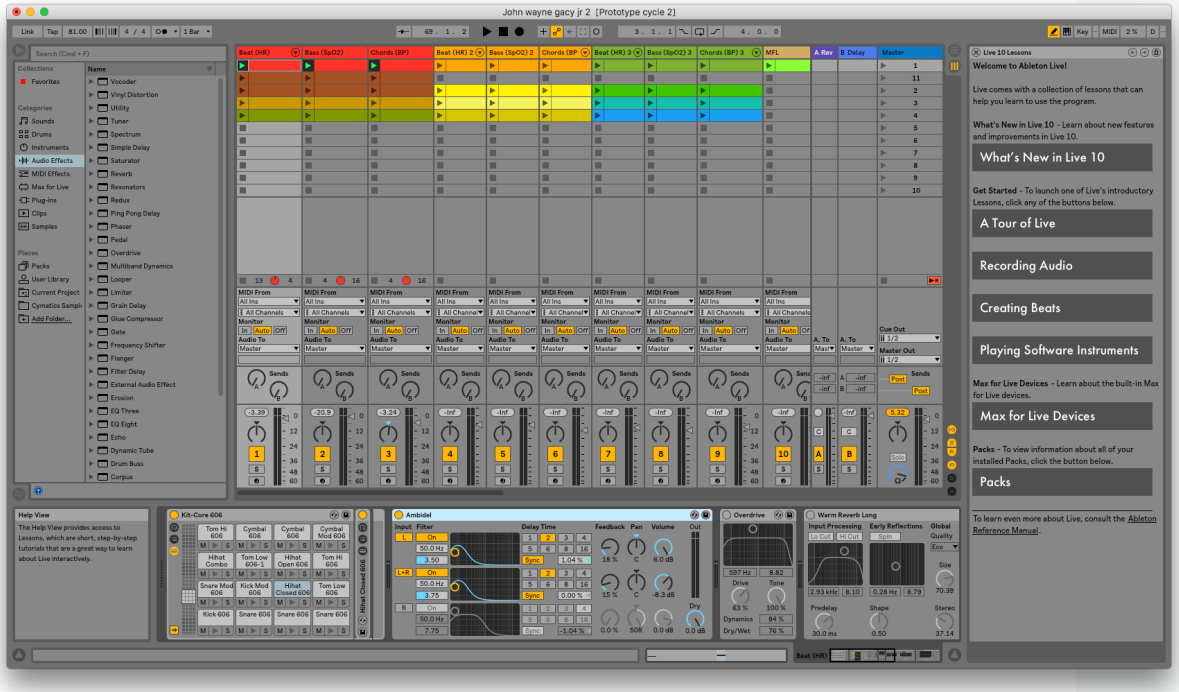


Image 16: Ableton Live in 'session view', where clips can be triggered to play in a loop

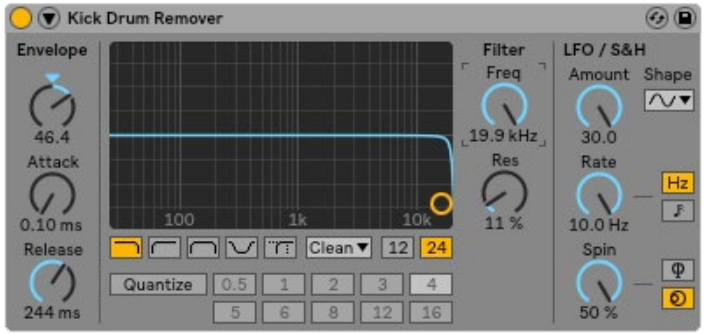
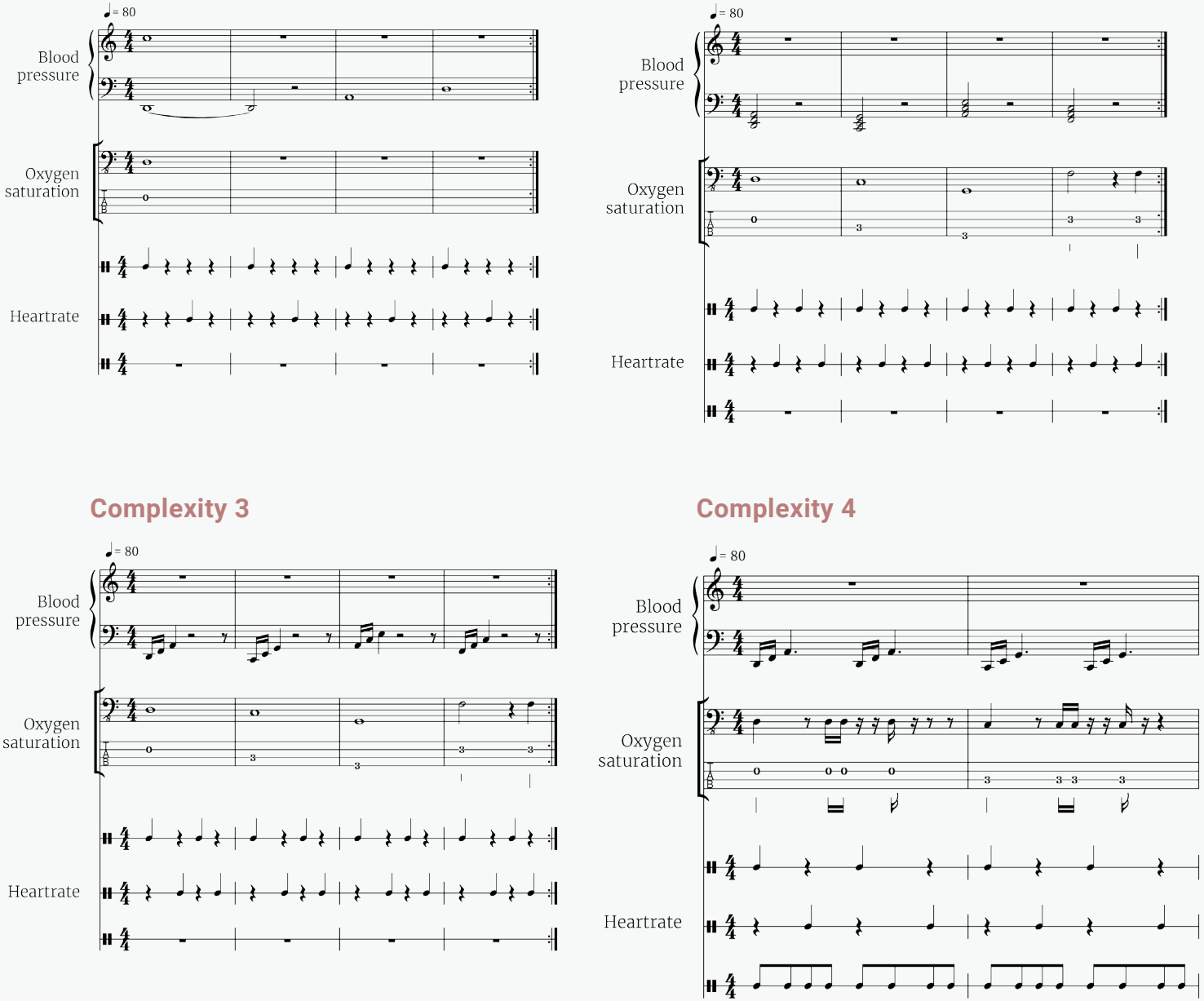


Image 17: Audio effects in Live can be controled throug Max for Live.



Genres and complexities

Three simple compositions are written in Ableton live, following the principle in image 12. They all consist out of a chord scheme accompanied by drums and a bass line. Each composition has slightly different instrumentation. This represents the different 'genres' the user can select from. Within each genre there are four different versions of the each composition, each of which is slightly more complex than the previous one. This is achieved by adding extra bass notes, adding accents in the drum part or by playing the notes of the chord sequentially and more often. Musical scores for the four intensities of one of the 'genres' are shown in image 18.

Image 18: Broken chord and more elaborate drum and bass rhythms make the piece sound more complex.

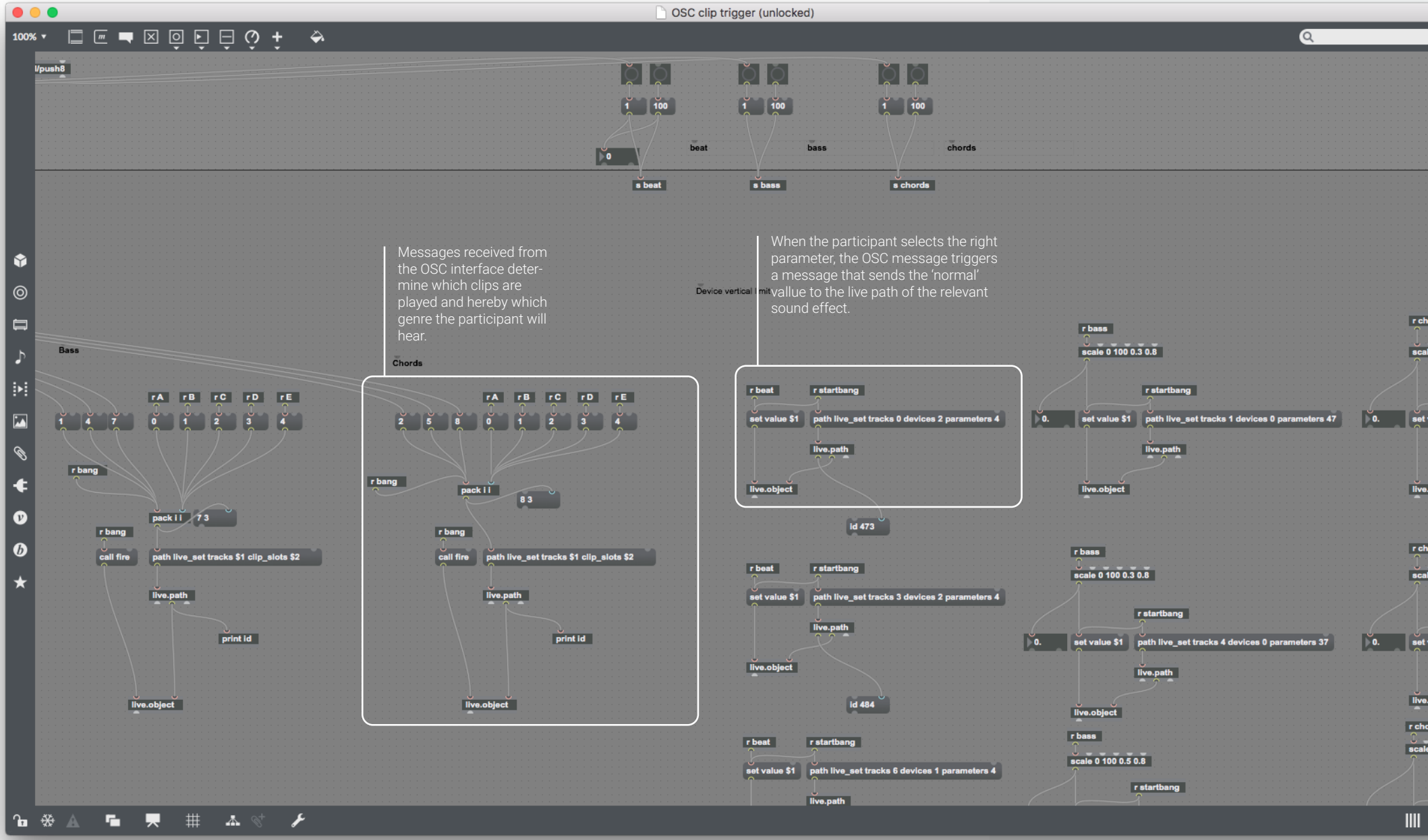


Image 19: A screenshot of the Max for Live patch

Image 20: By tapping controls in this OSC interface, the participant controls the sonification.

Max for Live

Max for Live (image 19) is used to create triggers that will automatically change one or more parameters in audio effects in Ableton live, like the low pass filter in image 17. In Max for Live, one can use the 'Live Object Model' (LOM) to control specific objects in Live. An object can be a clip, an audio of MIDI effect and many other parts of the software. In this case the LOM is used to let the user select the genre by triggering certain clips. It is also used to change the timbre of a parameter back to normal when the user selects the right parameter in the OSC interface. This way the timbre of each part of a composition can be changed by pressing a button in the Max for Live patch, and the test participant can hear they selected the correct parameter because it changes back to it's normal timbre.

Open Sound Control

Open Sound Control (OSC) is a protocol for communication between computers and other devices. It allows packets to be sent between two devices over a network. The device that sends the packet is referred to a the client. The receiving device is called the server. OSC messages are sent to an address, either locally or through a network, in which case the port and the address of the message are specified.

In the case of this prototype, OSC is used to enable the test participant to change the settings of the sonification they are listening to and to respond to what they hear. They will do so from a smartphone (image 20) as is explained further in the next section.

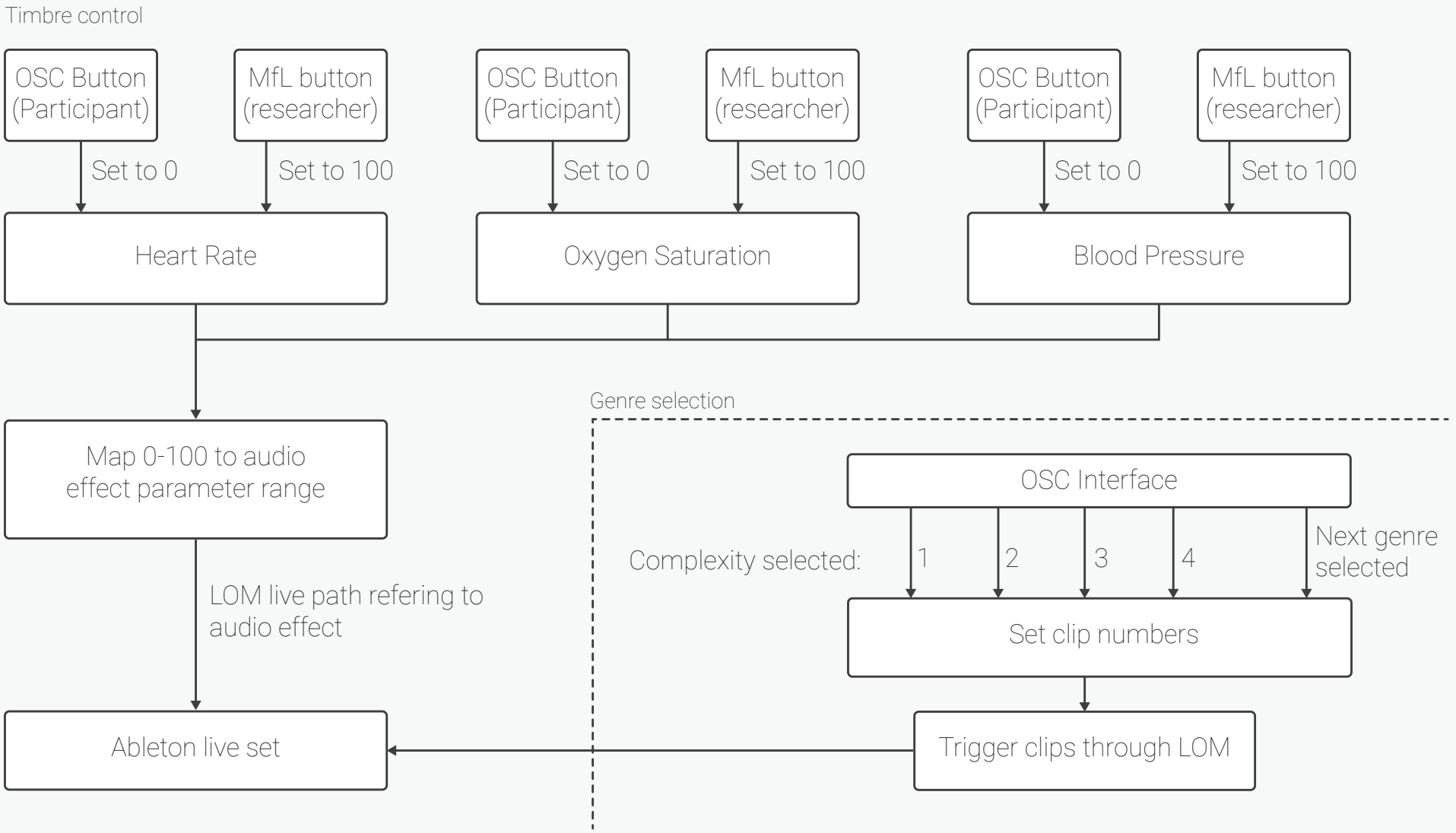


Image 21: State diagram of how the OSC interface and Max for Live are used to control timbre and let participants respond

4.5 Method and test setup

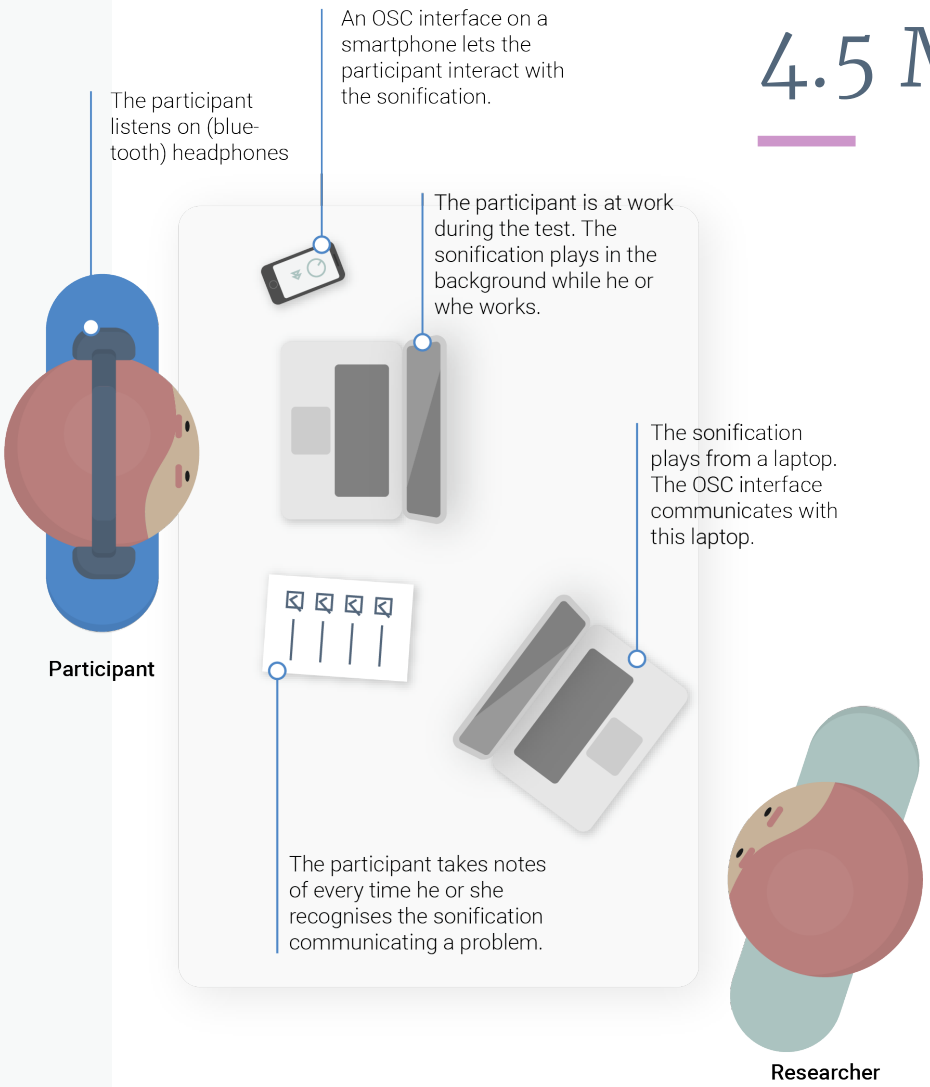


Image 22: The setup used in the user test

Participants are given the task to recognise changes in timbre and indicate them on the mobile device. Once they would prefer a more exciting version of the sonification they can choose to increase it's 'intensity'. A higher intensity increases the complexity of each part in the soundscape.

Participants are also asked to indicate when they want to listen to a different soundscape. They can do so by indicating this on the mobile device, and a new soundscape will start playing once they do so.

To be able to ask participants about the level of distraction the soundscapes cause, they are working on a task for the duration of the test. To create a spread in types of tasks, this can be a task of their choice.

Setup

The prototype that simulates the current version of the Care Tunes concept plays from Ableton Live on a laptop. The participant can listen to the sound from this laptop while working (image 22).

The participant is able to control the prototype through the OSC interface. The researcher triggers changes in timbre from the computer, which the participant can then reverse by pressing the right button on the OSC interface.

Participants

Even though this concept development focuses on nurses, the principles tested during this test should apply to anyone who listens to the soundscapes. Since arranging tests with nurses is challenging due to the unpredictability of their work, these tests will also be conducted with students (image 23).

Post test interview

A semi-structured interview after the participant finished the test aims to answer question 2 and 3. It also gives an idea of their experience of how well they are able to recognise different timbres and how confident they feel in doing so. The following topics are touched upon in this interview.

What is the participant's overall impression of the soundscapes?

How hard was it for the participant to recognise and distinguish the changes?

How quickly did the soundscapes start to bore the participant?

Were the soundscapes distracting from the work participants were trying to do?

Measurements

Certain data is recorded during these tests to be able to draw conclusions from them. The following records of the tests will be created.

Timestamped notes of the user's behaviour. This can include things like the times they switch between soundscapes, when they change the intensity or when they seem in doubt about how to respond to the soundscape.

The number of times the user successfully and unsuccessfully recognises a change in timbre.

The users answers to the interview questions.

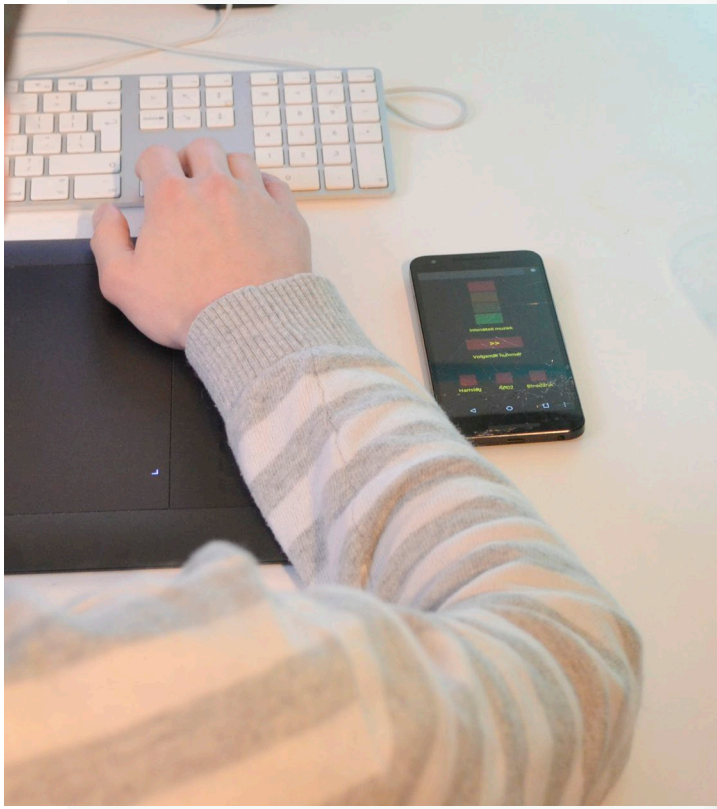
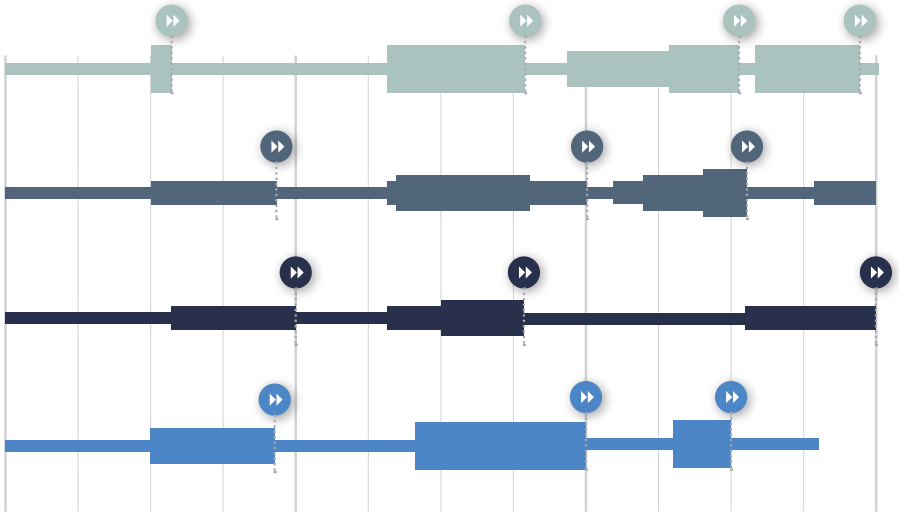


Image 23: Participants were working on a task of their choise while listening to the sonification.

4.6 Results



"I like the highest intesities best. The low intensities fade to the background more easily"

"That timbre change was not really disturbing. It could have just been a different effect in the music or something.."

"It's quite nice to play around with the intensities."

"It's not that straneous to listen to"

"The lower intensities can make it easier because in the higher ones you hear a lot going on anyway"

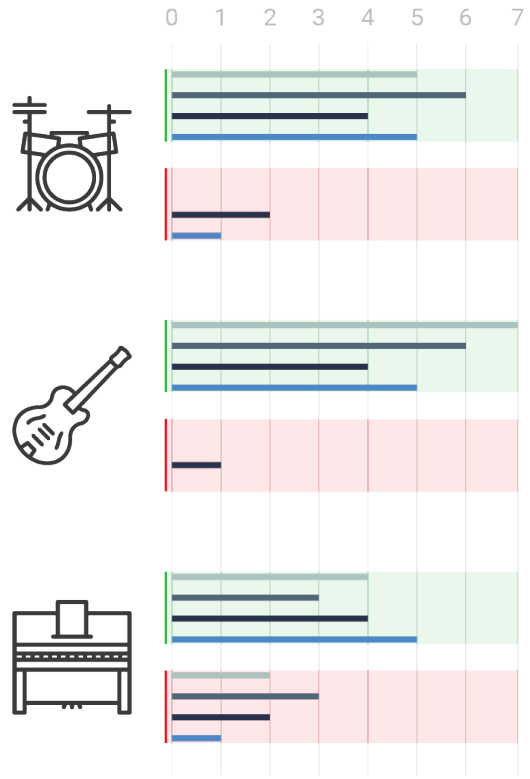
"I can hear it changing but it is hard to recognise which one it is."

"I think changing the intensities makes me doubt even more."

Image 24: The moments on which participant chose to switch songs.

The results from the user test are divided into the measured results and the participants' answers to interview questions. The amount of time participants were able to listen to the soundscapes before they wanted to switch to a next soundscape is reflected by the measured results of their behaviour. Participant quotes from the interview show how they felt about the different soundscapes and complexities and switching between them. Image 24 shows the participant's behavious in switching between songs and what they said about this.

How often participants were successful in recognising the changes in timbre was also measured (image 25). A large majority of timbre changes was successfully recognised by participants. Participant quotes show how they experienced the task. This for example includes how difficult they found recognising the changes.



"One of the changes was a bit more subtle than the orthers, the drums were very clear."

"At first the changes were hard to recognise, but I got used to it and it became easier."

"Doesn't sound very alarming."

"That change was not really disturbing. I thought it was just a different [effect] pedal or something."

"Changing the intensity just makes me doubt if I heard a change or not."

Recognition
No recognition

Image 25: The participants succes rate in recognising changes in timbre was measured.

4.7 Conclusions user test

Song-like sonifications can make it hard to consistently recognise changes. As one listens to a song, it is quite normal to hear changes in timbre as a part of it. Instruments may be played in different ways, or sound effects may be applied by the artist. The song-like structure in the current design therefore confuses people in whether the changes they hear are a part of the song or if they hear something they are supposed to point out.

Switching between songs can make it more interesting to listen to the soundscape for a long time, but can also make it harder to get used to using the sonification. Participants in the test were able to switch between different soundscapes and they did so roughly every ten minutes. The amount of time one can comfortably listen to the sonification can be increased by adding more songs. Some participants did however notice that they they had to get used to the new song to easily recognise timbre changes again.

Songs have parts that are layered, sounding at the same time, making it harder to distinguish them. Using a song like structure in the sonifications means each part representing a datapoint may sound at the same time as another part. Some of the participants were very easily able to detect a change in the soundscape overall, but found it difficult to point out which of the part it was.

There is a learning curve to using Care Tunes. Most participants note that it becomes easier to work with the soundscapes as they are listening to them for a while. This indicates working with a sonification may require a certain amount of training by the nurse.

4.8 Evaluation with nurses

Because only students participated in the user test, the implications of the design for work on the ICU could not be evaluated in these tests. Arrangements made with nurses for interviews (cycle 3) were therefore also used for a demonstration of the design to them. Nurses could then respond to the current design of the Care Tunes concept. The concept was explained and demonstrated to them at the end of the interview to discuss how they felt it would fit into their daily work.

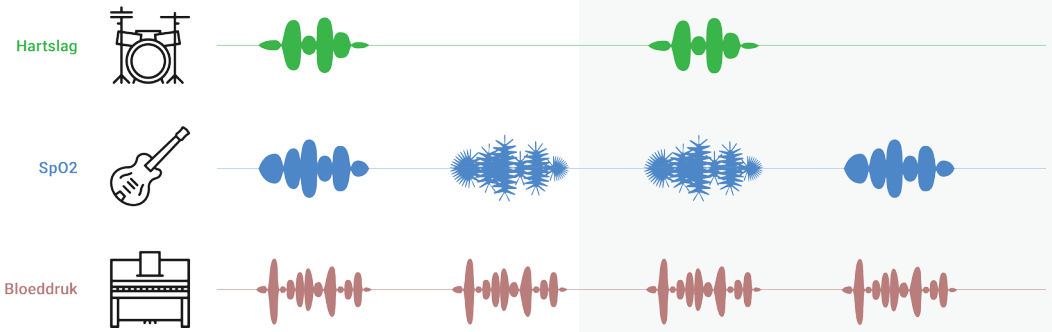


Image 26: The concept was explained to nurses with the help of graphical representations of the sonification

Method

Gaining the nurses' insights regarding the Care Tunes concept was done in three steps.

The concept was explained to the nurses using four visualisations like the one in image 26. They were asked to imagine they would use this instead of the monitor to watch over their patient.

They were asked to listen to the soundscapes. Each of the instruments was played individually to explain which vital sign each instrument represents. Then the whole soundscape was played in which the timbre changes could be heard.

The nurses were interviewed about their opinions about the concept (image 27). The interview questions can be found in appendix A.

Image 27: One the the nurses during the interview.

Results

The evaluation interviews resulted in eight insights into how nurse would use Care Tunes in their work environment. The cards on this and the next page show each insight with qoutes from nurses that are related to them.

The overall sound of the sonification is perceived to be pleasant. All interviewees respond positively to the overall idea of the Care Tunes concept. They seem intrigued by the idea of having more pleasant sounds to keep them up to date of the patient's well being.

"It would be very nice if you would hear this. Much better than alarms"

"I think it would be much less stress-inducing"

It is not feasible to listen to the soundscape for an entire shift. Many of the interviewees express concerns about whether they could listen to a song or soundscape continuously during their entire shift. They wonder if this would not be just as tiring as listening to alarm, or whether they might grow bored with the song or soundscape.

Another reason for an constant presence of sound to be undesirable is that it would get in the way of conversations between clinicians.

"Listening to the same tune for 8 hours would also drive you mad"

"We do need to talk to each other. In that case constantly hearing sound would be difficult."

"I hope it will not be some sort of muzak!"

"It might help if the volume goes down in some moments"

Switching between genres or different soundscapes could get in the way of developing a routine in working with care tunes. When suggesting to switch between different soundscapes to prevent the problem of listening to the same thing for a long time, some interviewees think this would not allow them to learn how to respond to what they hear in the soundscape.

"Switching to a different song every day won't work. You do need to be able to start recognising it"

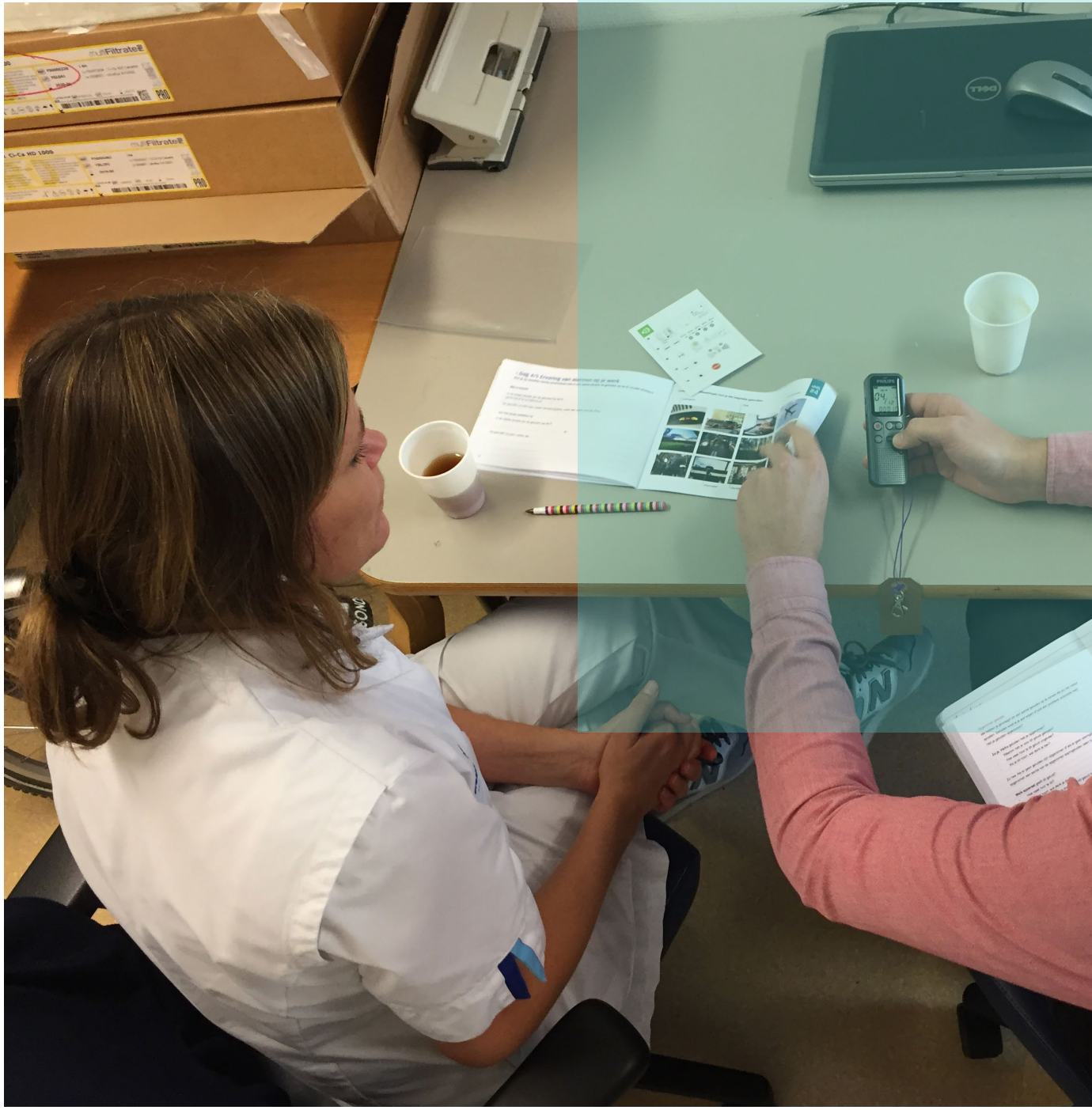
"If you were to change to a new song you would have to get used to that one again"

A sonification is probably more suitable for medium urgency alarms than for the highest urgency alarms. Some interviewees express concerns regarding the very urgent alarms that are used on the ICU. An example that is mentioned often up is the alarm for an asystole. Many of the interviewees doubt whether the care tunes concept would be safe to use for such an important alarm.

"Do you think this would be sufficiently alarming? Less so than an alarm I guess."

"A small change in blood pressure is not that urgent. When it drops rapidly it is."

There are many situations in which a nurse needs to be aware of two or more patients. The design should facilitate this. The current way of sonnifying patient data assumes each nurse will take care of one patient. This is clearly not the case. All interviewees wonder how they would use the concept when they are taking care of two patients at the same time. Additionally, some express concerns about cooperating with colleagues if they were to wear an in ear device.	*"You can't always be looking after just one patient."* *"How will this work when you are taking care of two patients?"*
Nurses think they will be able to identify different parts and changes in timbre within them, under certain conditions. When asked whether they think they will be able to identify the different parts of the sonification and catch the changes in timbre that occur, most of the interviewees feel confident they would be able to. Some suggest that there might be a learning curve after which they should be able to work with the concept.	"I think you should get the hang of it in one day" "You do need some practice to hear the changes" "It is a bit difficult hearing the changes, but you will get used to that I think" "I could easily recognise the drums. Others were too subtle"
The concept offers the opportunity to represent changes in values rather than just giving a signal when a value crosses a boundary. This is thought to be a useful way of working. Currently, alarms go off only once a value crosses a certain level set by the nurse. When a more gradual communication of patient data is suggested, most interviewees think this would be a very useful feature to help them do their work. Some think they would be more aware of the situation or be able to respond more easily.	"I think gradual changes would be a very good idea. You would be able to hear how far something is removed from the centre." "When you hear something coming you might be more alert" "The SpO2 sensor has the option to let you listen to a pitch"
An in ear device is considered to be a plausible solution for implementing care tunes. Two of the interviewees indicate that it would be worth considering an in ear device or headphones to use the sonification. One interviewee is especially enthusiastic about this.	"I think headphones would be great! It would be a bit harder to cooperate with others though."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Chapter 5
Experiences of sound in the ICU

In parallel to the redesign of the concept, several research activities in the ICU of the Erasmus MC were conducted. This chapter describes how this was done and what insights were gained from it. The results described in this chapter will be combined with the results from the redesign to formulate goals for cycle 3.

In the process of planning research activities at the ICU, an overlap between the research intended for this project and the work of Rosel van den Berg became apparent. A collaboration was initiated. This prevented a situation in which nurse were asked to participate in very similar research activities twice. It also greatly increased the quality of the research in this project due to the extensive experience Rosel has in similar research projects.

With Care Tunes as an application of the insights gained, nurses participating in the research could see the impact of their involvement.

5.1 Goals

The context research described in this chapter is meant to give a deeper understanding of how nurses currently experience sounds on the ICU during their work. It will also reveal some of the reasons for the problems with alarms on the ICU.

Because the research activities described in this chapter are performed in collaboration with Rosel van der Berg, who had already started planning research into the same topic, in the same context, some of the results give a broader image than may turn out to be necessary for this project. Where this is the case, such results can be read as an appendix to this document.

Overall, the context research answers the following questions

How do nurses work at the ICU?

What are their experiences of their workplace in general?

How do nurses experience sounds they hear at the ICU?

What are their experiences of the phenomenon of alarm fatigue?

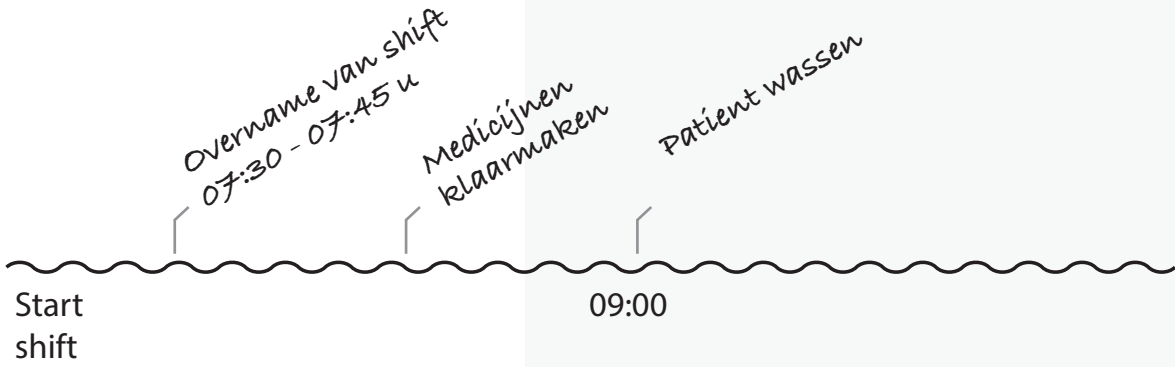


Image 28: Participants were given partly filled out timeline like this one that they could comment on.

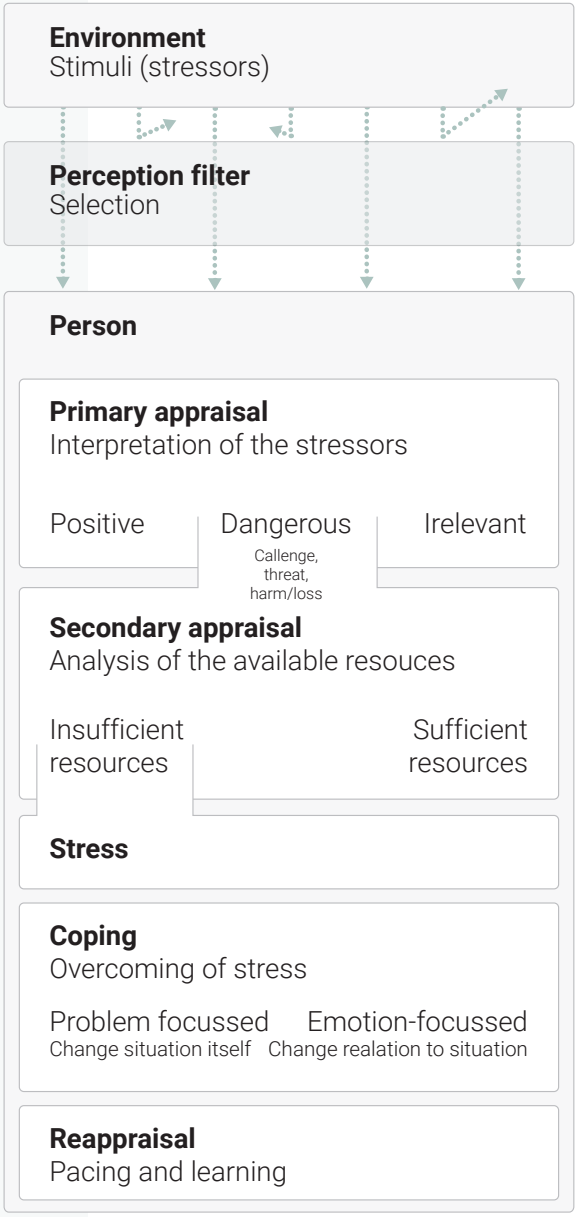


Image 29: Lazarus (1987) describes how people percieve stimuly in his model of stress and coping

5.2 Background

At the moment of planning the context research, certain information about alarm fatigue, the ICU at the Erasmus MC and the nurses' way of working was already known. This knowledge can be used as a starting point when determining what still needs to be done to find the information required for this project.

Timeline

From observations at the ICU and from workshops with the CAL team, a preliminary timeline of a shift at the ICU was created (image 28). This timeline will be used as a framework for further research activities. It has the intention to help nurses point to certain moments during the day and elaborate on their experience of alarms.

Appraisal theory

The appraisal theory describes how people's evaluation of events can determine the emotional state they are left in as a result of these events. There is a range of different theories that fall under this term. In the transactional model of stress and coping (image 29) by Richard Lazarus (1987), stimuli, or stressors, from the environment are are perceived through several stages.

The model shows how an alarm can be interpreted as actionable or non-actionable. It can therefore help understand how alarms are perceived by nurses and how each situation or person can make for a different appraisal of the alarm. Therefore different occasions may cause an entirely different experience of the alarm. By using the appraisal theory as a guideline for the questions to ask nurses about their experiences of alarms, more insight into how alarm fatigue occurs can be gained.

5.3 Approach

Gathering data is done through an approach based on the context mapping method (Stappers & Sanders, 2003). Where this originally involves generative sessions, the situation at the ICU and the nurses' unpredictable and busy schedules call for a more flexible approach. Interviews are therefore conducted in stead.

Observations

Two observations at the ICU on different times during a shift were done to elaborate more on the timeline that had already been established and get a better sense of what topics needed to be touched upon in the interviews. The observations were mostly done at the central nursing stations, where nurses will be during a large part of their shift. This is also where they monitor their patients by listening for alarms and looking at screens that display patient data.

Sensitisation

In context mapping, sensitisation is a technique that prepares participants for a generative session. The participant will do small exercises or activities that help them reflect on the topic that will be discussed during the session that follows. This improves the quality of the information they are able to share (Sleeswijk Visser et. al., 2005).

In this case booklets (appendix B) were handed out to nurses in which they were asked to think about several different aspects of their experiences at the ICU in the week leading up to the interviews. They were also asked to think about the sounds they heard around them and how they use them. Part of the sensitisation was for the nurses to record the sounds that they had strong feelings towards and they would like to discuss during the interview.

Interviews

Context mapping preferably involves a generative session in which a group of participants make an artifact to represent their latent knowledge of the topic (Sanders & Stappers, 2008). As mentioned, these sessions were substituted by interviews due to the availability of participants.

The interviews took place at the ICU at which the interviewee works, just after or before one of their shifts. The interviews took around 1,5 hours, during which the following topics were discussed.

The nurse's motivations for working on the ICU

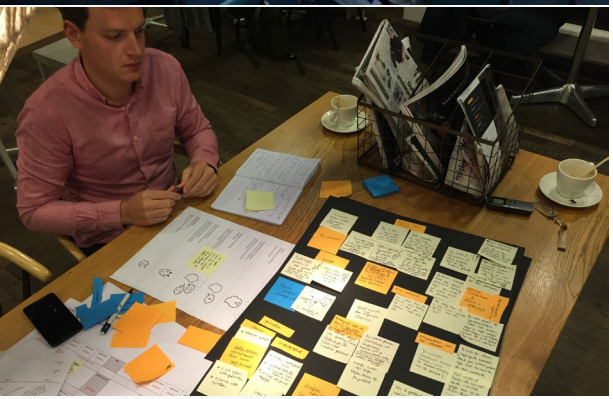
Activities and sound levels during a shift

Responding to alarms (based on the appraisal theory)

Alarm management and the nurses experience of alarm fatigue

How alarm sounds influence work and wellbeing

Discussing the sounds recorded by the nurse and why these sounds evoke the emotions they do



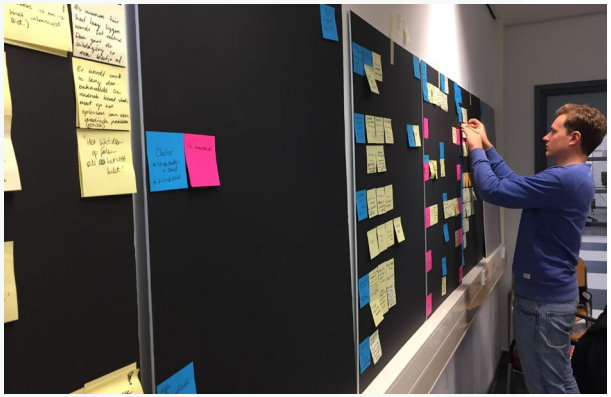


Image 30: A participant in an interview, data processing right after the session and looking for themes in the data.

Analysis

The interviews resulted in rich data, including quotes, anecdotes and observations from the conversation. These data needed to be structured to be able to gain insights into the nurses' experiences from them. This was done following three steps, based on the method of analysis as described by Sleeswijk Visser and others (2005).

1. Thoughts, quotes, comments and any other observations from the interviews are documented right after each session. Memory of the session will fade over time, so doing this right away helps capture as many of the insights as possible.

2. Data from all sessions is combined, searching for the relationships between them. Reading the documentation of each session, patterns become apparent.

3. Overarching patterns in the data are discovered. By creating an overview of all of the relationships between quotes or observations that were found, insights become apparent as themes appear.

From this analysis, insights could be divided into five main topics.

- Who is the ICU nurse?
- Using alarms and the problems involved
- Personal preferences in alarm management
- The soundscape of the ICU
- Explaining alarm fatigue

Because not each of these insights directly influences the design of Care Tunes, only the insights most relevant to the design process are presented in the following sections.

Who is the Intensive Care (IC) nurse?

Technology, Knowledge & Thrills

IC nurses are interested in the combination between people and the use of **technology** to help them. The ICU offers more room for the application of **medical knowledge** than other departments, which matches the **level of ambition** of many IC nurses.
They also appreciate the **unpredictability of the work** on the ICU. Working on the ICU can however be very **demanding**. The use of technology and the rate at which this is developing can cause challenges in **keeping up with technology.**

'Ik zocht op de IC meer verdieping in het werk.'

'Soms vraag ik me wel eens af: Hou ik het nog 20 jaar vol?'

'Het is leuk dat de IC zo onvoorspelbaar is'

I ♡ my team

Working on the ICU relies heavily on **teamwork**. Nurses need each others help regularly. It is important for them to be able to **trust their colleagues** to support them when they urgently need help.
The team also offers **emotional support**. Events at the ICU can be emotionally difficult. When they are emotional, it helps to be able to talk to people.

IC nurses deal with teamwork in different ways. Some embrace it, while other seek some **time alone** from time to time. Being alone can be very hard to do at the ICU, since it is not **easy to quickly hand-over your shift**.

'Je collega's zijn belangrijk. Je moet je veilig voelen bij elkaar, op elkaar kunnen bouwen.'

'Als je iemand van 16 ziet overlijden moet je dat kunnen bespreken.'

A solid base

IC nurses have well defined **routines** for many parts of their work. Having this as a **constant factor** in an otherwise tumultuous environment helps in being ready to **respond to unexpected events**. This does mean some habits can be **difficult to change**.
Nurses make sure that their work is **well organized** and things are neat. There is a certain **discipline** in this as it is seen as part of the responsibility to colleagues to provide a smooth handover. Also, there is a certain image that nurses would like visiting family to have of the ICU.

'Misschien zijn we bang dat we als we dat ritme loslaten de piekmomenten niet meer aankunnen'

'Ik vergelijk onze inzet en service op de IC wel eens met een sterrenrestaurant: als het een rommeltje is op tafel zal dat ook wel iets zeggen over de keuken.'

Guidance through hardship

For patients and their families, being on the ICU is often a **very difficult experience**. Nurses value the role they play in making sure they **guide patients and families** through this experience as well as they can, whatever the outcome of the situation may be. In this role, nurses can be truly **autonomous** in how they approach this, as they are best equipped to offer this guidance. The situation patients are in at the ICU is often very **complicated for family**. Because of this, **ethical dilemmas** can be a challenge nurses face.

'Het is belangrijk om ondanks veel verdriet alles in goede banen te leiden en alles goed uit te leggen aan familie.'

'Er wordt verwacht dat het probleem altijd op te lossen is. Het lijkt dan op falen als het niet lukt.'

'Soms reageren familieleden beschuldigend of drijgend naar mij toe, omdat ze in een emotionele staat zijn. Dit vind ik lastig. '

'Ook als iemand overlijdt dat dat op een goede manier gaat.'

Being a part of the ICU machine

Nurses on the ICU are **part of a larger collaboration** between lots of different people. This offers challenges in how this entire collaboration functions, but also regarding **the role they are able to play in it**. Some nurses worry about the collaboration between a range of disciplines. It can be difficult to all move towards **the same goals**. Regarding the role of nurses in this ICU machine, some express worries or displeasure about their level of **autonomy** in this collaboration. Some decisions that are made about, for example, people leaving the ICU, can be made without nurses being able to influence them.

'Soms moet je bedden leeg maken terwijl je denkt dat iemand nog niet goed genoeg is om de IC te verlaten.'

'We zijn redelijk uitvoerend. Het kan wel lastig zijn daar voor jezelf een goede vorm in te vinden.'

'Er moet vaak lang overlegd worden, we gaan dan niet echt vooruit.'

Image 31: Results from the research are presented in infographics like this one.

5.4 Insight: Who is the ICU nurse?

Five main insights about the values, motivations and personalities of nurses at the ICU have been found. The infographic (image 31) to the left describes them. The relationship many nurses have with technology, the importance of teamwork and the need for a routine in the their work are especially significant for the further development of Care Tunes.

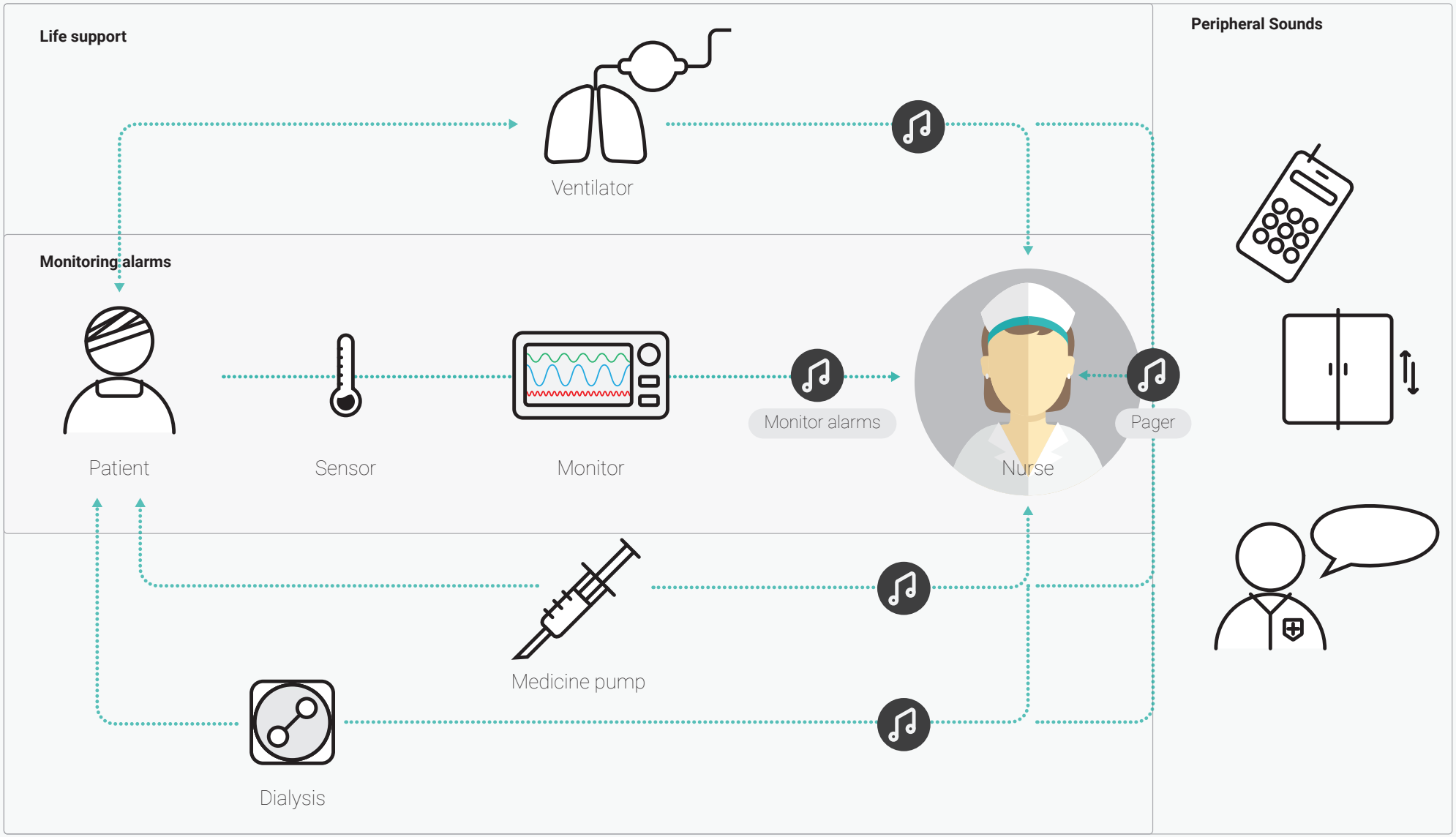


Image 32: Infographic showing how patients, nurses, equipment and alarms interact.

5.5 Insight: Using alarms and the problems involved

Using alarms on an ICU (image 32) ultimately has the goal of informing nurses of the situation in the patient room they are responsible for. The nurse needs to know the state the patient is in to be able to respond, for example by administering medication or adjusting life support.

Since the nurse is not able to be present in the room all the time however, alarms come into play to keep the nurse informed while attending to other tasks. The alarms that a nurse may hear while working on the ICU can be divided into three categories.

Monitoring alarms are alarms that notify the nurse about a patient's vitals. These vitals are constantly being monitored by equipment and nurses need to be aware of their values to ensure the patient is safe.

Life support consists out of a range of equipment that a patient may need to support their vital functions. Which of the machines in this category is used depends on the exact situation of the patient. Each of these devices gives alarms to notify nurses when they are not function as they should.

In the category of **peripheral sounds** are all sounds that nurses also hear but that are not directly related to the health or safety of a patient.

Problems with alarm sounds

Alarms induces by patient or nurse activity. Certain alarms are caused by a patient moving around or by nurses handling equipment during treatments. In such cases the alarm does not represent what is happening to the patient. A sound that should usually be associated with a problem with one of the patient's vitals, can now actually mean a patient is responding as expected to an injection. The alarms and the attention they ask of the nurse do not take into account how much information a nurse already has when looking at the patient.

Limitations of sensors. Sensors that are used to monitor patients may get disconnected or may malfunction. Examples are the oxygen saturation sensor on the patient's finger that is disconnected. Though it is important to know that all sensors work, alarms also occur when nurses know the sensor has come of during treatment.

Monitor alarms give an incomplete picture. The patient monitor will sound an alarm based on a range of vitals that are measured. Since each of these values has a set of boundaries, the alarm will often go of when just one of these values exceeds a boundary. The nurse however, needs more nuanced information about the combination of several values to be able to judge the urgency of the problem. The result is that most of the alarms the monitor produces are switched off because they don't require action.

Additionally, when nurses are in or around the central nursing station, they will hear alarms from all patients on that side of the ward. This means of all the sound they hear, the majority is intended for one of their colleagues. Though it is important to nurses to support each other (see Who is the IC nurse?), nurses also have personal preferences in alarm management, as described in the next section. Because of this, hearing alarms that refer to a colleague's patient can be disturbing.

5.6 personal preferences

One of the findings in the interviews was that each of the interviewees seemed to have their own way of managing the alarms they use. Nurses can influence the amount of alarms they hear from the monitor by setting the boundaries. This is where differences in preference can be found between nurses. Since nurses can also hear each other's alarms, very tight alarms settings can cause some irritation for people who prefer to only be alarmed when something very urgent happens. Discussing how they think about alarm management has led to insights into why they prefer either narrow or wide alarm settings. Image 33 shows what nurses on each side of the spectrum say about alarm management.

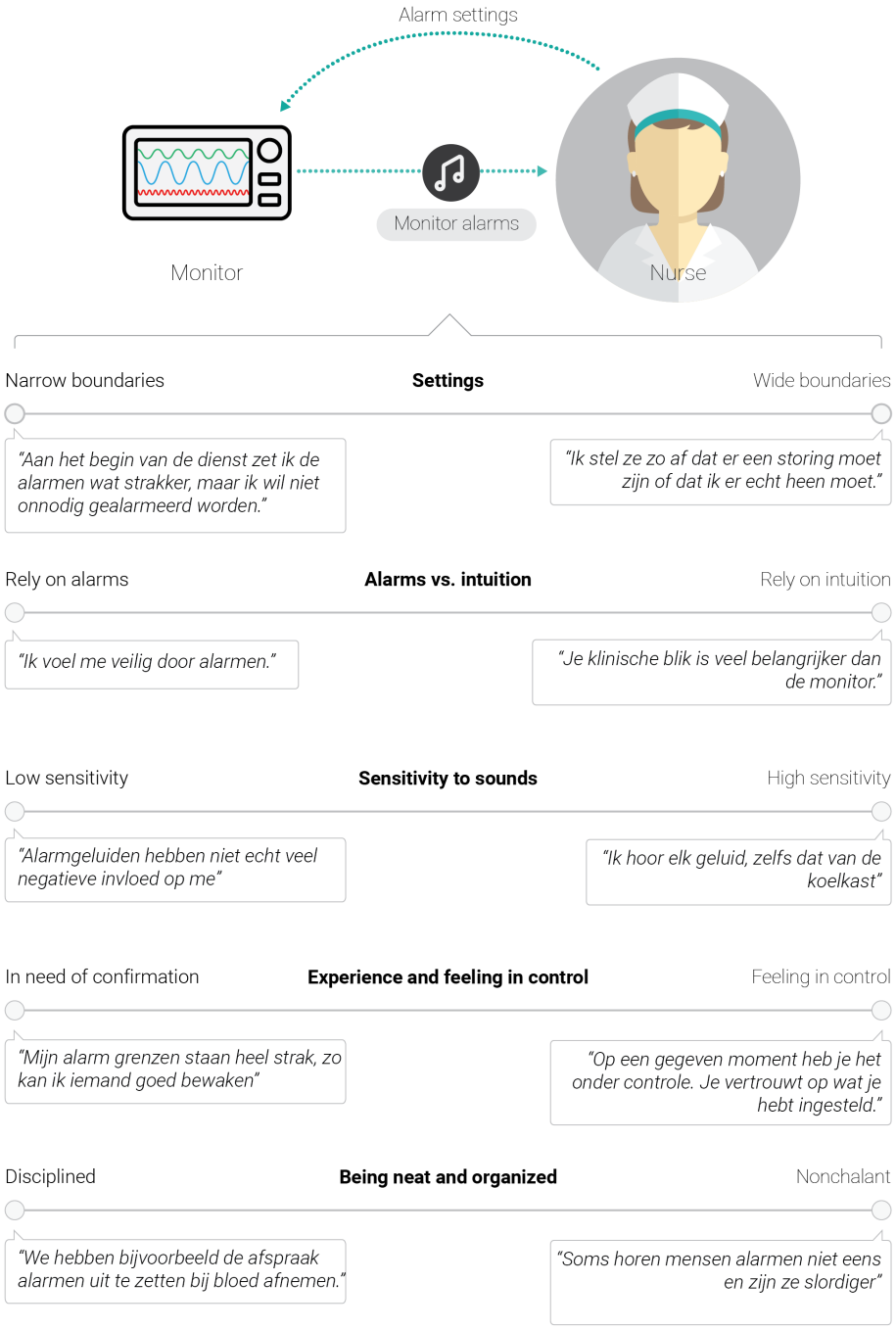


Image 33: Nurses have different preferences when it comes to alarm management.

5.7 Conclusions

This section focuses on those conclusions from the context research that will directly influence the Care Tunes design. In the next section, these and the conclusions from evaluations described in chapter 4 will result in design goals for the third design cycle.

Alarms are quite often misused as nurses look for possibilities to be constantly aware of the situation. The basic premise of an alarm is to be notified when action needs to be taken. Alarms seem to often be used by nurses as a constant status report. Nurses can do this by setting limits more tightly than they need to be, to be notified when the parameter approaches the actual limit. This use of alarms is the cause of many inactionable alarms. Because this, nurses can get used to switching off alarms right after they occur without attending to the patient.

Routine and habits in the work of nurses help to be able to respond to unexpected situations. Because very urgent situations can arise at the ICU at any moment, it can be reassuring to know that there is a certain routine in the rest of the work. Nurses value a well organised environment in which they know what to expect. This gives a certain peace of mind in a context where hectic situations can always arise.

Currently, alarms used for monitoring patients do not carry enough information. Nurses need knowledge about several values measured by equipment to judge how they need to respond. Current alarms never give them this information. Only the alarm for the very worst cases, like an asystole alarm, is it immediately clear what action needs to be taken.

All the less severe alarms may mean that any of the patient's vital signs exceeds the value that has been set as a limit. It does not convey which vital sign has exceeded the limit, by how far it has done so, or even whether it surpassed the low or the high limit. This means nurses nearly always need to verify the state of the patient by checking the exact values, often to find out no action needs to be taken.

Teamwork is very important in working on the ICU. Support between colleagues is essential to the work nurses do on the ICU. They need to be able to quickly communicate that they might need help with something.

In many cases, colleagues will also be aware of the situation that each others patients are in. When a nurse is taking care of two patients for example, it is important for other nurses to be able to recognise when one of them needs a lot of attention. Other nurses can than offer help in taking care of the second patient.

5.8 Design goals cycles 4 and 5

Insights from both parts of cycle 2 have implications for the further development of the design. In this subchapter, they are combined to formulate design goals for the next two design cycles, in which the Care Tunes sounds are redesigned and the way in which Care Tunes will be used in the new ICU is further defined.

5.1: The sonification should focus on monitoring equipment

Based on cycle 2, the decision to focus the sonification on the monitoring data made in cycle one can be confirmed. It seems to be possible to completely replace most of the alarms that are produced by the patient monitor with an continuous sonification. This means the yellow and technical alarms will be replaced. The asystole alarms will be kept in the form of an alarms, as this is very rarely an inactionable alarm and almost always represents a life-threatening situation.

5.2: The sonification should give complete information

The alarms that are currently produced by the patient monitor can be replaced by a sonification that conveys all of the information a nurse needs to decide whether action needs to be taken or not. By listening to the sonification the nurse should be able to understand:

- Which value is changing
- What the value of each vital is relative to the safe median
- Whether just one or more of the values are changing

5.3: An alternative should be found to the song-like sonification

Switching between songs or soundscapes prevents users from getting used to working with the sonification. Using a song-like structure and switching to a new one once in a while seems to conflict with the need for a certain routine on the ICU.

This implies that however going through a list of songs helps to make the sonification more interesting to listen to for long periods of time, it can also make the sonification harder to understand. The problem of listening for longer periods of time can also be solved with an approach of discontinuous listening, as described in goal 4.

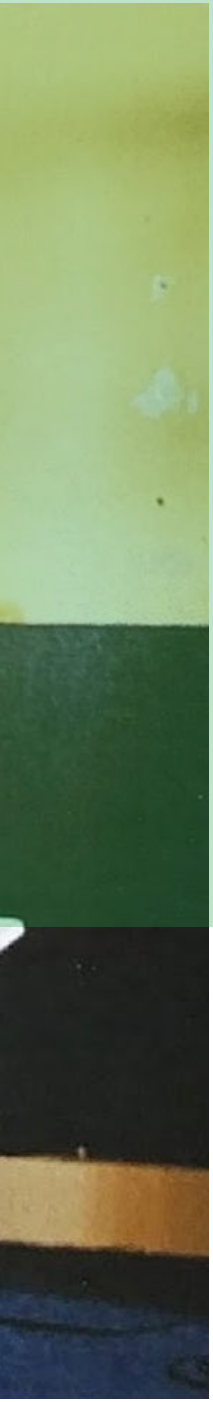
5.4: There is no need for the soundscape to be continuously audible

The current design still does not lend itself for listening for an entire shift. It even seems unrealistic to assume there is a way to create a soundscape that does remain bearable for an entire shift. Responding to the current design, some nurses have however also indicated the concept could work just as well if it would not sound continuously. The design can therefore be altered to sound just as a periodic update. It may even just give these updates when there is a change to report, or when nurses request one.

5.5: The sonification can be delivered through an earpiece, provided that communication and collaboration is not hindered by it.

An earpiece would eliminate the problem of hearing unwanted alarms that represent patients who the nurse hearing them is not taking care of. Different styles of alarm management between nurses would also become less of an issue.

There do however need to be easy ways to listen to two or three patients at the same time or alternately. Nurses should also still be able to easily support each other when necessary.



Chapter 6
Monitoring through musical updates

Addressing design goals 5.2, 5.3 and 5.4, requires a revisit of the music that was written for cycle 2. This cycle therefore aims to design a way of providing 'musical updates' to replace the song like approach of the previous cycles. This also satisfies the desire for a less continuous stream of sound. Lastly, a redesign of the sounds will take away the confusion that the previous sonification sometimes tended to create.

This sonification redesign took place in a relatively short cycle, as it involved a one day session in collaboration with a trained musician in which experimentation with a range of audio effects and musical concepts took place to find a musical sonifications that is most likely to satisfy the design goals.

6.1 Musical session

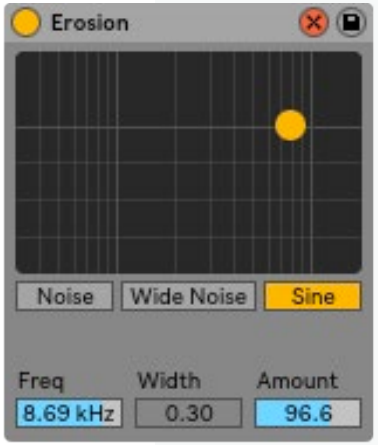
The song-like structure of the sonification in cycle 2 made it hard for users to distinguish between the different parameters they were listening to. A brainstorm session with the help of trained musician Ruben Nosaehi was organised to look for solutions for this and to fulfill other needs that arose for the sonification design. Several requirements for the sonification were used as a starting point for the session.

Requirements

- Each instrument used in the sonification to represent a different parameter should be easily distinguishable.
- Four levels of timbre change on each side of the safe middle should be recognisable by the listener. These should have clearly audible differences between values higher and lower than the middle value.
- The timbre of each parameter should become less pleasant to listen to as it approaches the limit set for that parameter.
- Sounds that represent a value over the limit should universally be regarded unpleasant to listen to.
- Instead of continuous music, the sonification should give the listener periodic updates.

Auditory ideation

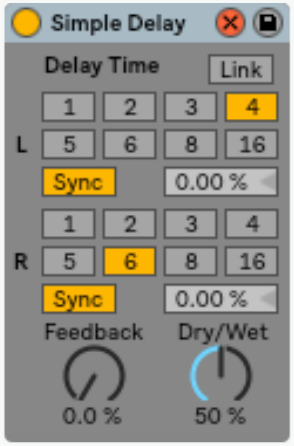
To look for the right solutions for these requirements, the session involved ideations with the help of Ableton live and several MIDI instruments. A range of instruments and sound effects were tested to find those that could be used to create the desired amount different timbres. Image 34 shows how each of the effects that was tested in the session can change the sound. The result of the session was an overview of how changes in each of three vital functions will influence an audio effect. Section 6.3 will elaborate on this.



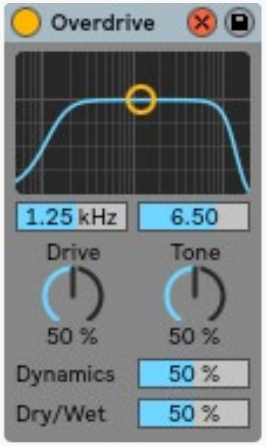
The erosion effects ads noise or a sine wave to the sound, thus changing the timbre. The part wil sound more distorted as the 'amount' of this effect gets higher.

A bitcrusher can make the sound more distorted by reducing the resolution of the audio. This can give a warmer or a harsher sound.

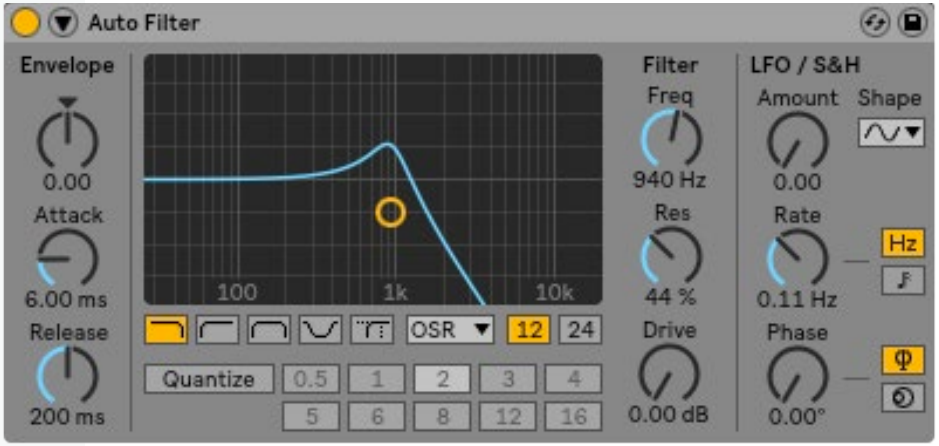
Image 34: During the musical session, a range of audio effects was tested for suitablility for the sonification.



A delay adds an echo to a sound that is played. It could be used in the sonification by changing the delay time based on the vallue of a parameter. This effect has a rhytmic influence on the sound rather than a timbral one.



An overdrive can increase the gain of sound to make it sound distorted. This results in a ‘fuzzy’ or ‘buzzing’ sound. In the sonification, a parameter could sound more distorted as it becomes higher.



With a filter, one can remove a range of frequencies from a sound. The filter above is set a a low pass filter, letting only lower frequencies through. This makes it sound muffled. When a filter is high pass, more high tones are present. This will make the sound more shrill. For the sonification these oposing types of filters can be used to indicate a vallue being either too high or too low.

6.2 Design

The parameters that are sonified were divided not just across different instruments, but across three different aspects of music: rhythm, harmony and melody. These three parts play in sequence to make them easier yet to distinguish. The listener hears three medical parameters, one by one.

Timbre change

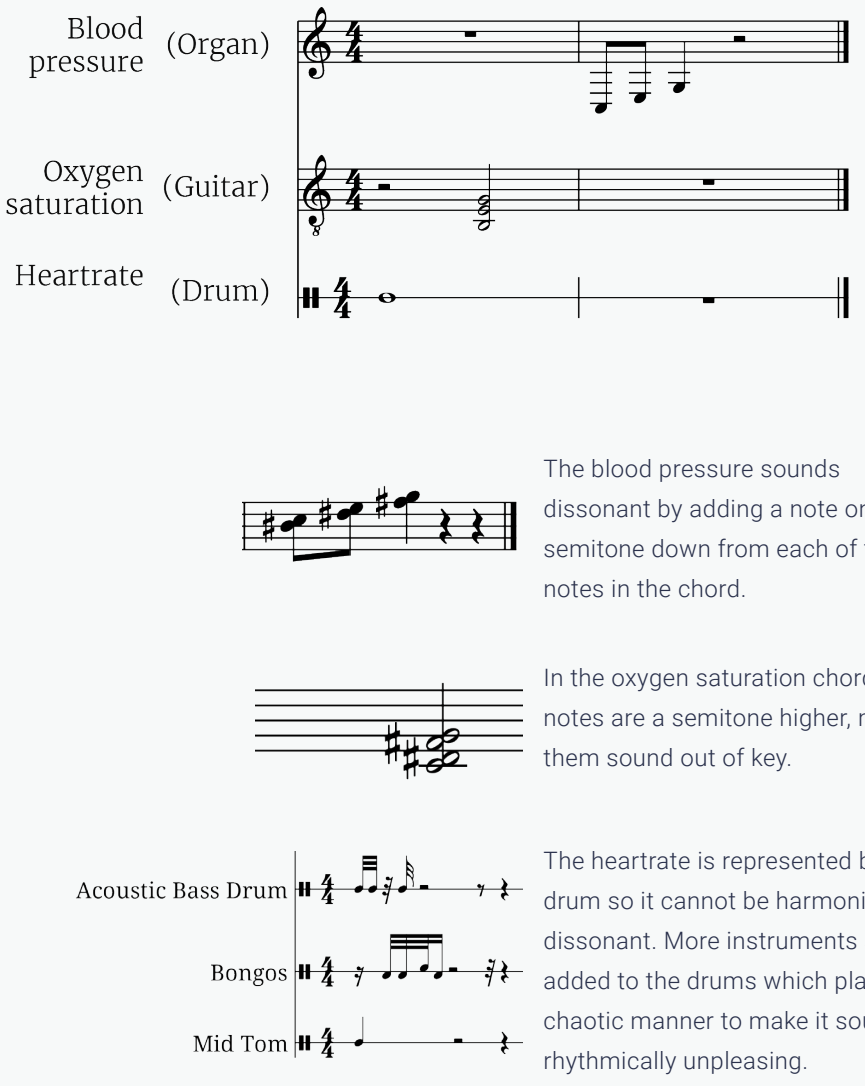
For each parameter, the range between the upper and lower limit is divided into four segments above the safe middle and four segments below it. Each of these segments has its own timbre so the listener can identify each segment by listening. This allows the nurse to be aware of how much change occurs in one direction or the other.

As the parameter approaches a low limit, the sound that represents that parameter will sound more muffled in each segment. This is achieved through the use of a low pass filter over the original, safe vallue sound. Each of the segments the frequency of the filter is changed just enough to create a noticable difference from the segment that precedes it.

The same technique is used to make each segment approaching an upper limit sound slightly sharper. In this case a high pass filter is used to achieve this effect.

Dissonance

The timbre changes described in the previous section can all be heard before a parameter reaches an unsafe value. They should help the nurse be more proactive in taking action as a patient's vitals change. When a limit that a nurse has set is crossed by a parameter however, this should still be made very clear to the nurse, as a dangerous situation may be the result of this. To ensure the nurse's attention is gained in such a situation, dissonance is used in the sonification. Dissonance in musical theory are notes that sound unstable together and need resolution. Out of key notes are added to the sound that represent the parameter that exceeds the limit. Out of rhythm sounds are added when this concerns the heart rate parameter.



The blood pressure sounds dissonant by adding a note one semitone down from each of the notes in the chord.

In the oxygen saturation chord, two notes are a semitone higher, making them sound out of key.

The heartrate is represented by a drum so it cannot be harmonically dissonant. More instruments are added to the drums which play in chaotic manner to make it sound rhythmically unpleasing.

Image 35: A value crossing a limit will be made clear by dissonance in the sonification.

Image 36: The range between the limits of each parameter is devided into segments that all have their own filter frequency.

Chapter 7
Cycle 5: Care tunes in the ICU

So far, the design has focussed on sound and how it can be used to represent patients' vitals. Certain issues that need to be solved for the presentation of a realistic concept for the ICU however, have yet to be addressed. A way for nurses to control the behaviour of Care Tunes and to listen to it needs to be designed. The requirements for a new ICU gathered from the interviews with the nurses form the starting point of the next design.

In this cycle, the design of these missing links in the Care Tunes concept are presented. They are the result of previous design evaluations and the context research at the ICU. An evaluation of the revisited sound design and the implementation design with different groups of people who work in the ICU, described in chapter 8, conclude this cycle and the design process in general.

7.1 The Care Tunes dashboard

As found in the context research, each nurse has his or her own personal preferences when it comes to alarm management. The therefore need to be able to control certain properties of Care Tunes. Since Care Tunes seems to have a learning curve, they may initially also need visual support to help them understand how the different sounds they hear are related to changes in the parameters they are monitoring. To achieve this, a graphical user interface (GUI) is designed. The following requirements, deducted from the design goals for this cycle, are established for the interface.

- It allows nurses to control the limits like they currently would to influence how sensitive the sonification is to change
- Nurses can control the frequency with which they receive musical updates. Different people and different situations will lead to different needs in this regard.
- Nurses can choose which room or rooms they want to listen to.
- This includes tuning in into a colleague's tune to support a colleague or for a colleague to hand of a patient for a short period.

Image 36 shows the interface with it's functionality.

Setting limits to a patient's vitals is currently how nurses determine how sensitive the alarms they hear are to changes in the parameter they are monitoring. Care Tunes allows for a similar way of adjusting the sensitivity of the musical sonification.

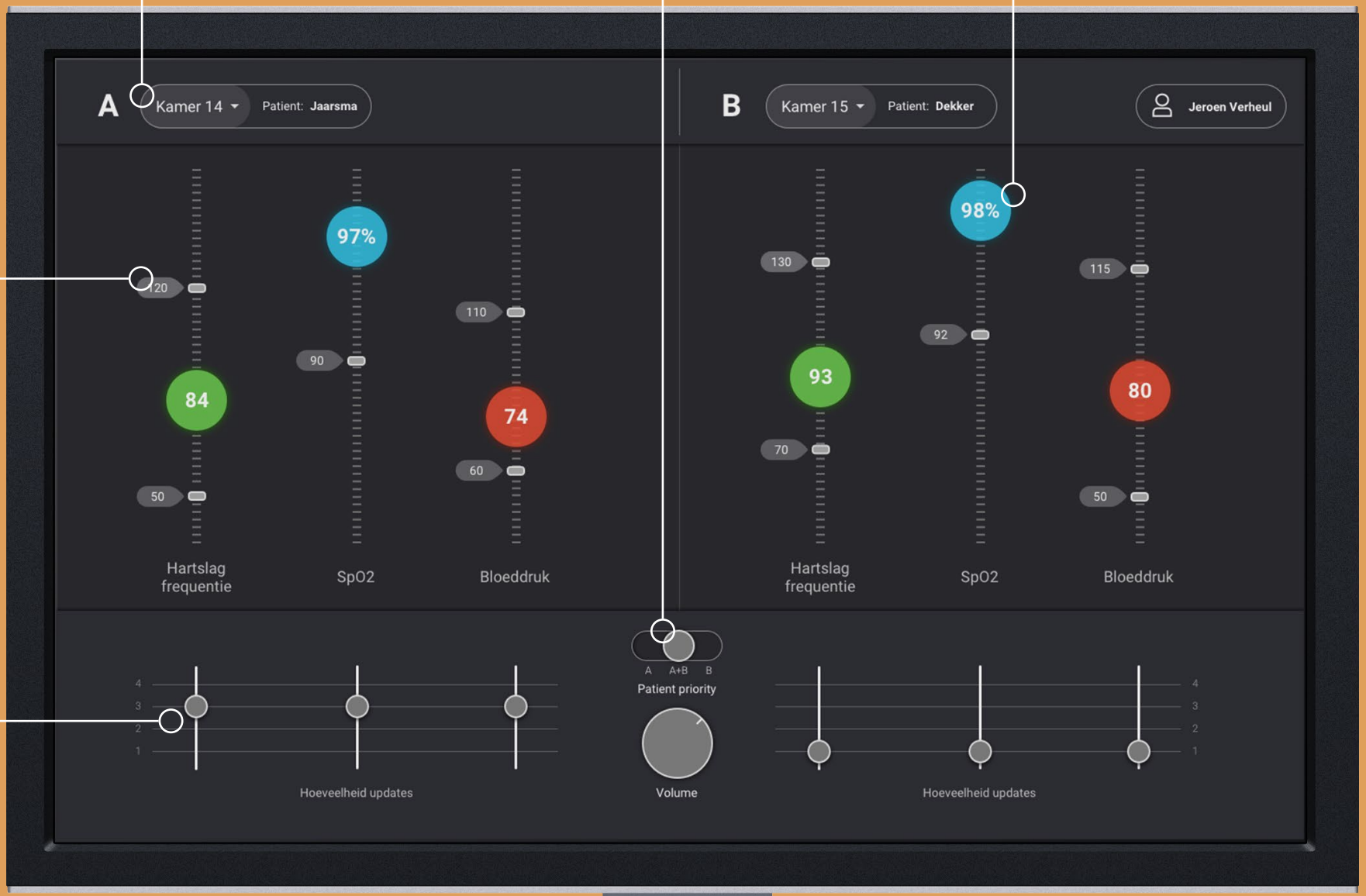
Personal preferrences and different situations call for different amounts of updates. Looking at a stable patient from the nursing desk, A nurse may want to opt for as few updates as possible. When away from the desk, more frequent updates offer more control over the situation.

Image 36: The Care Tunes dashboard gives nurses control over the beahaviour of the sonification

Nurses select the room they want to listen to. This may be the room right next to their nursing station, but they might also want to listen in on a colleague who is taking care of a very unstable patient.

At night, every nurse will monitor two patients. In this case they can choose whether to listen to both of them or just to either one.

As users become more familiar with the sounds of Care Tunes, parameters are animated to vibrate with the accompanying sounds.



7.2 Listening to Care Tunes

Care Tunes will keep nurses informed about the vital functions of the patients they are taking care of. Regarding how exactly it will be employed in the ICU however, the following questions are yet to be addressed.

1. *What is a suitable way of delivering the sonification to nurses?*
2. *How do nurses view the Care Tunes dashboard?*

Earpieces

In the current situation in the ICU, auditory warnings regarding many different patients all sound at the central nursing station. As covered in section 5.6, this causes the problem of hearing alarms for all patients at the same time.

Using Care Tunes in an environment with decentralised nursing stations offers the opportunity to only listen to the sounds that are relevant to the nurse. All of the nursing stations will still be in the same, open hallway so playing the sonification through speakers would again cause sound from different patients to clash.

Nurses will therefore listen to Care Tunes through a wireless earpiece sistem. Listening through an earpiece allows them to have full control over what they hear. It also gives the possibility to listen to the sonification while attending to other tasks, away from the nursing desk. The storyboard (image 38) shows how this works.

Dashboard placement

Patient monitors can be visually inspected from the current centralised nursing station. Like with the alarms sounds however, data from all patients in the vicinity of the nursing station is shown next to each other. The centralised nursing desks will have a patient room on either side. By placing the dashboard at that desk, the A and B sides of the dashboard can refer directly to the left and right room respectively. Image 38 shows how the display would be placed at the nursing desk.

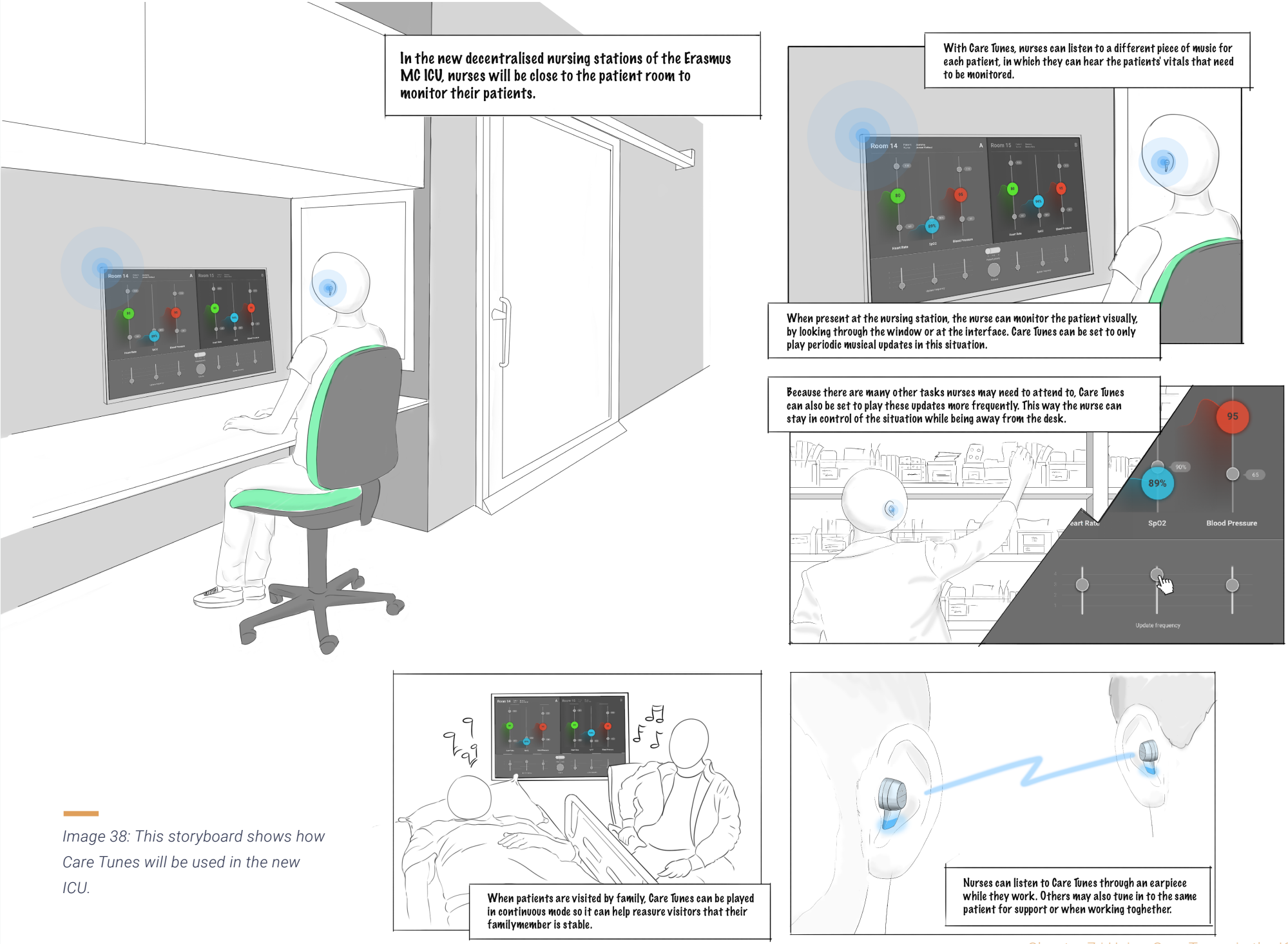


Image 38: This storyboard shows how Care Tunes will be used in the new ICU.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Chapter 8
Design evaluation

In each cycle in this design process, a different design for Care Tunes was developed. Each step that was taken towards the final design was motivated by what was learned from the previous version. How well have all these insights from design activities been interpeted into the final design? Does Care Tunes succeed in improving the environment in which many nurses work every day?

This chapter describes tests and interviews that were meant to answer these questions. Evaluations have been carried out with the help of the people in the target group of the product. This will point to new directions for further development and will indicate whether the design reached the goals that were the start of this project.

The evaluation consists of three studies that are described in this chapter. These are a clinical lesson with nurses, usability tests with four nurses indivisually and a technical evaluation with three ICU technicians.

8.1 Goals

The final Care Tunes design was based on the needs that were identified from the context research in cycle 3. The insights gained there motivated the design decisions that lead to the current sound and interface design. An evaluation of the design is needed to verify whether these decisions have the desired effect on the nurses' experience of sound. The following questions are addressed in this evaluation:

1. Are nurses able to identify a patient's vitals with the help of Care Tunes?

2. How much practice with visual support do nurses need before they can monitor vitals through hearing only?

3. How do nurses generally respond to Care Tunes as a tool that they would use in the ICU?

4. Which issues currently exist in the communication between medical devices that prevent Care Tunes from being implemented and how is Care Tunes likely to be implemented in the future?

The evaluation activities will result in insight into how well the design succeeds in fulfilling design goals formulated throughout the process. These insights will help formulate recommendations for how the design may be altered in further development.

Image 39: Nurses attend a clinical lesson (Erasmus MC YouTube channel)

8.2 Clinical lesson

Image 40: The space in which the clinical lesson was held.

Nurses in the ICU in the Erasmus MC periodically attend clinical lessons (images 39 and 40). These lessons are normally used to teach nurses about certain equipment or techniques. A clinical lesson usually lasts about 45 minutes, and around 12 people attend. One of these clinical lessons will be used to introduce nurses to Care Tunes and to gather their feedback as follows.

Goals

The clinical lesson is meant to give a first impression of how Care Tunes is perceived by nurses. It gives group of nurses the change to quickly respond to the concept. This gives a broad overview of issues that should be addressed in evaluating the design.

Questions that are answered with the help of the clinical lesson are:

1.1 What general impression so Nurses have of Care Tunes?

1.2 How well are nurses able to understand the information that Care Tunes communicates?

1.3 What are the practical implications that nurses feel Care Tunes would have in their work?

Participants

Around 15 nurses attended the clinical lesson, all of whom work in the ICU. The participants choose to attend based on a short description they read in the clinical lesson calendar that is provide to them. Nurses were not selected for the session. Barring one nurse, all participants were unfamiliar with Care Tunes at the start of the session. There was a spread of ages in the group that attended.

Procedure

Using a 10 minute presentation, the problem of alarm fatigue and some of the research insights gained earlier in the design process are introduce. Care Tunes is introduced to the nurses as a concept that can help prevent this problem. Storyboards (image 38) are used to help participants imagine the role Care Tunes will play in the ICU.

The prototype, as described in chapter 8.5, is used to demonstrate introduce Care Tunes further. The audience can take a while to listen to the sounds as the parameters they would be monitoring change.

After the presentation and demonstration nurses are asked to give their opinion of the concept or ask any questions they might have. Short notes are made of their questions and remarks during this discussion. These are documented further, partly from memory, right after the session. Appendix C covers the full clinical lesson plan that is followed during this activity. Results from the clinical lesson consist of quotes from nurses and the topics that were addressed during the discussion. The most exemplary quoted are collected on a board, shown in image 41, that can later be used in the results analysis.

Results

The following points were most clearly reflected in the feedback nurses in the clinical lesson gave regarding the Care Tunes design.

The Care Tunes sonification sounds pleasant. Nurses indicate it sounds much more pleasant than the alarm sounds they are used to.

Most of the nurses in the clinical lesson indicate they don't want to add any sounds to the environment, because they allready hear so many alarm sounds.

Hearing the timbre differences in the sonification of parameters is not easy for most of the nurses attending the session.

Most nurses agree they should only hear Care Tunes when a vallue exceeds a limit in stead of hearing updates continuously.

Wearing an earpiece seems inplactical to some nurses. Others think it would not be a problem. A few nurses wonder how their colleagues wearing hearing aids would listen to Care Tunes.

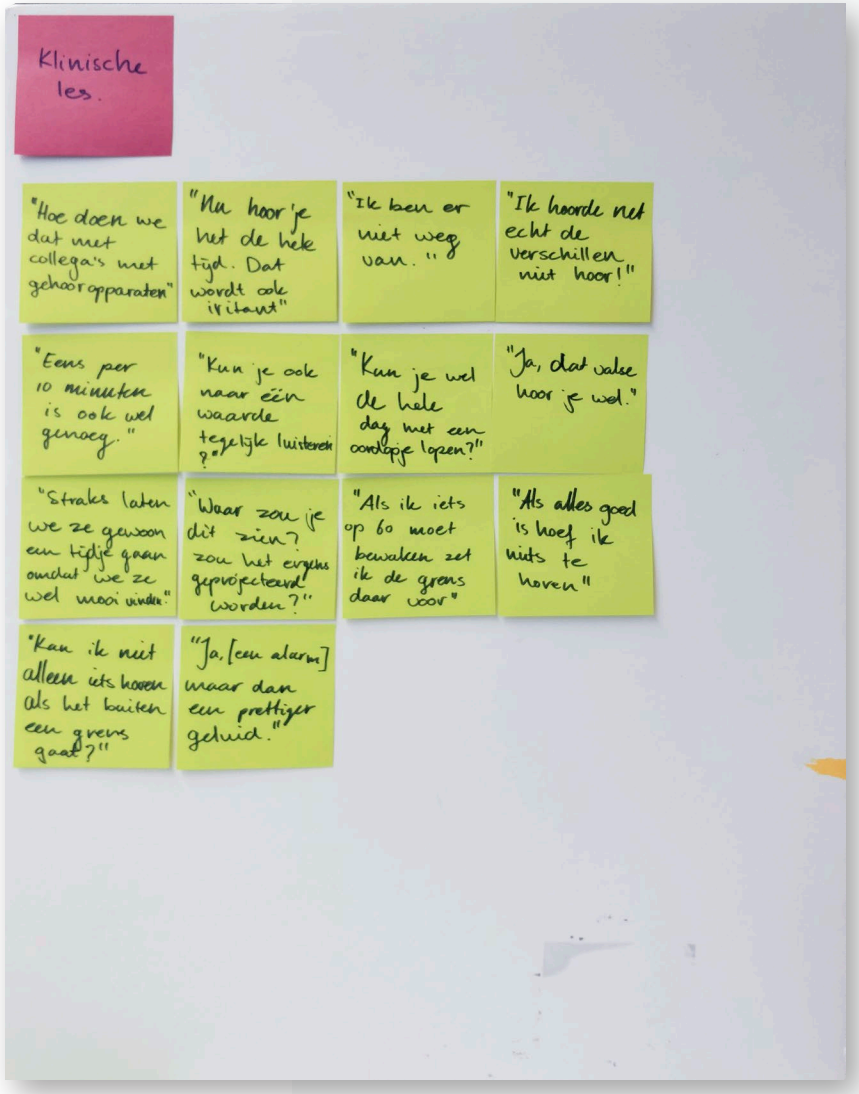


Image 41: The results board for the clinical lesson

8.3 Usability test

A usability test is conducted to get more in-depth insights in how well Care Tunes works and how it is experienced by nurses. During the test, four nurses listen to the sonification of simulated patient data, both without and with the dashboard to support them. After the test an interview is conducted to reflect upon their experience of the design.

Goals

User test allow nurses to experience the design and form an opinion of how well they think the design will work for them. The user test can also indicate how well they understand the sonification and the visualisations in the GUI accompanying it. The questions addressed by the user test are:

2.1 What values do nurses intuitively assign to the different timbres in each parameter they hear in Care Tunes?

2.2 How well are nurses able to recognise the different parameters and the changes within them?

2.3 Do the visual cues in the user interface support nurses in understanding what they hear?

2.4 How do nurses feel about using Care Tunes in their work?

- What do they see as advantages and disadvantages?

- Would they trust themselves to hear changes in the sonification?

- How would they feel about wearing an earpiece?

Participants

Four of the nurses, two male and two female, who previously participated in the interviews about sounds in the ICU have been found available for usability tests. They have different levels of experience in the ICU but they all have the same roles. The participants had been introduced to Care Tunes during the interviews, so they were somewhat familiar with the concept.

Procedure

Before starting the test, the basic principles of the design are explained. Like in the clinical lesson, a storyboard is used to help the participant understand the role that Care Tunes would fulfill in the ICU.

The test starts by the participant listening to the sonification without looking at the GUI. The participant listens through on-ear headphones. These allow for conversation to take place while listening. While the participants listens to the simulated patient data, they are asked to think out loud and explain what they hear and what they think it could mean. When all timbre changes have been covered, the participant is asked to remove the headphones to answer questions about their experience, as described in the full test protocol in appendix D.

The Care Tunes dashboard is introduced to the participant and once again, the participant is asked to listen to the parameters while the vital signs of the patients change. Participants are asked to describe what they hear and see, and what they think that means.

The session is concluded with an interview, for which the questions can be found in the test protocol.

During the test, notes are taken of observations regarding the users response to the design and their performance in recognising changes in the sonification. The session is recorded to allow for the documentation of quotes from the participant at a later time. Observations and selected quotes from all usability tests combined are organised on a board based on the recordings that were made during the session.

Results

Two boards are used to show the difference between listening without and with the GUI. Quotes are linked to the different timbres that the nurses heard during the session, showing how they intuitively perceive them, and how this changed when the GUI was introduced. This gives the following insights.

Some of the timbres in each parameter intuitively sound urgent to participants. For other parameters, some participants feel the timbre change may be too subtle.

Most participants are able to recognise the timbre change corresponding with a value close to the limit. All participants recognise a value crossing the limit.

The introduction of visual support clearly makes it easier for participants to follow the parameters and hear which part of the music belongs to each of them.

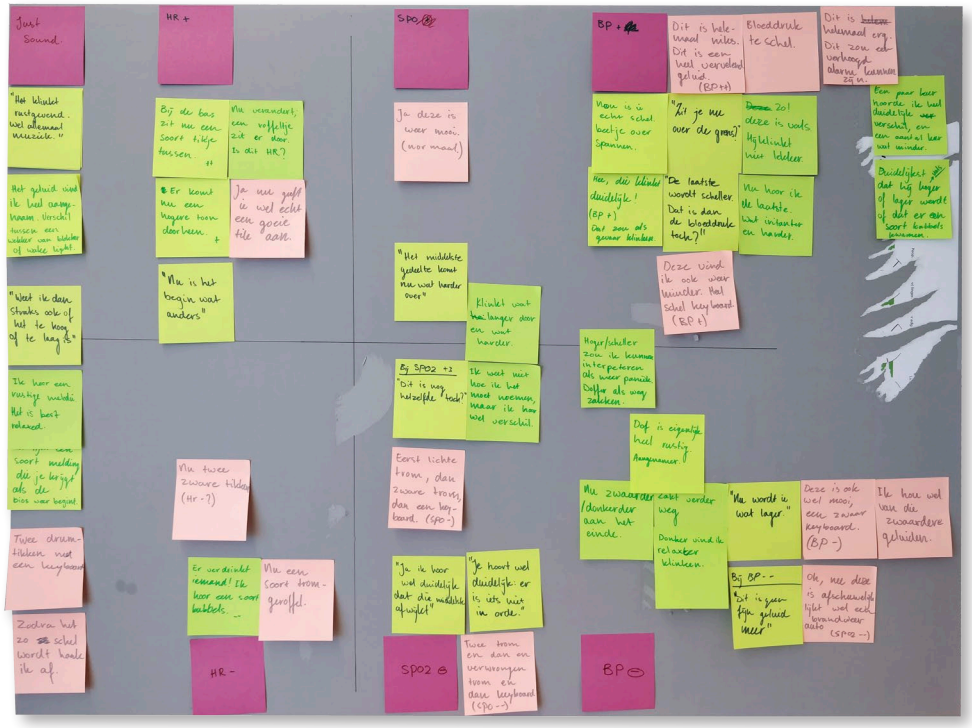


Image 42: One of the results boards from the tests.

When listening to the sonification with visual support, some participants indicate the sonification sounds less urgent than they would expect for the heartrate and oxygen saturation parameters.

Three participants feel wearing an earpiece would be convenient way of listening to Care Tunes. One participant indicates wearing an earpice might be uncofortable and expresses concern about nurses wearing hearing aids.

8.4 Technical evaluation

Many of the technical implications of implementing Care Tunes are still unknown. Judging from conversations with ICU technicians during the project, an open communication between medical devices seems challenging. Three technicians who work in the ICU are asked to participate in an evaluation session to elaborate on this.

Goals

The technical evaluation is held to determine how realistic it is to implement Care Tunes in the current landscape of ICU equipment. The session should also provide information about how information is generally communicated between ICU devices. The following questions are addressed:

3.1 What are the possibilities for communication between devices in the ICU?

3.2 In the case of Care Tunes, can the data that is displayed be sent from the monitoring system?

3.3 How can a connection between the monitoring system and Care Tunes be made?

Participants

Three ICU technicians join the technical evaluation session. They all have experience in nursing and currently work in the ICU to offer technical support. One of the participant also advises the suppliers of equipment about requirements that clinicians have of ICU equipment.

Procedure

Again, the Care Tunes design is introduced to the participants using the storyboard. After this introduction the prototype is used to allow the participants to try listening to the changing parameters for about 10 minutes. The participants also view the GUI while they do so.

After the introduction and demonstration a discussion is held to discuss the technical implications of Care Tunes for the ICU. The topic of implementation of the design is also discussed. A full list of interview questions can be found in the evaluation protocol in appendix E.

The session is recorded for later documentation of quotes from the technicians during the interview. From the recordings, another board with quotes is created.

Results

From the answers to interview questions and the general discussion that arose after the demonstration of care tunes, several topics of interest become clear. The following points arise from the technical evaluation.

The ICU technicians feel Care Tunes potentially offers a valuable advantage in it's ability to not only communicate that a value crosses a limit, but also indicate by how much.

Care Tunes currently does not display all parameters that are of importance for ICU nurses. If the design were to becom part of a monitoring system, it would have to be able to display all of the parameters that are used in the ICU.

The technicians think there are possibilities for the implementation of the design in the ecosystem of devices that is currently in use in the ICU. There are protocols that allow data communication between devices in the ICU.

The introdcution of more sound as a measure to reduce alarm fatigue seems counterintuitive to the technicians. They are sceptical about possibility for nurses to set the update frequency because they feel this might overcomplicate the system.

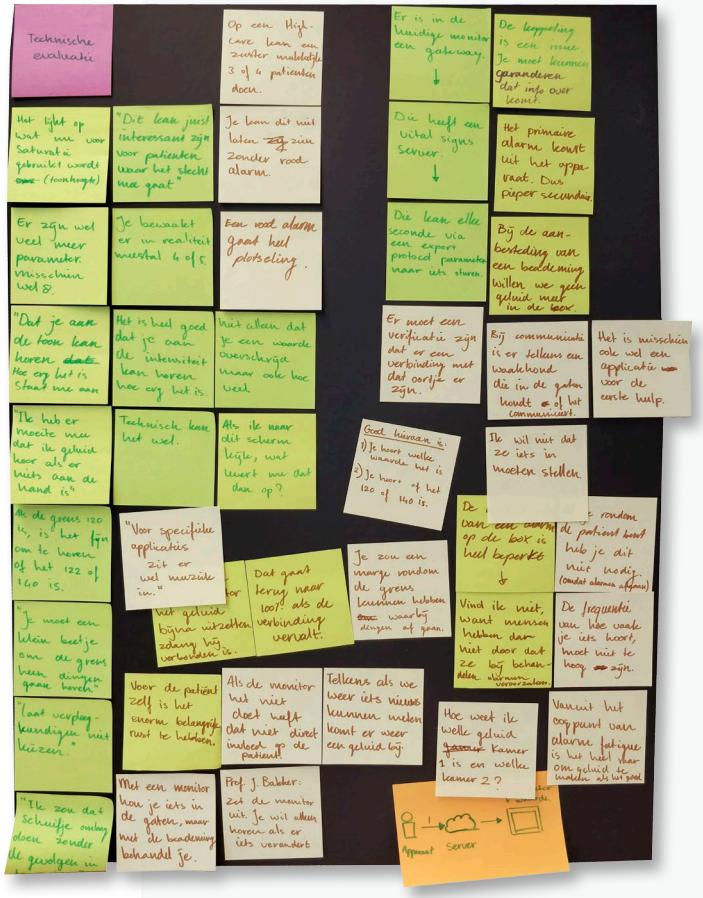


Image 43: Results from the technical evaluation

8.5 Prototype

Each of the evaluation activities involves the use of a prototype to help users understand the design. It lets potential users of Care Tunes experience what it is like to use it, allowing them to express their experiences with the design. This section explains what functionality is implemented in the prototype, and how this was done.

Functionality

The prototype allows potential users to listen to Care Tunes as if they were listening to a patient. The patient's vital signs are simulated, and the prototype responds to those vital signs. Initially, the prototype would take these vitals from a text file that contained these parameters for every second of a few hours. Such files can be exported from the patient monitor. The values can then be read in a Max patch after some alterations in the text file. For the purposes of the usertest however, this would cause issues in timing the parameter changes.

The current prototype is therefore controlled by a wizard to simulate the patient (J.F. Kelley, 1989).

The prototype also allows users to experience the visual link between the auditory information and the parameter of each vital functions. It does this by visualising each of the sounds in a mockup of the Care Tunes dashboard as they play.

Tools

A combination of software, shown in image 44, is used to achieve the desired experience for the users participating in tests and evaluation sessions. Most of the software has already been found suitable for these tasks in previous cycles.

Ableton Live was used to design the sounds in cycle 4. A project file in live contains the midi tracks and instruments that generate the sound a user will hear. Live also contains the audio effects that cause timbre changes. Since live is set up as a sequencer, it takes care of the timing of each sound relative the the others.

A **Max for Live** patch contains the logic that links each medical parameter to a setting of the corresponding audio effects in the Live project. It also measures the audio levels of each of the three sounds played in Live. The values from these measurements control the animation that visually represent each sound in the dashboard. Max also receives messages from **TouchOSC**, which the researcher uses to simulate the patient.

Processing displays the medical parameters, as set in TouchOSC by the wizard, in the dashboard mockup. The movement of the circles displaying the parameters, linking the sound to the visual interface, are also animated in processing. This way, as the timbres change, the animation changes with it.

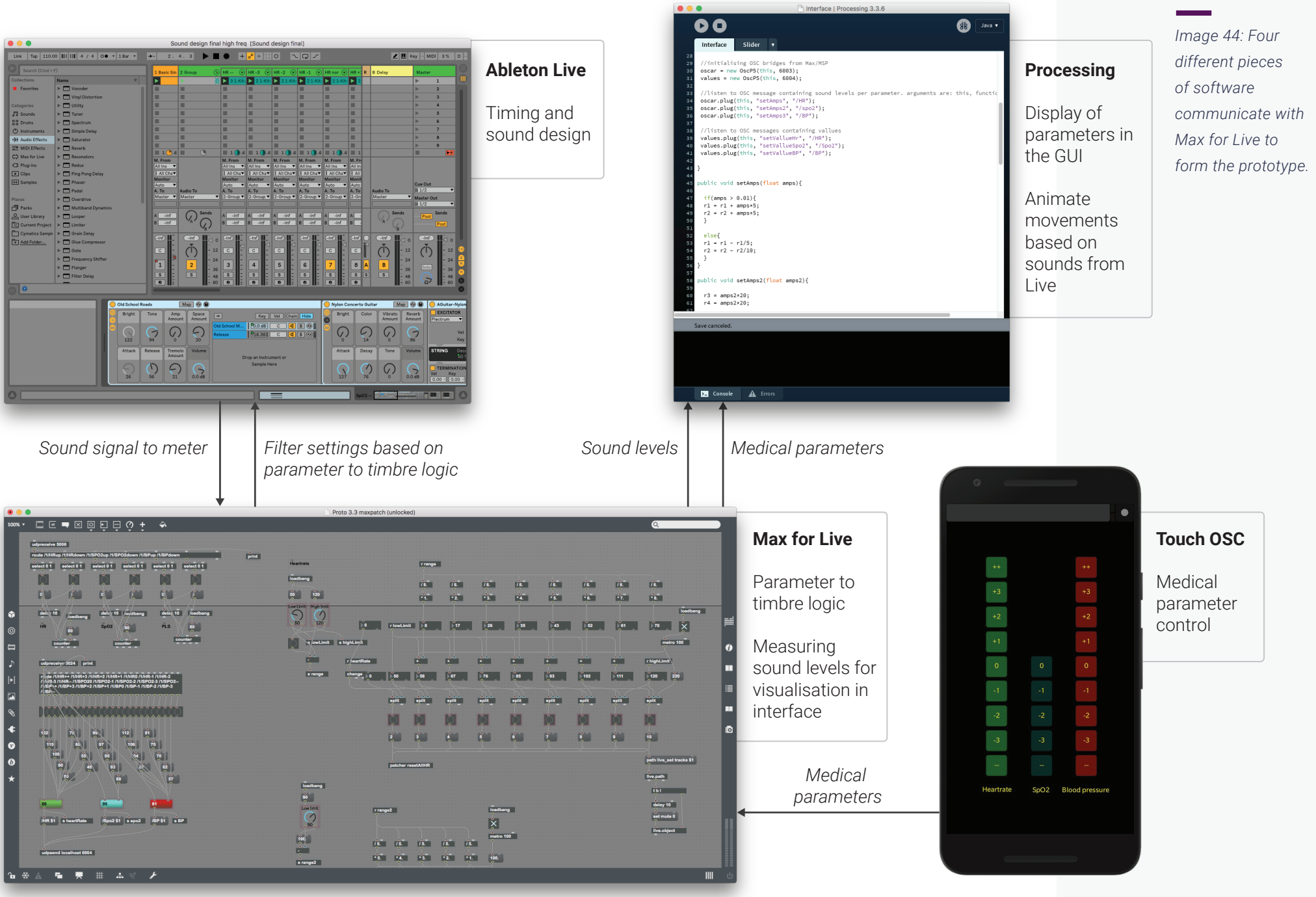


Image 44: Four different pieces of software communicate with Max for Live to form the prototype.

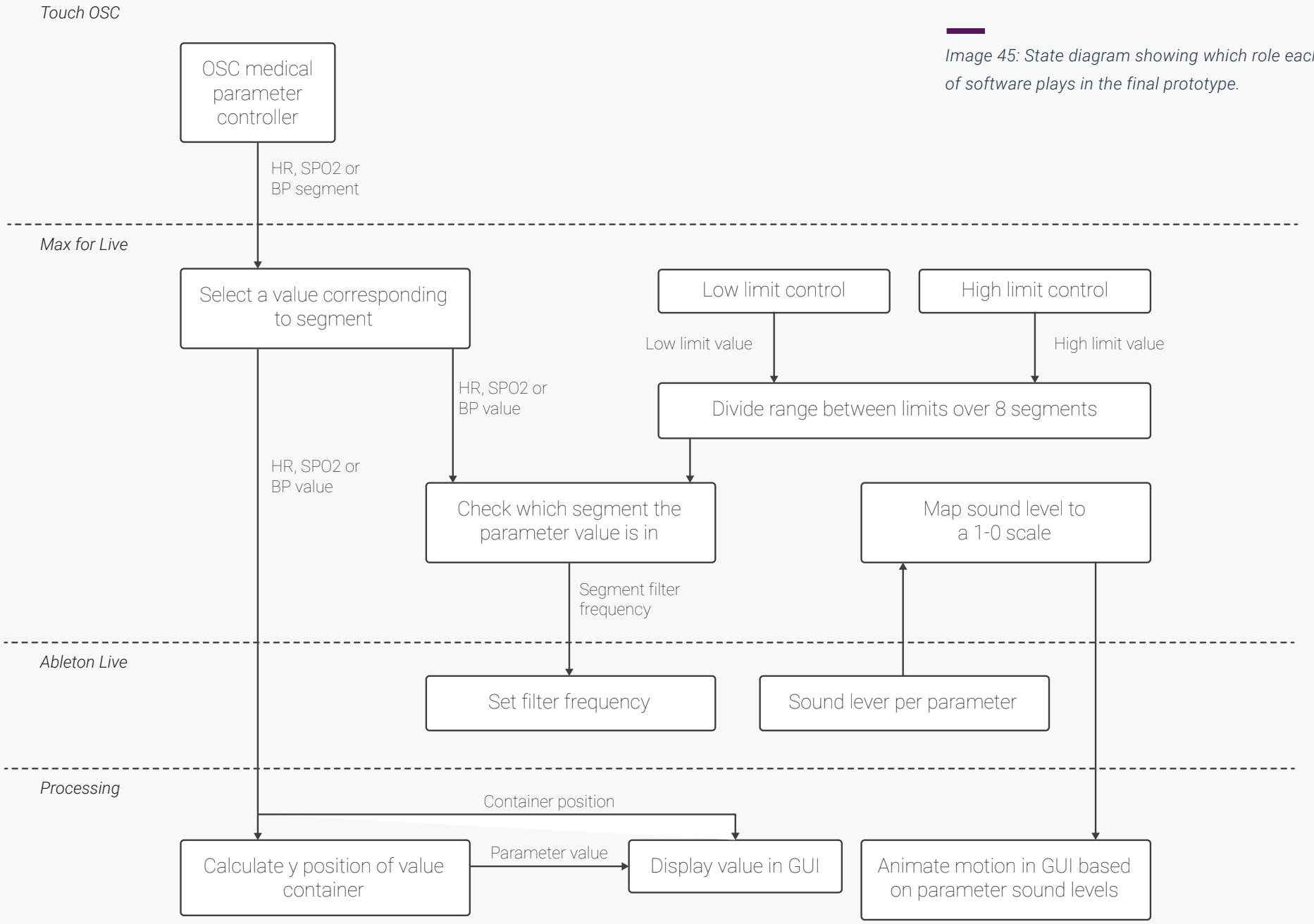


Image 45: State diagram showing which role each piece of software plays in the final prototype.

8.6 Integrated results

Results from the three evaluation studies were analysed to find patterns that occured across the different activities. This resulted in five themes in which the integrated results of the product evaluation overall are presented. These are represented in the infographics in the remainder of this chapter.

How nurses experience Care Tunes shows the overall impression nurses expressed of the design. There are aspects of the design that participants are skeptical about and ones they are positive about. There is a middle category of design features that nurses are unsure about or about which opinions differ.

Listening to the sonification indicated how participants respond to each timbre segment in each parameter, without looking at visual support. This gives an indication of how well the sound intuitively communicates each value.

Listening with visual support show how the perception of each timbre segment changes when the visual support is introduced. This indicates whether the interface supports the sound as intended.

Different situations with and without Care Tunes goes into the different applications for Care Tunes that were mentioned by participants in all three evaluation activities. The infographic shows how each of the mentioned situations can benefit from Care Tunes.

Care Tunes in the ICU data structure explains how data communication between devices and networks on the ICU occurs according to the ICU technicians. It also indicated where Care Tunes can be implemented in this ecosystem.

How nurses experience Care Tunes

In a 'clinical lesson', Care Tunes was demonstrated to around 15 nurses, allowing them to share their opinions of the concept. The design was tested more thoroughly with 4 other nurses. These tests also resulted in an understanding of how they would feel about using the design. This infographic shows what they thought they would benefit from in the design, what they thought should be different, and what aspects of the design they were unsure about.

Care Tunes introduces sound that is perceived as unnecessary.

"From the perspective of alarm fatigue, it seems strange that this makes sound when things are going well"

"When everything is fine, I don't want to hear anything."

"I think this will become very repetitive when you hear it all the time."

Using all paramaters current monitors offer would be complicated with Care Tunes.

"Hearing three parameters in one sound might be difficult"

"There are way more parameters then are shown here."

People are unsure whether they will be able to distinguish between several patients

"When one of the rooms is always the high chord, and the other always the low one it should be clear."

"How will I know which sound belongs to room 1 and which one to room 5?"

"When you mentally reverse the sounds, that's fine as long as the rooms are next to each other."

Some nurses don't think they can wear an earpiece all day, while others think it would work very well.

"I don't like wearing headphones that much, I don't do it in my daily life either."

"How would this work with our colleagues who wear hearing aids?"

"I think I could get used to an earpiece"

"An earpiece would be ideal! You can individually determine you preferences."

Setting the update interval can be useful for nurses, but may also diminish how well Care Tunes works.

"I would immediately put it in the lowest setting without realising the consequences"

"You shouldn't let nurses choose the intervals"

"For some, stable patients, once every 10 minutes is enough"

Care Tunes sounds pleasant and calming

"It sounds very relaxed. They are pleasant sounds."

"You don't feel stressed listening to this."

"As long as everything stays within limits, you are listening to a very harmonious sound."

Care Tunes can offer an intuitive overview of the patients health and create better sound management.

"When you use alarms only as a reminder for yourself, it would be much better to use this [design]."

"I was focussing much more on the parameter I was hearing"

" [currently] when i have to monitor something at 60, I will have the limit just before that."

"I really like that you don't just hear that you cross a limit, but also by how much"

Participants believe they will quickly learn to work with Care Tunes

"I Think you will start recognising it very quickly."

"Maybe once you get used to it, the sounds are completely embedded in your routine."

"I could hear some slight changes, but at the limit it was really clear."

"Yes, I'm very sure I will learn to hear those [subtle] differences."

The Care tunes dashboard clearly helps people understand what they are hearing

"This definitely makes it much clearer."

"Because I can see what I am hearing move on the screen it becomes very clear."

"Aha! So I can hear heart rate, saturation and blood pressure in sequence"

"I can see everything in numbers but also hear it in the music."

Care Tunes accommodates different preferences

"When you can individualise sound, everyone can determine how they want it to be"

"I use quite broad limits compared to others."

Listening to the sonification

General remarks

Care Tunes sounds pleasant and calming

"It sounds pleasant, very musical"

"It's like the difference between a cheap alarm clock and a wake up light"

More shrill sounds are less pleasant

"When I hear those shrill sounds I don't like it anymore"

"I find the darker sounds quite relaxing"

Listening with visual support

General remarks

The dashboard makes listening easier

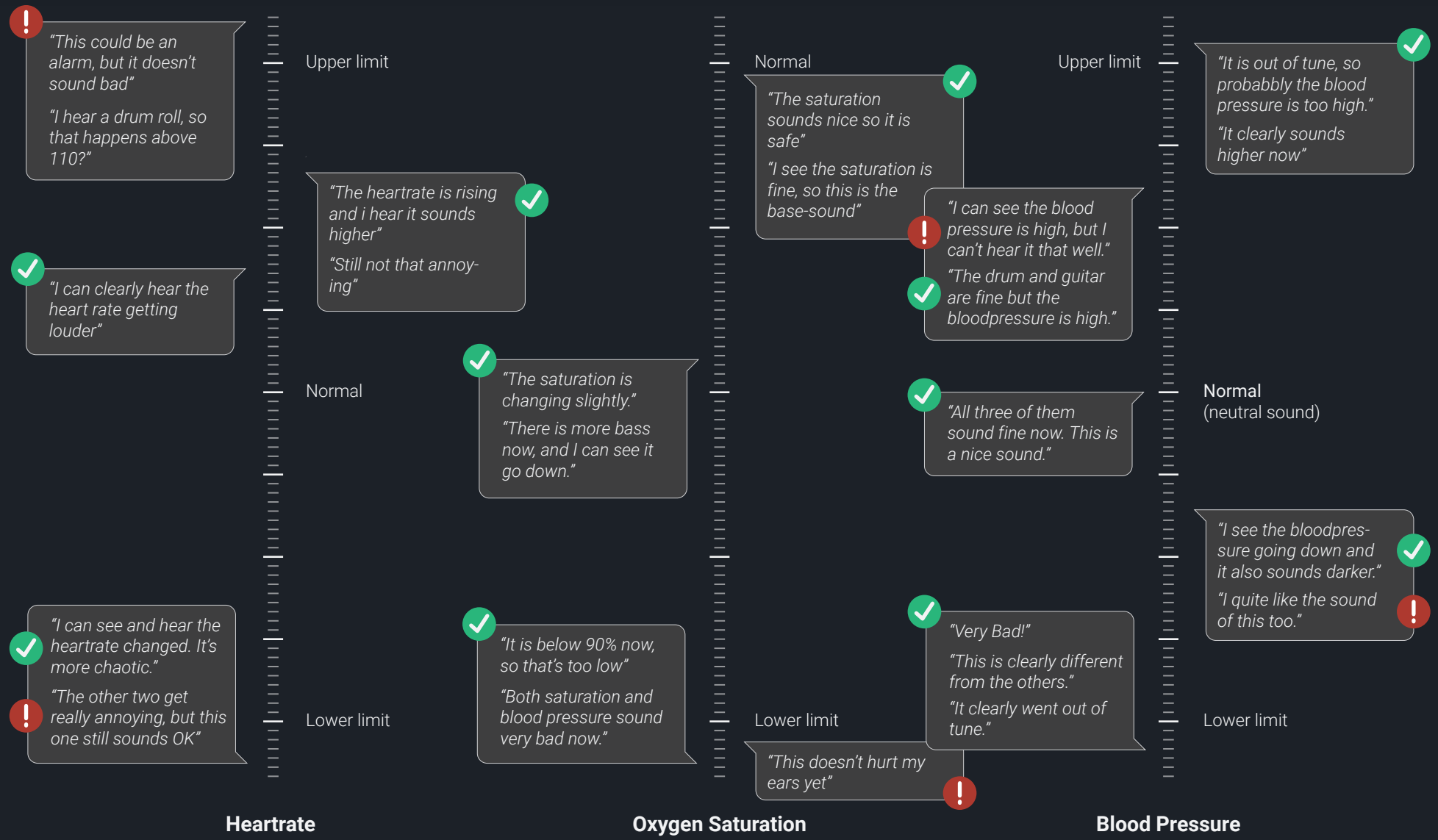
"I can see what I am hearing on the screen now."

"Aha! So it is heartrate, saturation and bloodpressure in sequence!"

Unpleasant sounds mean something is wrong

"The sounds become unpleasant when things are going worse"

"The saturation sounds good, so it's OK."



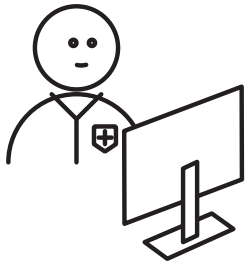
Different situations with and without Care Tunes

During the tests and interviews that were conducted to evaluate Care Tunes, the prototype an storyboards helped participants imagine what the ICU would be like if Care Tunes were used there. Because of this most of them mentioned several situations they were currently familiar with to explain how these situations would benefit from the design. Some participants expressed specific situation that they thought Care Tunes wad most suitable for.

Monitoring patients

Currently

Nurses constantly keep an eye on the monitor to keep track of a patient's health.

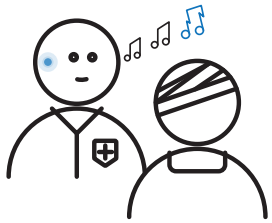


"Based on a sound you hear you will have a look at the monitor"

"In the new ICU, when you walk away from the desk, you don't have the monitor ...

With Care Tunes

Nurses can listen to parameters to stay up to date and focus more on patients and other tasks.



"You could use this in stead of looking at the monitor"

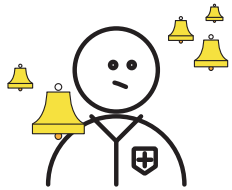
"...In that situation this could replace the monitor"

"From the sound you can already hear something is happening"

The soundscape of the ward

Currently

Each alarm sounds in at the nursing desk and will be heard by everyone who is there. Alarms that go off in the patient room while a nurse is there, will also sound at the nursing desk

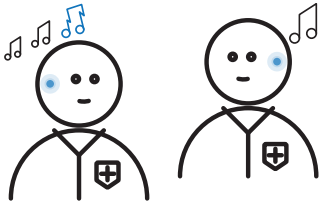


"My limits are usually set quite broad."

"When I am monitoring at 60, I will have the limit just a bit before that so I get an alarms a bit earlier"

With Care Tunes

Every nurse hears only what is relevant to him or her. Nurse can focus better on the patient they are monitoring.

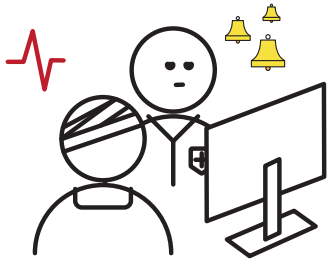


"When you can individualise the sound, everyone can set it just like they want it"

In the emergency ward

Currently

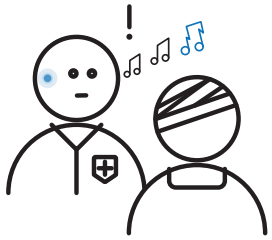
The emergency ward, can be very noisy and filled with alarms. Patients in the emergency room have not been diagnosed so many parameters fluctuate and alarms frequently sound.



"...parameters can change very quickly there."

With Care Tunes

Clinicians in the ER could benefit from Care Tunes as it can help them to be fully aware of fluctuations in the different parameters they need to monitor.

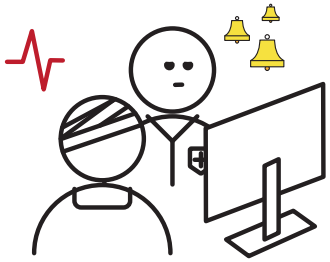


"I think this could be applied to the emergency room."

Very ill and instable patients

Currently

Very ill patients in the ICU have vital signs that fluctuate constantly. This means nurses need to be very alert in monitoring these patients. This often causes alarms to sound constantly.

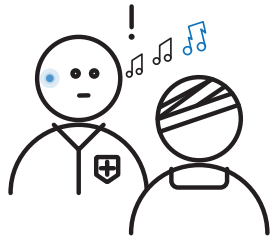


"With very stable patients, the updates don;t need to be as frequent."

"Sometimes things can changes very quickly..."

With Care Tunes

When nurses can listen to the vital signs of a very ill patient they can continuously hear the state of important parameters. Other nurses and patients are not disturbed by constant alarms.

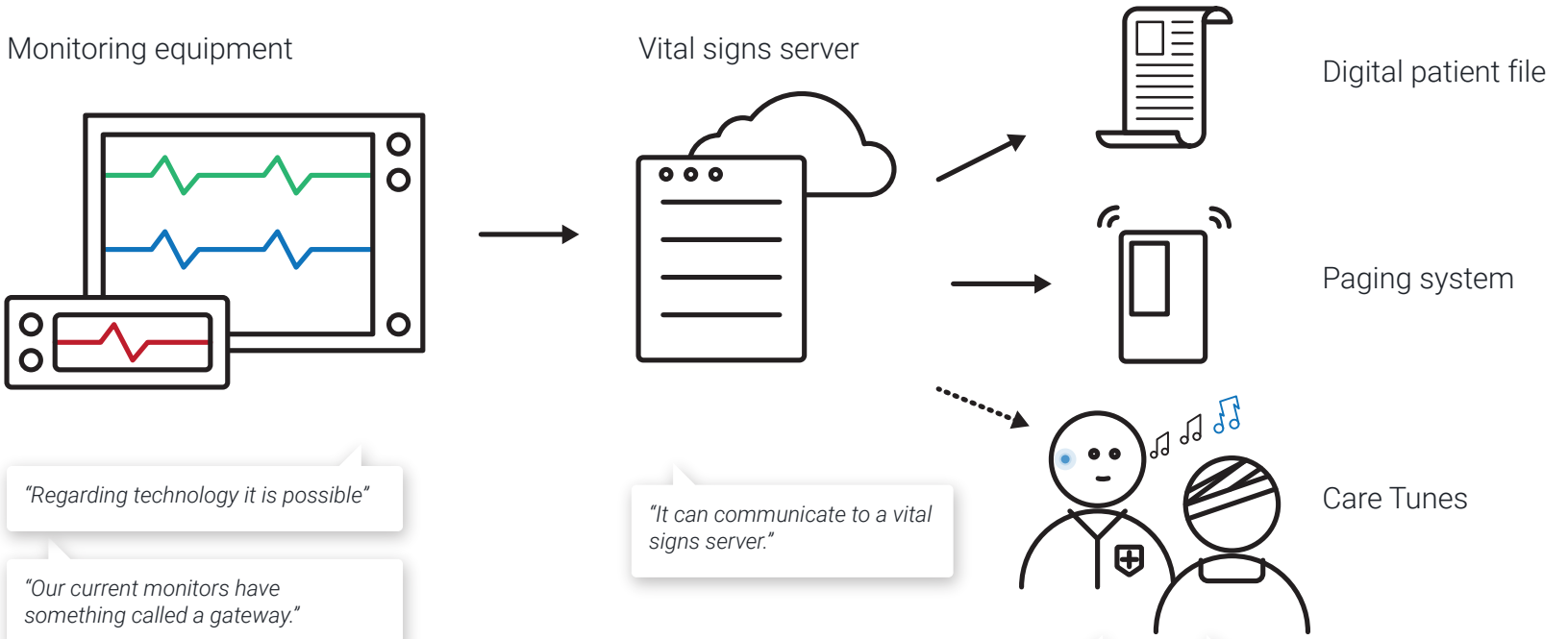


"This would be especially interesting for very ill patients."

"... in that case it would help to hear this constantly."

Implementation of Care Tunes

The technical evaluation took place to gain a better understanding of what it would take to implement Care Tunes in the ICU. Technicians elaborated on the communication between devices that is currently used in the ICU and how devices are designed to ensure safety. They were generally confident that the implementation of Care Tunes would technically be feasible through existing technology. This graphic shows how they generally describe this would work.



8.7 Conclusions

The evaluation of the Care Tunes design took place to verify whether the design succeeded in improving the current situation. It also exposes aspects of the design that can be improved upon to increase it's effectiveness and improve the experience nurses will have with it. The conclusions presented here, drawn from the integrated results in section 8.4, show how the evaluation results are interpreted to formulate recommendations for further development (chapter 9).

This design project was initiated with the goal to improve the soundscape of the ICU to decrease alarm fatigue. It was also meant to show an alternative to current alarm design to help along a paradigm shift that is needed in monitoring and therapeutic equipment design. During the design process more specific problems were found that could be solved through the Care Tunes design. These include the low specificity of alarms sounds, the tendency to take a 'better safe than sorry' approach and the disharmony created by a large amount of alarms that sound in the same space.

General reception

How nurses respond to Care Tunes seems to depend to some extent on the application of the design they have in mind. This is further elaborated on in section 9.2.

The design was generally received well by the nurses participating in the user tests, who were able to have the most complete experience of the design of all respondents. They were positive about the aspects of the design that aimed to fulfill design goals of providing a pleasant soundscape, offering information in a proactive manner and satisfying the need for constant awareness of the patient.

They were very positive about the way Care Tunes sounds, thinking it sounds much more peaceful than the current ICU soundscape.

They acknowledge the value of having a full overview of there patients just by listening to the sound. Some recognise the advantage of the sound being tailored to each situation and each individual nurse.

They appreciate that the soundscape keeps them in touch with the patient while they attend to other tasks or need a short break.

The concern expressed by every respondent, in the test as well as in the clinical lesson and technical evaluation, was that Care Tunes introduces sound to the ICU when the patient's vital signs are normal. Many respondents find this hard to understand, since Care Tunes is presented as a measure to decrease alarm fatigue. Many of the respondents in the clinical evaluation expect Care Tunes to be present together with all of the current alarms.

Some respondents are concerned about being able to recognise all the different parameters they need to monitor when they listen to the sonification. The parameters currently represented may be the limit for some nurses.

Lastly, nurses are divided when it comes to wearing an earpiece. Some think it will be very uncomfortable and some mention that their colleagues wear hearing aids. Others seem to believe that an earpiece can improve the soundscape of the ICU. Most of the concerns with earpieces seem to be of a very practical nature and will be further discussed in chapter 9.

Sound design

The overall sound of the sonification when all parameters are in the safest range is described as calm, relaxed and musical. This satisfies one of the main goals of the design: improving the quality of the sounds that nurses need to listen to during their shift.

When listening to the sound design on it's own, most participants very quickly notice the three separate sounds that they need to recognise. Also, when values cross a limit, each participant is able to indicate they heard a change. This indicates Care Tunes has the potential to be at least as safe as current alarms.

When values are within limits however, the perception of the sounds varies between participants: two are quite accurate on recognising subtle change, one hears some changes but misses others and one finds it quite hard to recognise changes. The sound design on it's own seems to succeed in communicating the limits, but communication of smaller decreases and increases are uncertain when user rely on sound only.

When participants do recognise subtle changes, the intuitive response they have to them differs between parameters. A heightened blood pressure clearly causes the biggest increase in annoyance, while a decreasing heart rate is called deep and relaxing by some. When sounds have a prevalence of high frequencies, most participants note it sound urgent. This is not the case for sounds with mainly low frequencies. This inconsistency between and within parameters is a problem, because the annoyance of the sound is meant to rise proportionally to each parameter.

Listening with the dashboard

When listening with the visual support of the dashboard, users clearly understand much better what they are hearing. All participants mention the movement in the interface clearly links each sound to the corresponding parameter. As the test progressed, all participants started referring to each sound by the name of the parameter it corresponded with, showing they were able to make the mental connection between them after a few minutes of visual reinforcement.

During the approximately 20 to 30 minutes of the test, some participants showed some improvement in recognising the subtle changes, especially when compared to listening without the dashboard in front of them. This suggests visual support can increase the nurses' performance in learning to work with a sonification.

Where in the part of the test without the dashboard the link between a change in sound and the change is sometimes made intuitively (some participants find some changes sound more dangerous) the connection is quite easily made with the dashboard. Some user do however note they would expect a sound to sound more urgent for the value they see on the screen. This again refers to an inconsistency in the annoyance levels between parameters.

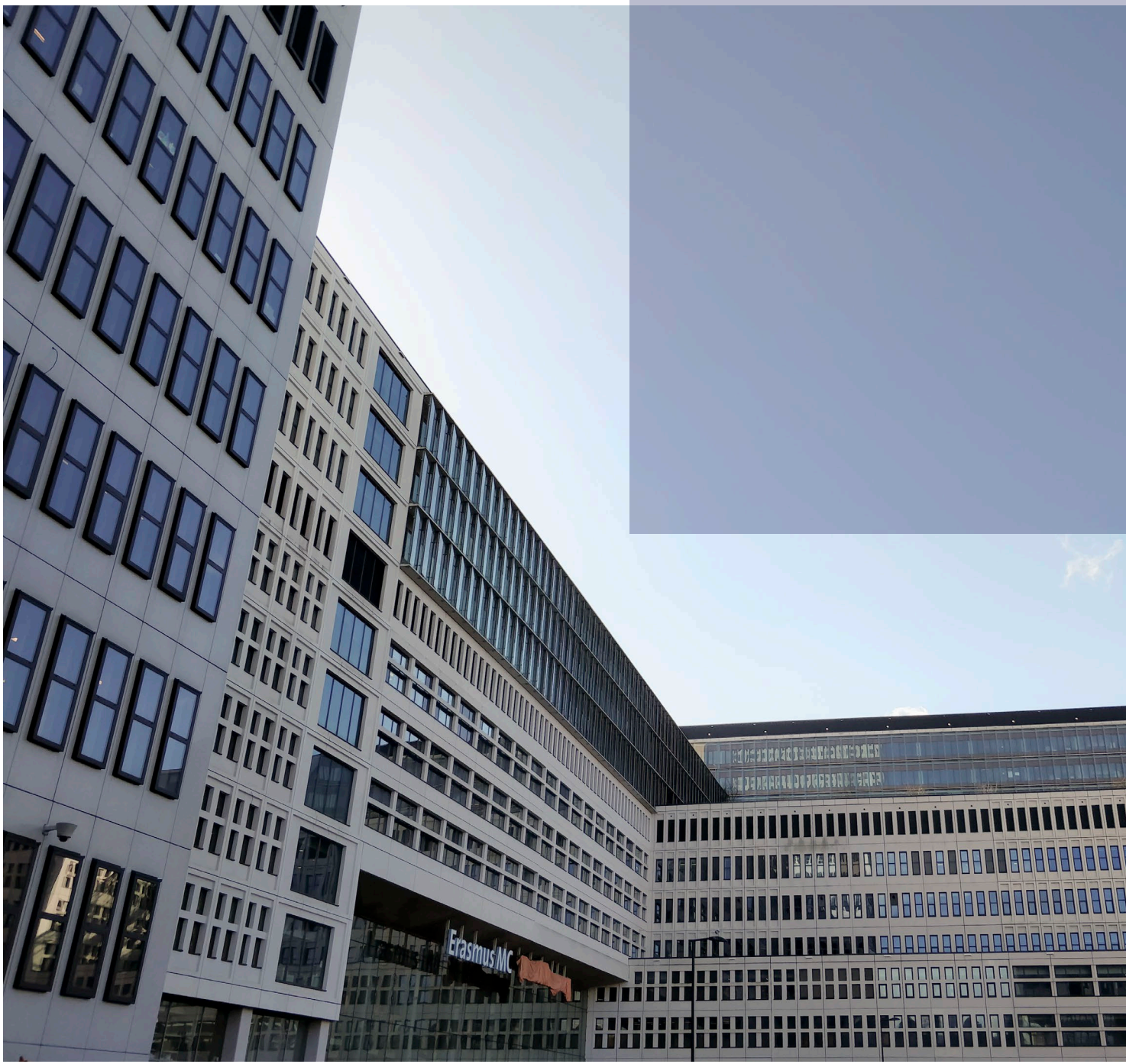
The most important goal of supporting nurses with the dashboard is to support them in listening to the sonification and to teach them how to use the sonification on its own. The dashboard seems to succeed in offering support. Determining how well the sonification can be used without this support after some time needs long testing but this too seems promising from what could be observed in the usertests.

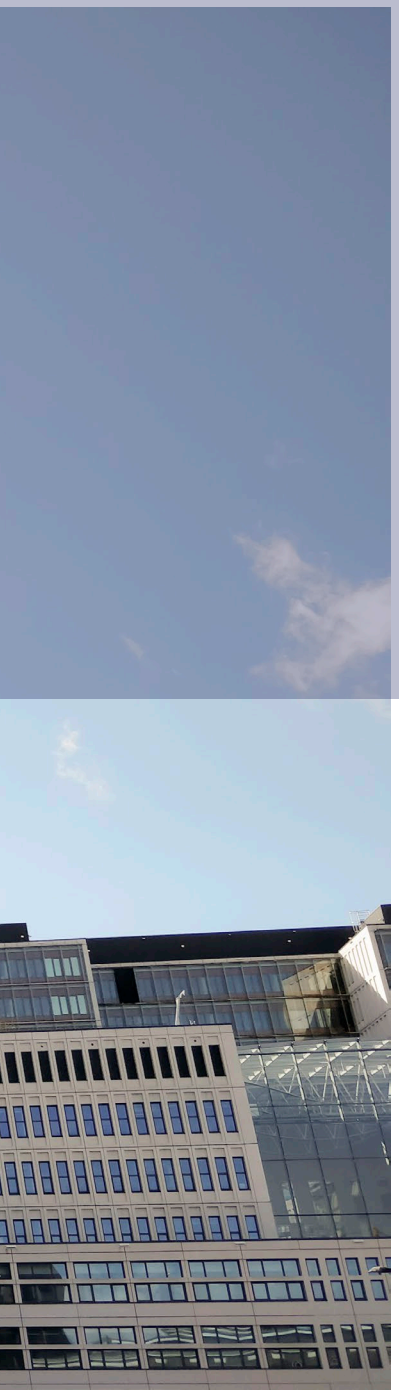
Areas of application

Asking respondents and participants to imaging how their work might change with the introduction of Care Tunes prompted them to discuss several situation that might be influenced by it. As the results page on Care Tunes in different situations shows, there is a range of applications within the medical practice in which people could benefit from Care Tunes.

When considering nurses, who are the target group the research and design in this project focuses on, the relative health of a patient seems to have a big influence on how Care Tunes would be used and how big the advantage is it offers. Very stable patients who are about to leave the ICU don't require a nurse to be constantly aware of all vital signs. Periodic measurements may suffice. When a patient is very unstable however, nurses see much more value in using Care Tunes as it would help them to hear exactly how all parameters relate to what is considered a safe value.

Furthermore, people evaluating Care Tunes are divided when it comes to introducing a sonification to help them monitor patients. Some are very enthusiastic and indicate they would use it if it were implemented, while others are much more hesitant. Some nurses who are sceptical suggest changing the sonification to only sound when a value crosses a limit, which would mean it works just like an auditory alarm. These differences between nurses can be taken into consideration in how Care Tunes would be implemented. This will be further discussed in chapter 9.


Erasmus MC



Chapter 9
Recommendations

To further develop Care Tunes into a tool that can be implemented in the ICU, some work on the design and the technology behind it remains. Possibilities for implementation of the Care Tunes concept seem promising. While the current state of the ICU in the Erasmus MC leads nurses to often perceive Care Tunes as more sound added to what is allready there, Care Tunes can play a role in the ongoing development of quieter environments for critical care.

This chapter describes some of the aspects of the design that need more attention. Recommendations for how Care Tunes can benefit from further research are given.

9.1 Sound design

The evaluation of Care Tunes shows that dissonance works very well in communicating action needs to be taken. Some of the timbre changes that nurses listened to in the tests are intuitively interpreted as the sound becoming more urgent.

In the current sound design however, there are still inconsistencies in how people intuitively respond to the timbres. It seems the sounds containing more high frequencies are perceived as urgent or annoying, while the sounds with more low frequencies, communicating a decline in a parameter, sound relaxing to some.

In further research, an alternative to a low pass filter may offer a solution to this. A lower value could for example become increasingly distorted as the value falls. Another option that is worth considering is to communicate urgency by changing timbre while pitch communicates the value of the parameter.

Updates

Care Tunes allows nurses to choose how often they would like to hear an update. While nurses feel this is a useful feature, it may turn Care Tunes in yet another auditory alarm as nurses indicate they would like to hear an update at quite long intervals. This would mean Care Tunes no longer works as a sonification.

Based on the evaluations, the update frequency should not depend on the user. It should rather be determined by the state of the patient, as this is what nurses refer to as the factor that would influence how they would set the update frequency.

By sounding each parameter as it changes from one timbre segment to another the sonification would work better in three ways:

Nurses would feel more like they are only updated about changes, while they are still provided with information that helps them be proactive.

The stability of the patient's vital signs determine how lively the music sounds. When Care Tunes sonnifies an unstable patient is will be an almost constant stream of music, while a very stable patient will merely induce periodic musical updates.

The musical sonification will sound more organic because each patient's Care Tunes will sound completely unique as each parameter sounds in different beats within the Care Tunes rhythm.

A disadvantage of organising Care Tunes like this can be ease with which users can use the sonification to recognise the patients health. This would have to be reevaluated.

9.2 Areas of application and introduction

Several participants in the evaluations pointed toward specific situations in which Care Tunes would be most valuable. These specific applications of the design, like the emergency room or for only very ill patients, should be taken into account. To situations in which a patient is very unstable or where, like in the ER, parameters need to be constantly monitored, Care Tunes can be especially beneficial. This does not mean however that Care Tunes should not be introduced as a design that the entire field of critical care can benefit from.

Care Tunes is in part meant to create awareness of how sound can play a much more positive and supportive role in the environment of the ICU than alarms are currently able to. It should help initiate a paradigm shift where it comes to sound design in critical care. This also means that the design will not exists in parallel to the alarms that are currently in place in the ICU. This is not considered when concerns about adding 'yet another sound' to the ICU.

A better understanding of what the advantages of Care Tunes can be can most likely be gained from reevaluating the design once the new ICU in the Erasmus MC has been in use for a while. The decentralised nursing desks found there will create situations in which nearly all alarms nurses currently have to cope with are silenced. The decentralised nursing stations can therefore make it easier to demonstrate the benefits of Care Tunes. Nurses generally assume their workflow will be mostly unchanged in the new ICU, making it difficult for some to imagine how Care Tunes can help them there.

9.3 Implementation

Evaluating the Care Tunes design has given insight in how medical devices are currently able to share information, and how Care Tunes could be integrated in this. ICU technicians were quite confident Care Tunes could work with the equipment that they are familiar with and use in their ICU. This section shows how this could be done if Care Tunes would be implemented at the Erasmus MC.

Medical equipment gateway

The ICU in the Erasmus MC currently uses the Draeger infinity monitoring system. This system consists of several different devices. These include the bedside monitor, which measures vital signs, and the central monitoring system. In the Erasmus MC ICUs The latter can be found in the central nursing desk. These components of the Infinity product family are all interconnected in the infinity network and data is communicated between the devices within this network.

The Infinity network also has a 'gateway' to the hospital network (image 46). The hospital network can include a range of devices and databases. The hospital keeps a record of patient data in the Hospital Information System (HIS). The gateway allows patient monitors to communicate with such information systems so data can be saved there. The communication to a HIS is bidirectional, so data from the HIS can be imported into the monitor.

Health Level Seven

Health Level Seven (HL7) is an organisation that aims to achieve interoperability between healthcare systems. They provide standards for the exchange of data between devices. This means they define messaging standards that allow for the communication of clinical and administrative date.

The Infinity gateway uses the HL7 2.3 protocol to send and receive data. This protocol is not restricted to just Draeger devices, as is the objective of HL7, meaning devices from all manufacturers can communicate to the infinity system using the HL7 2.3.

Communications between medical devices

Despite the networking possibilities the monitoring system has, the ICU technicians interviewed in the

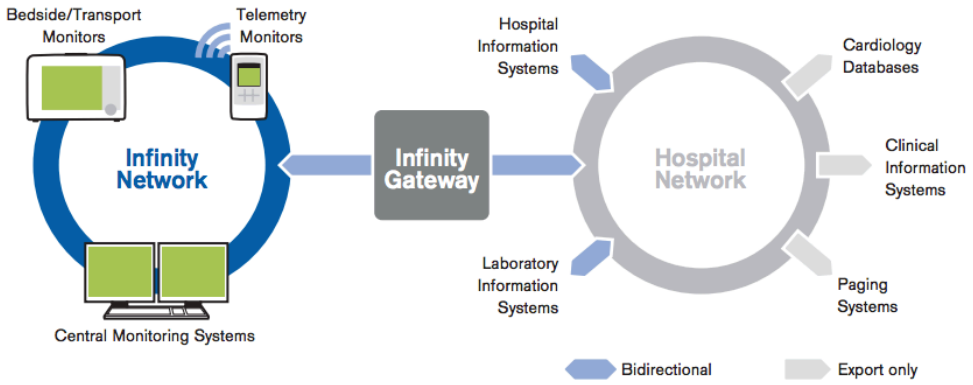


Image 46: The monitoring sytem has it's own network, but can also communicate to third party devices through a gateway.

evaluation indicate communication between devices is not always as smooth as they would like it to be. This seems to often be the result of the responsibility a manufacturer has to ensure information is perceived by clinicians. Connections between devices are constantly monitored, and when a broken connection is detected, the device will respond to this.

An example the technicians use to describe this mechanism is the infinity bedside monitor. The volume of alarms in the patient room can be almost completely turned down when a connection to the central monitoring system is established. Whenever that connection breaks however, the bedside monitor is automatically set to the maximum. This should ensure clinicians don't miss any alarms.

Connecting Care Tunes

So it seems quite realistic for the Care Tunes system to receive data directly from the Infinity monitoring system through the HL7 protocol. Care Tunes is a product that will be used for monitoring only, so it would not need to communicate anything back to the monitoring system. Because HL7 is used across devices of different manufacturers, Care Tunes will communicate in the same way with other monitoring systems, much like paging systems from different manufacturers can be used in conjunction with different monitoring systems.

As with all data communication in the ICU, Care Tunes will face the same challenges that technicians point out regarding safeguarding connections. To be sure parameters are received by the nurses using Care Tunes, the connection from an monitoring system to the main Care Tunes unit will have to be established. Another connection that is essential for the nurse to be aware of a patient's vital signs is the connection between the main unit and the ear piece. The main unit would receive the parameters, display them, and generate the corresponding sound based on them. It would then send a sound signal to the earpiece.

The latter poses the challenge of guaranteeing that the sound signal is received and played back by the earpiece. Especially because the sequential nature of the sonification means the user will often not notice the connection being broken. In further development, this should be taken into consideration when choosing the technology that is used for the connection to the earpiece. When the connection can be verified, a disconnected earpiece could be reflected in the sonification so the user can take action to establish the connection or by returning to the dashboard for visual monitoring.

9.4 Earpieces

Some concerns voiced by nurses responding to Care Tunes were related to wearing earpieces. Earpieces are essential to using Care Tunes outside of patient rooms, because listening to Care Tunes through speakers would cause yet another cacophony. Some nurse worry that earpieces may not be comfortable enough to wear during an entire shift. Another problem that is mentioned is that there are people with hearing aids.

Comfort

The ergonomics of an ear piece need to be considered when nurses are expected to wear them for a full shift. There are examples of professions, like in law enforcement or on construction sites, where people are required to wear earpieces during their shift, either for protection or for communication. Similar earpieces could be used for Care Tunes to maximise comfort.

Hearing aids

When people wear hearing aids to assist them because they suffer from hearing loss, they depend on the hearing aid to be able to hear well. This would mean they will not be able to wear the Care Tunes earpiece.

Most modern hearing aids however, are equipped with Bluetooth that can be used to send an audio signal to the hearing aid. Care Tunes can be sent directly to the hearing aid using such a connection.

In older hearing aids, that may not be equipped with Bluetooth, a connection to the hearing aids can be made through telecoil. This is a coil in the hearing aid that can detect an electromagnetic field. A signal that is sent to this coil can be played back by the hearing aid as a sound signal (global.widex.com).

The telecoil can receive a signal from a central system, which is often how it is used in concert halls. Personal devices that communicate to the telecoil are also available. A common form for this is a neck loop (image 47). Users wear this around their neck and connect the device to a source of audio via Bluetooth. The neck loop then sends the signal to the hearing aid's telecoil (Phonicear.com).

Image 47: A neck loop can connect Care Tunes to hearing aids that don't have bluetooth.

Image 48: The telecoil symbol indicates people can use telecoil in places like concert halls or museums.

9.5 Further validation

The evaluation presented here focuses on the usability of the Care Tunes design and the experiences and associations nurses have with its sound design. This shows that for nurses who find the sonification pleasant to listen to, Care Tunes can reduce the alarm fatigue they experience and create an awareness of their in a more pleasant way than current systems.

Before Care Tunes can safely be used however, quantitative research regarding the accuracy with which nurses can detect a patient's health through Care Tunes is needed. This would involve a much larger group of nurses, who can be asked to listen and respond to Care Tunes in a controlled environment. Nurses and technicians who were interviewed indicate that monitoring systems used in the ICU are often equipped with simulations that are used for training. When Care Tunes can receive data from such simulations, this could offer a controlled setting in which the reliability of Care Tunes can be established.

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