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Graduation Thesis Project

Final Report

Critical audible alarm-sound design for handheld monitoring devices in Neonatal ICUs

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With heartfelt gratitude,

[Anjay Valiyaveedu

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Abstract

This graduation thesis is on the topic of Critical audible alarm-sound design for handheld monitoring devices in Neonatal ICUs. Hand-held mobile devices are being tested in the field for effective alarm perception and response in the NICU at Erasmus MC Sophia's Hospital, Rotterdam. Based on the context analysis, the major stakeholder, and the focus of the design is the nurses and possibly neonatologist at the NICU, with the former being the main scope of this project.

The goal of this project is to The new critical audible alarms on the device must be able to distinguish the individual alarms, identify them for each patient per nurse, and respond to them by reaching the ideal destination of the patient room in a NICU. These responses should be achieved without the assistance of a visual cue.

A grammar for the new design is established via semantic network association methods (analogy) and in this case, it is the use of 'Baby Toys' as the building block for the sound design, The newly designed audible alarm library consists of 6 sounds namely Chimes, Lullaby, Shakers, Dial Tone, Piano A, and Piano S, which are then equalized under masked conditions for effective use in the NICU environment.

The alarms library tested for its perceived pleasantness, via mixed-method states that Piano A, Lullaby, and Chimes are the top

Introduction

The focus of this project is on the sound design of audible alarms in the critical alarm realm for neonatal ICUs at the Erasmus MC- Sophia Children's Hospital in Rotterdam, Netherlands.

The current critical alarm system used in the Neonatal Intensive Care Unit (NICU) at Erasmus Medical Center Rotterdam varies and includes ASCOM MYCO3, IQMessenger, Dragger alarms, etc., handled by the MICIS (medical Integrated Communications and Information System) department which integrates all the information streams from various devices into a single platform. Currently, the system is being integrated with an addition of special handheld mobile devices (HMD) which will be used to deliver and send various patient information within the faculty.

There will be a shift in the auditory alarm database due to the change in alarm standards and alarm devices affecting its perception. The goal is to create an efficient audible alarm sound library for the nurses at the NICU where the HMDs can help the nurses identify and respond to their patients through effective audible alarms from the mobile device for varying patient events.

The priority of the new audible alarm is to help nurses locate different patients effectively during an event and effectively respond to the event without visual cues when they (nurses) are mobile in the hospital.

The design process for this project follows that of a modified double diamond structure based on the requirements of this project. This is because many of the aspects of these requirements are discovered only during the actual development process here many of the requirements can be further defined. The alarm sound design is based on analogies that are baby-associated and built into audible auditory icons. The final phase of the project was to validate the usefulness of the newly designed grammar for the nurses in the NICU. The main function of these alarms which include response time, recognising urgency, and identifying the patients will be tested in validating the use case.

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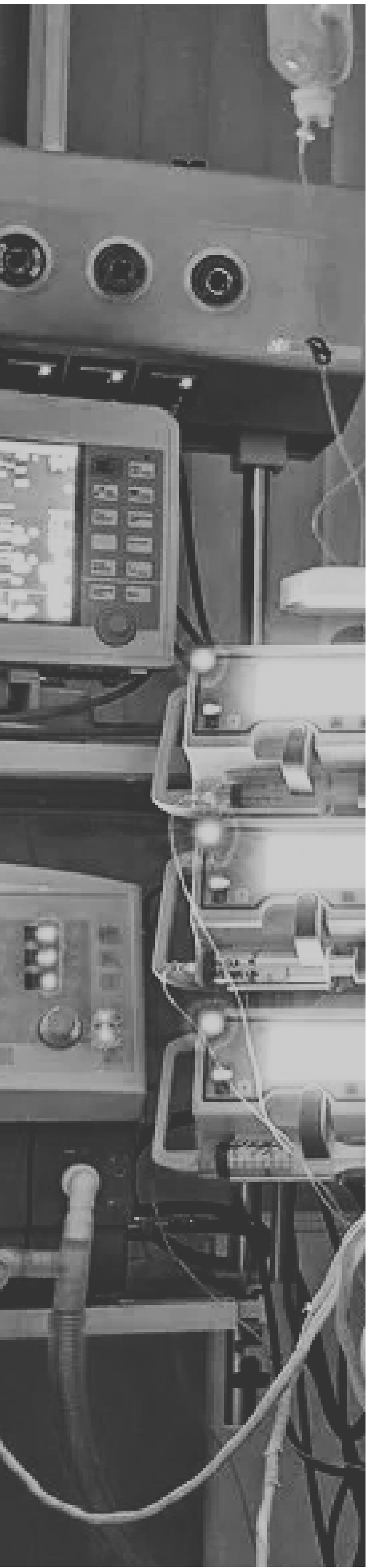


1.1 Design Brief

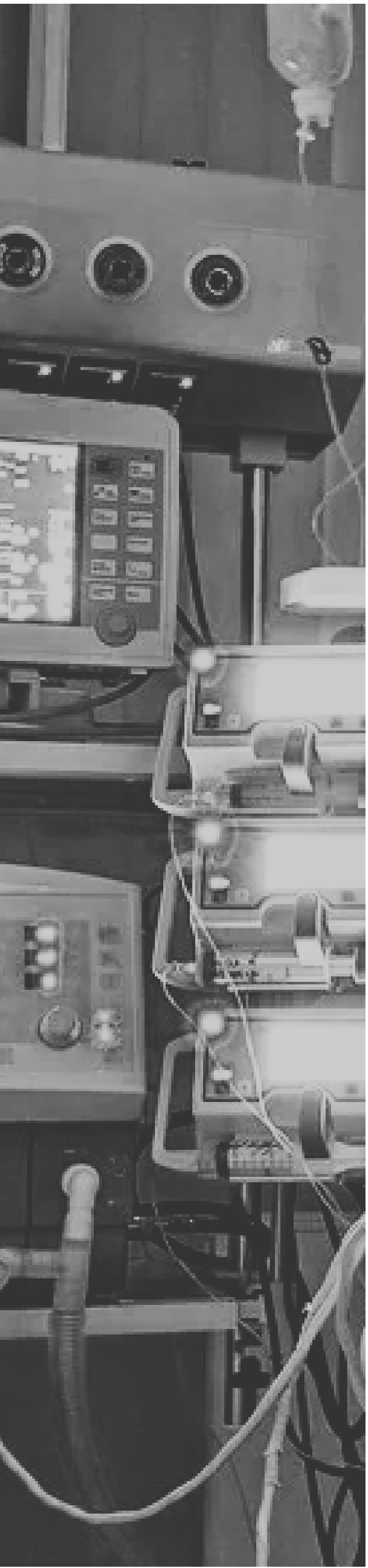
New handheld mobile devices (HMDs) are being introduced into the critical alarm infrastructure within the NICU. This results in mapping and creating an effective audible alarm grammar for the nurses to effectively use the device for apt responses to a patient event. The current alarm grammar result in more than 120 alarms being

1.2 Design Vision

“To help Neonatal ICU Nurses identify their assigned patient through unique audible-critical alarms from the mobile device in order to effectively respond to the patient emergency event.”

1.3 Scope

The current scope of this project is limited to introducing a audible grammar for the nurses at Erasmus MC Rotterdam through the sound design of auditory icons (i.e., metaphorical alarms) and earcons (i.e., musical alarms), which would increase the effective response by identifying patients through the new audible alarms (Edworthy et al., 2022) for the nurses at Erasmus MC, reducing the complexity of the information interpretation, in turn, reducing risks when under stress



1.4 Context

The current Neonatal ICU facilities at the Sofia Children's Hospital consist of 4 units with 10 beds each. Each unit has about 6 nurses, a head nurse and a Neonatologist. These units have 24-hour care with a day and night shift with the staff covering all the hours. Similarly, the existing alarm system will also introduce a mobile device (spectral) which will indicate patient information and related alarms based on the vitals. Nurses will be using this hang-held mobile device more often to check the status of their assigned patients.

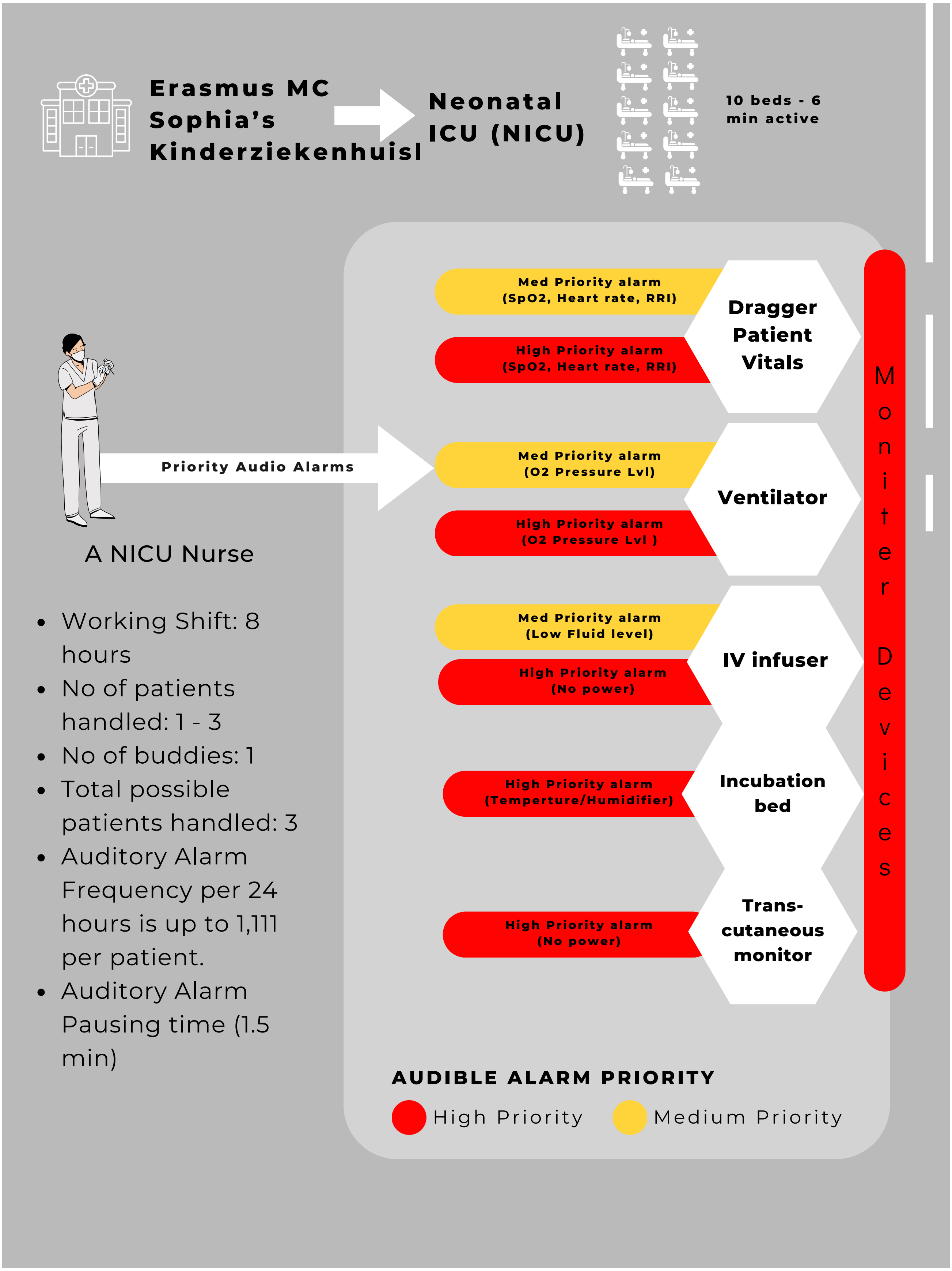
1.4.1 The Current Context

The current Neonatal ICU facilities at the Sofia Children's Hospital consist of 4 units with 10 beds each. Each unit has about 6 nurses, a head nurse and a Neonatologist. This unit system of having multiple beds will be shifted to the more modern individual beds for privacy at an expanded capacity and thus will also see a large change in the existing critical alarm infrastructure. Similarly, the existing alarm system will also introduce a mobile device (spectral) which will indicate patient information and related alarms based on the vitals. Nurses will be using this hang-held mobile device more often to check the status of their assigned patients.

Each nurse and the NICU are assigned up to 2 patients and they have a buddy system of sharing the patients with another nurse. A patient unattended becomes every nurse's priority in the unit till the required action is completed.

This nurse-patient interaction will remain similar in the future infrastructure, but the amount of NICU patient beds will increase and they will become individual rooms in the coming future.

Fig1: The Current scenario at Neonatal ICU for a single nurse



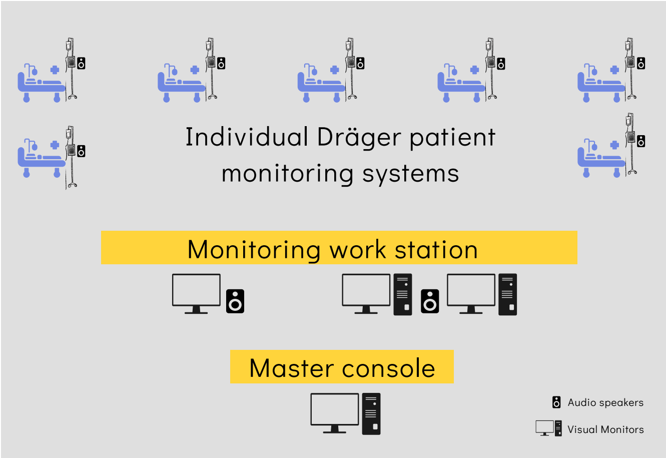


Fig 2: A Single Room Unit Setup in current context

Each nurse and the NICU are assigned up to 2 patients and they have a buddy system of sharing the patients with another nurse. A patient unattended becomes every nurse's priority in the unit till the required action is completed.

This nurse-patient interaction will remain similar in the future infrastructure, but the amount of NICU patient beds will increase and they will become individual rooms in the coming future.

The Future Context

The current room unit system of having multiple will be shifted to the more modern individual beds for privacy at an expanded capacity. Thus, it would also see a change in the existing critical alarm infrastructure. The HDMs will increase the ability to have specified alarms for nurses and their travel distance will vary to a certain extent. This is hypnotical since the new scenario is yet to be established and is in its preliminary stages.

The individual patient rooms may be divided into larger unites and the team of nurses will be categorized based on these unites. The units may have central monstering station, but the HMDs will play a pivotal role in patient emergency event recognition through out a patients stay in the NICU.

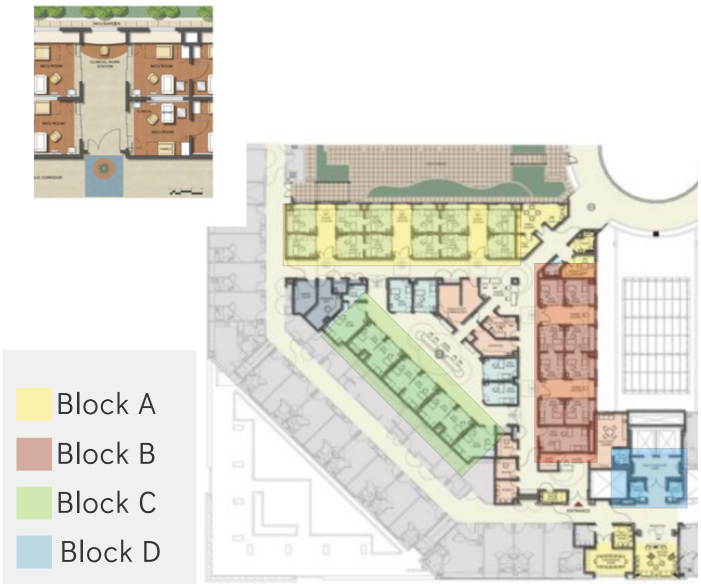


Fig 3: An example outlay of the new patient rooms

1.5 Literature review

The general research behind audible critical alarms requires an analytical approach, hence terms to be used in the paper will require critical analysis of the context.

Alarm fatigue can be defined as a mental state via overexposure to frequent alarms desensitizing the user and leading them to not adequately respond in case of a critical event (CA Summit 2011). Only 20% of all the clinical alarms are relevant and the increased set of alarms from various devices also results in noisy environments and may also result in false positive alarms and relevant ones being ignored by the medical staff. But alarm management systems are built on the better safe than sorry philosophical methodology (Chambrin. M.C, 2001), resulting in high false alarm rates (Crit. Care Med, 2010). Hence, the user's response rate to these alarm sounds can be due to precognition from previous alarms (Cvach, 2012).
This also influences the user's ability to identify alarms, hence limiting the number of alarms is vital.

A general hospital NICU can generate up to 228000 alarms on the handheld device per day (Van Pul, C, Joshi,2015), which could be categorized as alarms from 146k by monitoring alarms, 43k by the ventilators, and 17k infusion. Only 20% of these alarms are for relevant events, added on to the 80db plus noise created by medical equipment and vocals in hospitals are considered as noise, and added to this is the 50db limited medical alarms.

It is also made evident from a study of a single NICU (Puerta del Mar University Hospital) that did not comply with the acoustic quality objectives set by the national and international legislation and guidelines and may, therefore, harm biological development in preterm neonates in the NICU.

Continuation

The alarm system also sends backup alarms to a ‘buddy’ nurse if alarms are not confirmed within an average of 45-60. First nurses assigned to a premature baby can also escalate the alarm directly to their ”buddy” when they are not available. A third escalation happens when the alarm is not acknowledged by the first nurse or the buddy nurse, the alarm is sent to all handhelds. This results in multiple audible alarms not only sent to the handheld but also to the monitor speaker at nurse workstations.

Sound designers should also consider conceptualization through semantic methods as vital for the context of design. When designing any alarm interphase, there should be a consistent one-to-one mapping between functions and the information from the interface. As indicated by various authors, auditory icons are much more easily differentiated from audible alarms and are preferred (Edworthy et al., 2022). Similarly, the intuitiveness of the auditory icons in mobile notifications has also been proved (Garzonis et al., 2009).

The audible alarm sound design approach is directly taken from the Design Framework for Audible Alarms (R.Sanz, P, Pere, E. Özcan, 2022).

The design of critical audible alarms needs to take into account the design components such as criticality of alarm events, informative quality of audible alarms, and compliance with nurse action. These play a major role in validating the effectiveness of a critical audible alarm for ICUs. Lack of vision when designing audible alarms for a specific context must be scrutinized.

Fig 4. Design Framework for audible alarms

A study with university undergrad students also indicated that the use of mnemonics associated with melodic alarm tunes for alarm systems build on IEC 60601-1-8 standards resulted in less than 30% of its 33 participants being able to 100% accurately identify the alarm sounds. This study also included 16 different alarm sounds for varying patient vitals. Making it evident that the learnability of complex alarm systems with mnemonics is not practical. However this study has the limitation of not using clinical staff as participants.

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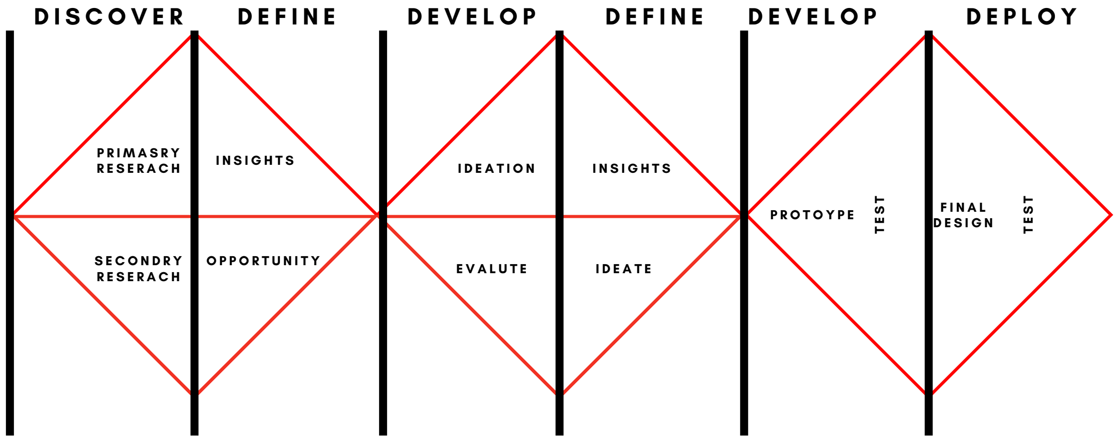
The average response time of the nurses for patients in emergency response wards was in the range of 4 minutes and 54 seconds during the day shift and 4 minutes and 55 seconds during the night shift (Bridi et al., 2014). Similarly, the response time of anesthesiologists in operation theaters/ICUs was found to be between 1-6 seconds from audio and visual cues. It additionally took them 61 seconds to see the difference when an event parameter shifts.

Key Takeaways

- Relevance of Alarm limits and reducing fatigue
- The current state of NICU is a large set of alarms and related audible alarms overwhelming users.
- The importance of conducting alarm training programs before implementing
- Auditory Icons are more recognized compared to earcons
- One-to-one mapping of functions for high-priority alarms is vital
- A Triple Check System (Patient Monitoring device - monitoring station - other devices)- where alarms for mobile devices are low in number and filtered reducing up to 75% of the monitor alarms.
- Custom alarms tend to be acoustically close to their last custom design resulting in ambiguity
- The pitch difference in alarms doesn't directly indicate urgency.
- Mnemonics association is not relevant when designing melodic alarms especially if they are large in number
- The multidisciplinary approach in designing critical alarms for ICUs is vitals, via context analysis.
- Audio cues in clinical alarms during major events/operations could be recognized in under 6 seconds, regular patient events might go unnoticed for up to 4.5 minutes,

2. Design Method

The Deisgn method



The design approach is that of a modified triple diamond approach. This is taking into account the multidisciplinary design framework as well as bringing in a more familiar delft design approach for this thesis project.

The initial discovery part of the design went into understating the human factors, systems engineering, and information design at Sophia Children's Hospital. Desk research on critical alarm systems was conducted parallelly to understand if there were any gaps in the existing or upcoming clinical alarm infrastructure. Once the opportunity was discovered, a design goal was defined. The initial ideas indicated a lack of understanding of alarm sounds in terms of semantics, and so was the understanding of structured sounds, which required further definition.

The goals were later evaluated, and requirements based on the goals were then used in the development phase. The newly designed library is to be then tested & and validated for its functionality.

2.1 Stakeholders in a NICU

Stakeholder	Interest	Impact
Neonatologists and Pediatricians	Providing high-quality medical care to infants	Direct impact on infant health
Nurses	Ensuring daily well-being through continuous care	Significant impact on daily health and development
Parents and Family	Ensuring health and well-being of newborns	Emotional well-being of infants and families
Respiratory Therapists	Ensuring proper respiratory function in infants	Respiratory health and overall well-being
Nutritionists/Dietitians	Providing appropriate nutrition for growth	Nutritional health and growth of infants
Pharmacists	Ensuring safe and effective medication management	Medication safety and efficacy for infants
Social Workers	Providing emotional and practical support	Emotional well-being and post-NICU transition
Physical/Occupational Therapists	Supporting developmental care and milestones	Motor and developmental outcomes for infants
Laboratory/Radiology Technicians	Conducting diagnostic tests for medical assessment	Accuracy and timeliness of diagnostic results
Hospital Administration	Effective management and resource allocation	Overall efficiency and quality of NICU services
Ethics Committee	Ensuring ethical decision-making in challenging cases	Resolving ethical concerns and protecting rights
Pateints	They are the occupants of the NICU	Their recovery is the vital function of the whole system

When analyzing the stakeholders in terms of power vs interest, the most relevant players are Nurses and neonatologists/pediatricians. This is followed by the technicians and then the parents. Administration although have a large power interest, they are not one of the main end users (exception),

Hence the focus of the requirements that would be built from challenges will focus on the Nurses and neonatologists/pediatricians within the scope.

2.2 Alarm Sound Concept Design

What are the challenges?

- To reduce the number of alarms from a hand-held mobile device
- To be able to communicate emergency patient event information through audio cues without visuals
- To be able to identify a patient.
- To respond with accurate action on the identification
- To be able to recognize the audible grammar.
- To be audible in a hospital work environment

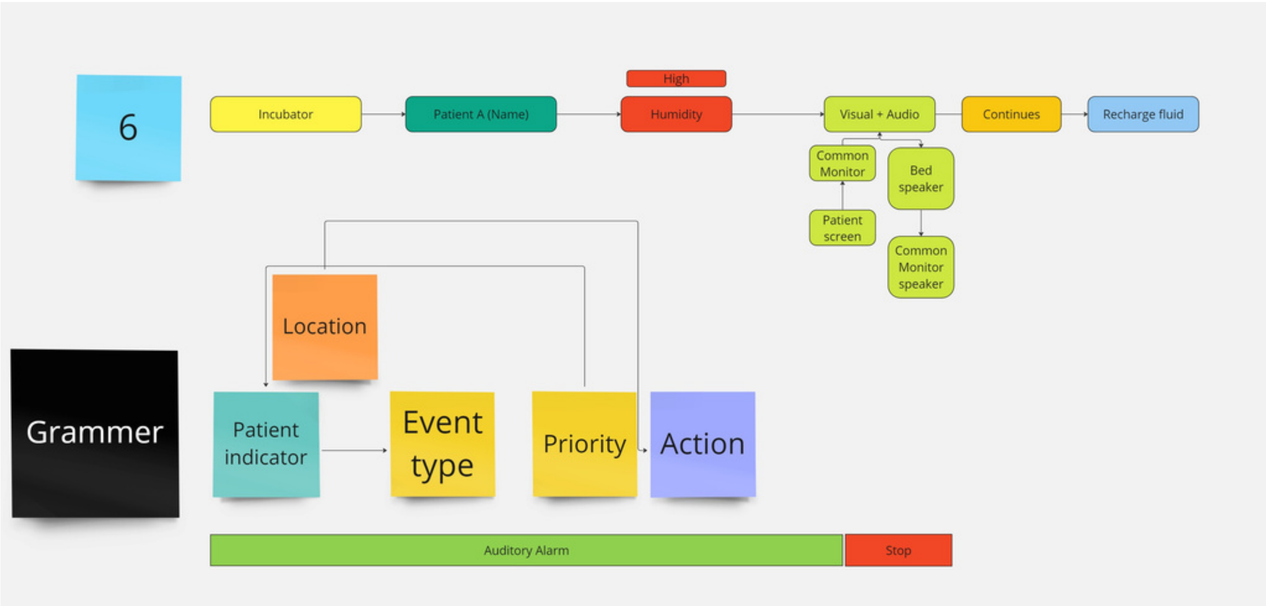
The property of an alarm to be distinguishable and recognizable through training is vital in this project. The initial phase of research was to see what existing alarms are sent to the HMDs and what their functions are. the second is to iterate the meaning of the handheld device and its effectiveness in communicating the emergency.

The initial phase of mapping out major audible medical alarms at the NICU was done in person as seen in Fig. 6, and the total number of alarms from them accumulates to 13 audible alarm sounds. The relevance of other alarms is still being investigated, but mapping them was vital to put them into the context of sending these alarms into the HMDs.

Tackling these challenges required one to understand the relevance of sending multiple alarms to the HMDs when there is a presence of workstations across the NICU blocks in the hospital. Similarly, the way alarm sounds are built for various patient vital monitoring systems was also looked into. Preliminary research was to break down the current grammar user in the alarm soundscape across the NICU and their relevance, Also to analyze the quality of the alarm sounds in terms of their design, Most of the major event clinal alarms were built as auditory icons associated with the type of device. These sounds were only standard based on the manufacturers but were exclusive. Most of the devices used pure tones for their bones (sampling).

Fig 6. Mapping out the exisitng alarm grammar

Fig 7. Mapping out the existing alarm grammar



This breakdown of existing alarms, which only considers the major device alarm sounds has made it evident that not only is there a large complexity in the existing infrastructure but also that using this as a basis for building an effective library with an audible grammar on the handheld device will result in chaos caused by two major points:

- All the alarm sounds here are general for all patients in a unit.
- Patient identity and status can only be confirmed through visual cues, such as from the monitoring station, device, or via the handheld mobile device in the coming future.
- The said set of alarms will cause fatigue and could make the handheld device obsolete in terms of function (mobility)
- This helps us discover a gap in the newly tested communication & and information system at Sophia's Hospital NICU.

2.3 The relevance of semantic network.

Alarms sound concept will require an understanding of the context and hence the new scenario is mapped and the flow of the patient alarm information is seen here.

The present alarms will need to be kept as final actionable alarms at the patient's bed and the HDM alarm should be the only relevant valuable information for the nurse to perceive the NICU bed location or the closest workstation monitor location.

The semantic network for the concept will be further elaborated as the concept is completed hence resulting in a grammar

The grammar for the new audible alarm is built on this network based on the new context.

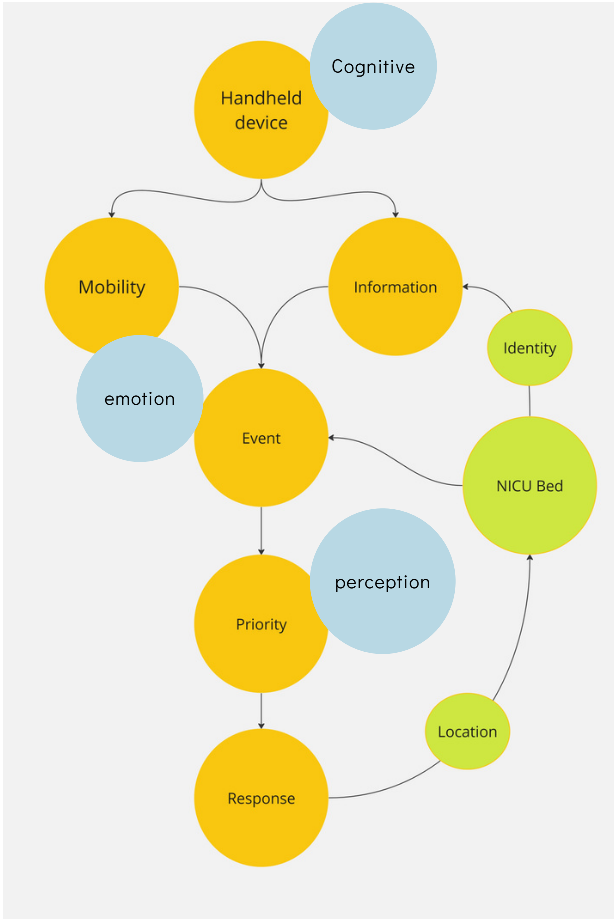
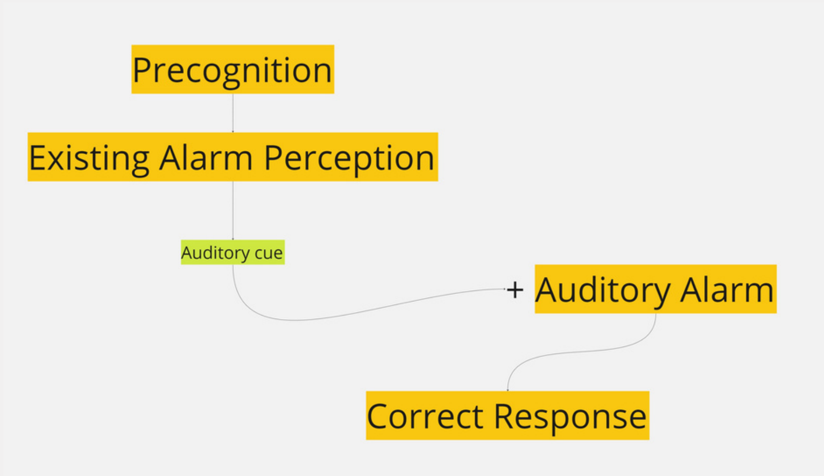


Fig 5. Basic Semantic Network

The existing events are of a large number within a 24/hours period, as indicated in the context. This means that the number of alarms per individual patient is also high in number, To gain an adept response from an HMD without the need for a visual cure requires one to look into the importance of the existing grammar. In this situation, the grammar that has been learned and perceived by the nurses only indicates the type of event, and not the identity of the patient (location/bed). To subvert this gap, the alarm sounds must overtake the importance of the need for visual alarm cues for the latter. This can be achieved if the sound design results in a positive semantic association with the cognition and emotion of the alarm sounds by the nurses,

2.4 The Audible Alarm approach

fig: Approach



The current alarms audible from the medical devices can go up to 5 main devices and the alarms from them can go up to 13 such alarms as indicated before. This was initially hypothesized as the main audible alarms sent to the handheld but the response action from the design would highly reduce the effectiveness of the handheld alarms since these alarms can be heard and then viewed on the workstation monitors. Since hand-held devices prioritise the mobility of the nurses, the approach toward the need for audible alarms was further researched and hypothesised.

The said hypothesis is that the new handheld device should be able to result in nurses responding to their patients (in this case identifying and reaching them) only through audible alarm sounds which needs to be designed specifically for this task.

A new alarm in fact will require training for its use case, but the phenomenon of precognition on practice results in presentiment. This is explored in the form of predictive physiological anticipation which is still a developing field in meta-analysis of psychology and can have a direct impact on this designing process.

Fig 6. Priliminary Grammar Semantic approach

Defining a goal:

The new critical audible alarms on the device must be able to distinguish the individual alarms, identify them for each patient per nurse, and respond to them by reaching the ideal destination of the patient room in a NICU. These responses should be achieved without the assistance of a visual cue.

This will help in leading the project in terms of defining its requirements through the wants and needs of the stakeholders, Considering this, the use of Data sonification canvas (Ciuccarelli & Lenzi, 2020) helped in defining the approach towards the initial design process.

2.5 The new audible alarm design

Research in audible alarms indicates the major types which include Auditory Icons, earcons, and spearcons. Through literature reviews, it has been made evident that icons and earcons are preferred in the context of medical alarms. Hence the sound concept design was based on this foundation

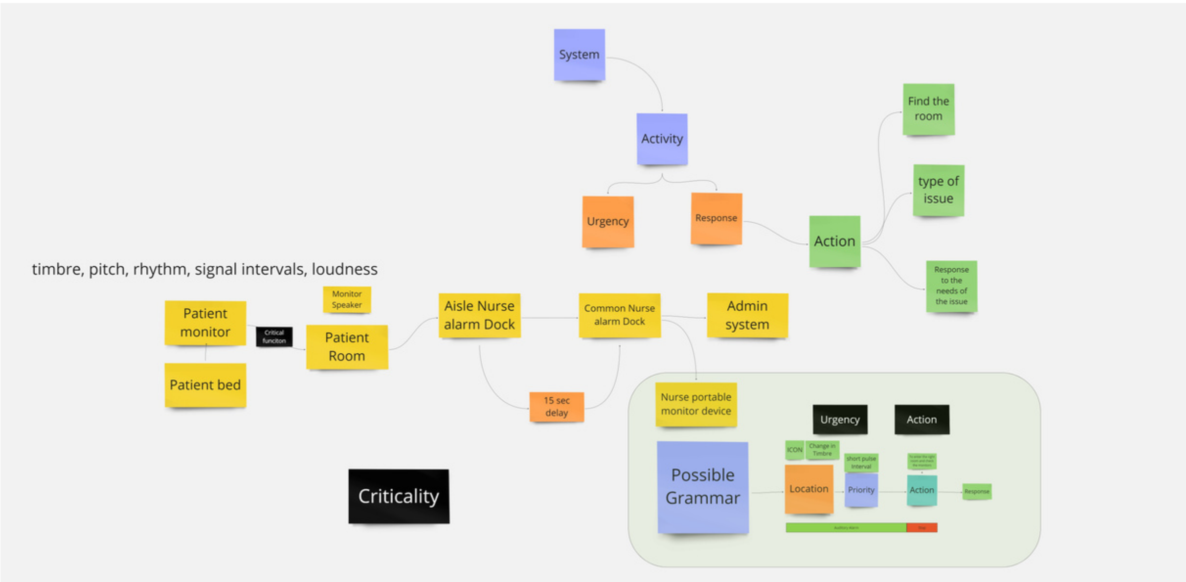


Fig 7: Embodiment, context and event

The audio grammar had to be built on sound logic, and the required response here for nurses to identify their patients on audible alarm sounds. Hence a patient medical alarm from the bed when sent to the HDM should help them first identify the patient. The corresponding response would be for them to go to the right location of the bed and then check the vitals information at the dock station (monitor) at the patient bed or a nearby workstation especially when they are mobile across the medical ward.

This reduces their response time by skipping visual alarms and helps them reach their required patient location without the triple-check system that is currently present.

Hence the nurses should be able to differentiate between their assigned patients (each is assigned 1 main patient and another through a buddy). The third audible alarm will be for an escalated case where a patient is left unattended by their assigned nurse.

Initial Prototyping:

Since designing alarm sounds doesn't have a standardized method for a starting point, we have to look at the context. Consider the existing audio alarms in the NICU, of which the majority of the alarms and their varying urgency come from 6 patient monitoring devices (fig.4), they were all pure tones built based on the type of device. In this case, we will focus only on the hand-held mobile device and its use case. The HMDs will have to communicate the patient's event and identity. Presently majority of the alarm recognition requires visual cues since all the monitoring devices send out alarm sounds that are standard across a unit. This needs to be changed for effective use of the device in emergencies, Where audio cues should be able to communicate the latter, and for this, we must look into how one can uniquely design sounds to gain adept responses when they are in use.

Hence, the NICU HMDs must have a new library that would be exclusive and should bring ease of association and response in terms of perception. The most uniquely associated word for the NICU would be Neonatal which is premature babies. Hence this was the special factor behind designing a new alarm library. The next step is to look into sounds that are associated with babies and try to build new sounds,

For the initial testing of a new analogy of design, baby-related sounds which included icons and ear-cons were built and tested.

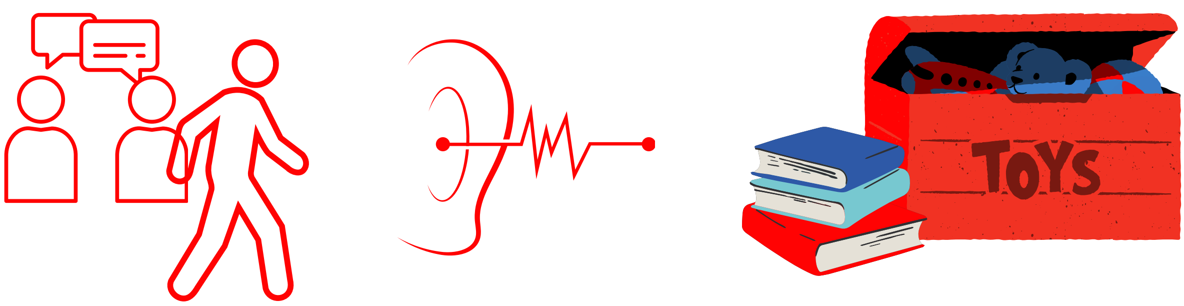


Fig 8. Auditory Icons vs Earcons

The design approach required to look into the semantics related to babies and the context of NICU. Hence a basic mind-map was built to explore the various terms that could become tools in the sound design process. An example of these terms would be Walking, Talking, Eating, Toys, Learning tools, etc.

The analogy of sound design stems from the analogy of sounds related to a developing child. The terms here used are audible cues like a baby toy, a baby's speech, a baby's walk, and a baby's utility such as their bed. This was further explored by designing auditory icons and earcons via Fruity Loops using the Dune synthesizer and sampling existing instrumental sounds.

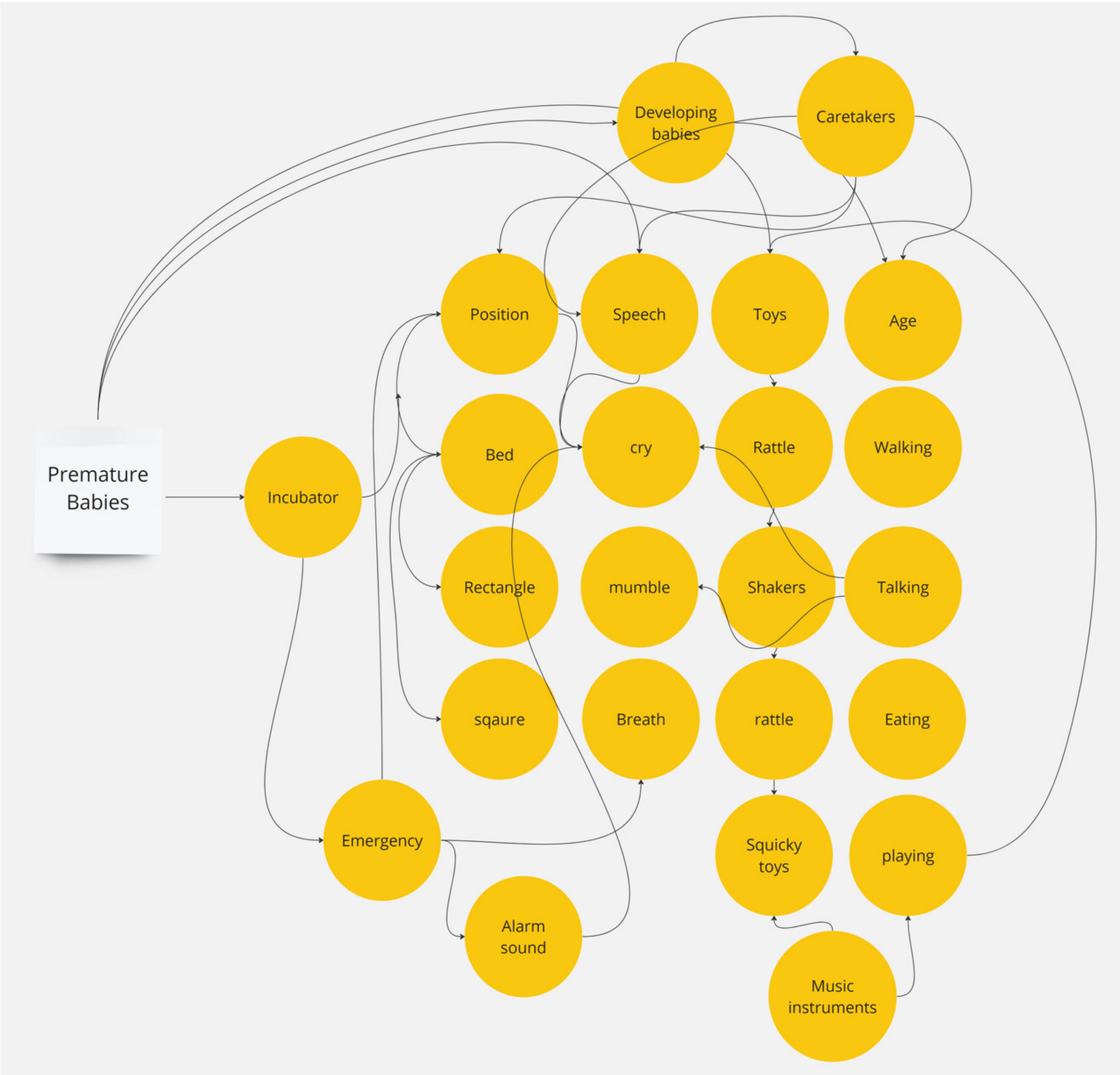


Fig 9. The Baby related Sound analogy network

the initial sound design made evident that there were certain constraints in the design process. Timbre is considered the best building block for selecting sound samples for the alarm sounds (Foley et al., 2020).

The sounds built were based on the following semantics
The auditory icons were preferred over ear-cons by the majority of the participants. However this test had its limitations since the design approach lacked clarity. Similarly, the distinction between Icons and ear-cons was vague hence the results being non-viable. But this also gave me the opportunity into the true meaning of analogy and design approach for audible alarms.to look

The perceptual factors of a sound can be hierarchical where (attention, roughness, smoothness, and temporal constancy) could influence cognitive factors (power, machinery, and familiarity) and emotional factors (unpleasantness) (Vieira & Van Egmond, 2012). Hence it's vital to look into cognitive and emotional factors of the upcoming audible design library

Hence when choosing the new samples (bones) of the sound, these factors are vital and very influential in the decision making. On top of that, the need to adhere to IIEC 60601-1-8 clinical alarm standards will also result in constraints in selecting the samples for further design.

2.6 Building blocks of the library

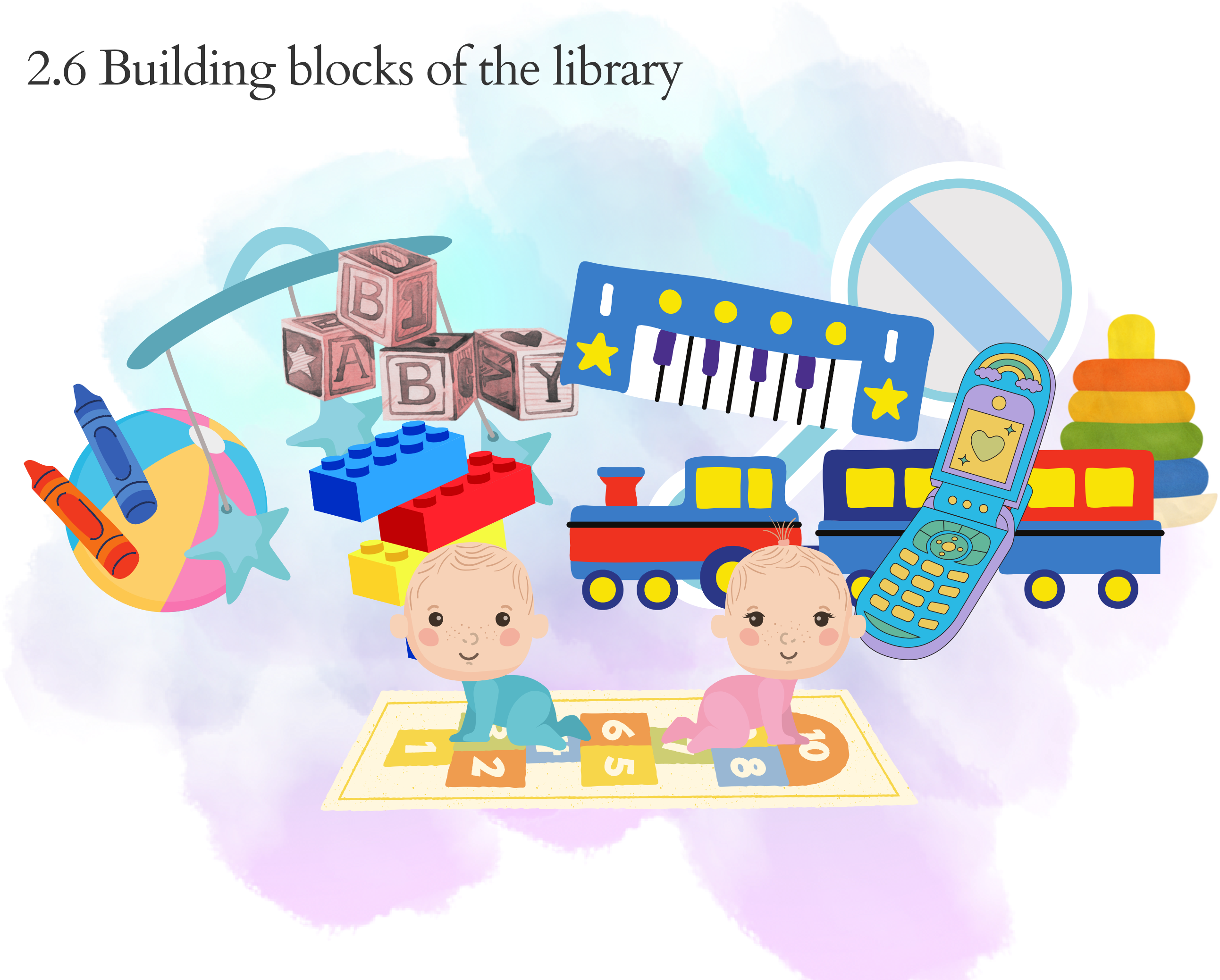


fig 10. Baby toys visual collage

The building block of the alarm sounds uses the analogy of Baby Toys. The reason for choosing this particular variety was to be able to gain ample samples that would fit within the hierarchical semantical approach in sound design. Toys had the malleability of varying material properties as well as a metaphorical association towards baby growth. It also gave many timbre choices as each toy could result in a unique texture.

The ability to sort out toys in terms not only through sound perception but also by how its build makes it the best candidate in terms of an analogy for the sound design.

Building block of the alarm

Table 2. Toys associated with possible instruments and their timbre profile

Toys	Associated instrument	Timbre Texture
Shakers	Maracas	metallic & organic material
Cars	Siren	Sharp
Chimes	Xylophone/glockenspiel	Metallic
Dial Tone	Digital Synthesizer	Metallic & Warm
Hanging Lullaby	Xylophone/Piano	Metallic
Toy Piano	Piano	Metallic
Writing Instruments	Wooden sticks	Sharp
Interactive books	Digital Synthesizer	Metallic & sharp

An example list of possible toys to be used as samples for the sound design gives us an idea of how the process of the new sound library design started. These were then sampled and tested on the Fruity Loops studio (DAW).

Building block of the alarm

The samples were placed in Dune 3 by synapse, a virtual synthesizer where the arpeggiator and filters could be easily controlled. BBC orchestra was used to sample some of the percussive elements for its high quality.

Fig 11. Dune 3 and BBC orchestra

The samples were placed in Dune 3 by synapse, a virtual synthesizer where the arpeggiator and filters could be easily controlled. BBC orchestra was used to sample some of the percussive elements for its high quality.

Characteristics of the sound

- Onset: The alarm sound begins with a gentle, rising tone rather than a sudden, jarring start, helping to avoid startling healthcare providers and infants.
- Pitch: The pitch of the alarm is in the mid-range, avoiding very high-pitched or piercing tones.
- Volume: The volume is set at an appropriate level—audible enough to get attention but not excessively loud. The goal is to ensure that the sound is noticeable without causing stress or discomfort. (below 50 Db)
- Distinctive Pattern: The alarm sound has a distinctive pattern or melody that is easily distinguishable from other ambient sounds in the NICU. This helps healthcare providers quickly identify the source of the alarm.
- Distinctive tone: If one is too close in tone to another alarm, there is a high chance of missing alarms or creating false alarms.

3 The new alarms library

On experimentation on a sound design level it was made evident that there were certain contains in the design process.

The design must also adhere to the latest. This meant the pulse length for each sound used was short and hence required an extensive trial and error method in finding suitable sounds for the grammar.

Characteristic	HIGH PRIORITY ALARM SIGNAL	MEDIUM PRIORITY ALARM SIGNAL	LOW PRIORITY ALARM SIGNAL[d]
Number of PULSES in BURST [a, e]	10	3	1 or 2
PULSE spacing (t_s) (see Figure 1)			
between 1st and 2nd PULSE	x	y	y
between 2nd and 3rd PULSE	x	y	Not applicable
between 3rd and 4th PULSE	$2x + t_d$	Not applicable	Not applicable
between 4th and 5th PULSE	x	Not applicable	Not applicable
between 5th and 6th PULSE	0,35 s to 1,30 s	Not applicable	Not applicable
between 6th and 7th PULSE	x	Not applicable	Not applicable
between 7th and 8th PULSE	x	Not applicable	Not applicable
between 8th and 9th PULSE	$2x + t_d$	Not applicable	Not applicable
between 9th and 10th PULSE	x	Not applicable	Not applicable
INTERBURST INTERVAL [b, c] (t_b)	2,5 s to 15,0 s	2,5 s to 30,0 s	>15 s or no repeat
Difference in amplitude between any two PULSES	Maximum 10 dB	Maximum 10 dB	Maximum 10 dB

Where: x shall be a value between 50 ms and 125 ms,
y shall be a value between 125 ms and 250 ms,
the variation of t_d, x and y within a BURST shall ~~be~~ not exceed ± ~~5~~ 20 %, and
MEDIUM PRIORITY $t_d + y$ shall be greater than or equal to HIGH PRIORITY $t_d + x$.

The INTERBURST INTERVAL (t_b) for HIGH PRIORITY auditory ALARM SIGNALS shall not be greater than the INTERBURST INTERVAL for MEDIUM PRIORITY auditory ALARM SIGNALS which shall not be greater than the INTERBURST INTERVAL for LOW PRIORITY auditory ALARM SIGNALS.

Fig 12. IEC 60601-1-8 clinical alarm standards

The current set of audible alarm sounds includes (Appendix I):

- Lullaby (xylophone)
- Shaker (Wooden)
- Dial Tone (phone)
- Piano A (Keys Analogue)
- Piano S (Keys Synth)
- Chime (Glockenspiel)

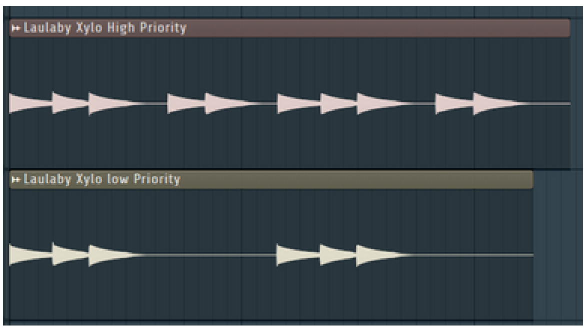
These instruments were chosen with the analogy of using children's toy sounds that can be easily distinguished by the nurses. The following 6 sounds will be interpreted to give 3 unique sound sets which will indicate each nurse their primary buddy and escalated alarms.

This set of 6 pulsated alarm sounds is built with the following pulsated sequence. The total time of a single alarm pulse sequence loop is about 4 seconds. This is extended to a 60-second loop.
A high-priority and a mid/low-priority alarm will be different in their melodic pulse.

Table 3. Calculations for the alarm intervals and pulse length

PULSE 1	in ms
Pulse length	19
x value	12.5
td	15
2x+td	40

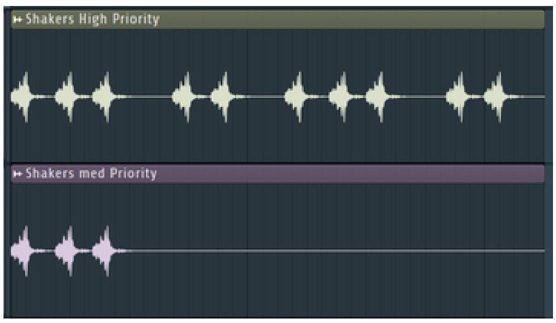
Fig 13. The wave form and score for each of the new alarm sounds



Lullaby

Pitched Percussive

Major notes: D#6-G#6-F#6

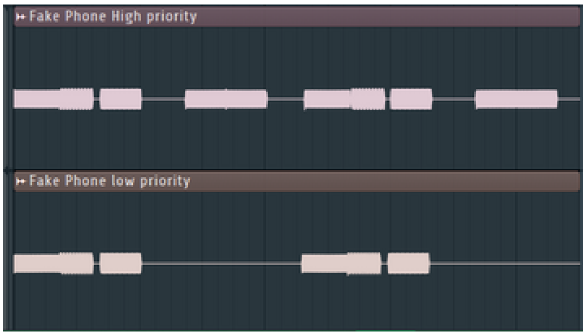


Shaker

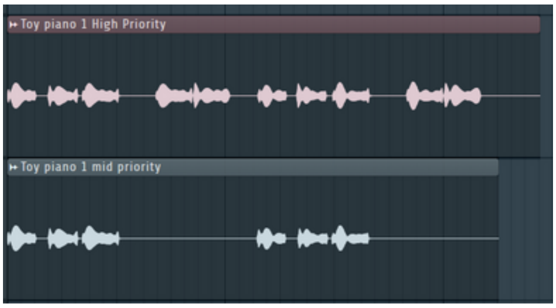
Percussive

Major notes: F#4-A4-F4

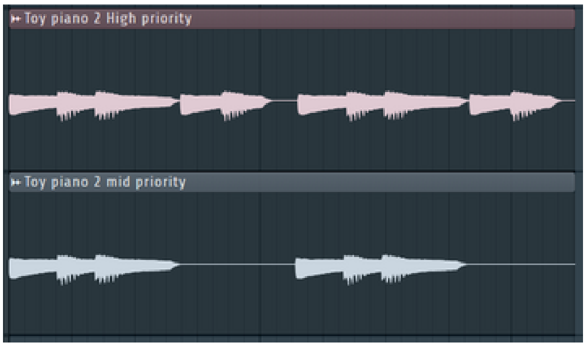
030



Dial tone
Synthesiser
Major Notes: E6-F#6-G5

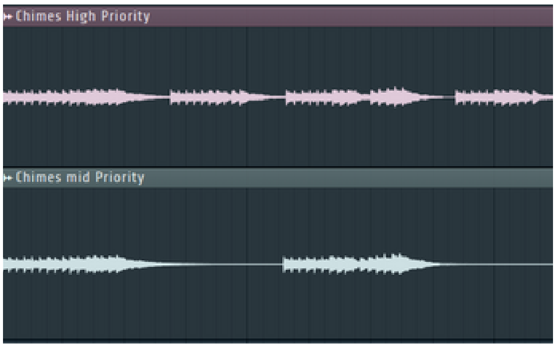


Piano A
Chordophone
Major Notes: F5-D4-B5



Piano S

Synthesiser
C5-D5-C5



Chime

Pitched Percussive
G#4-A5-E5

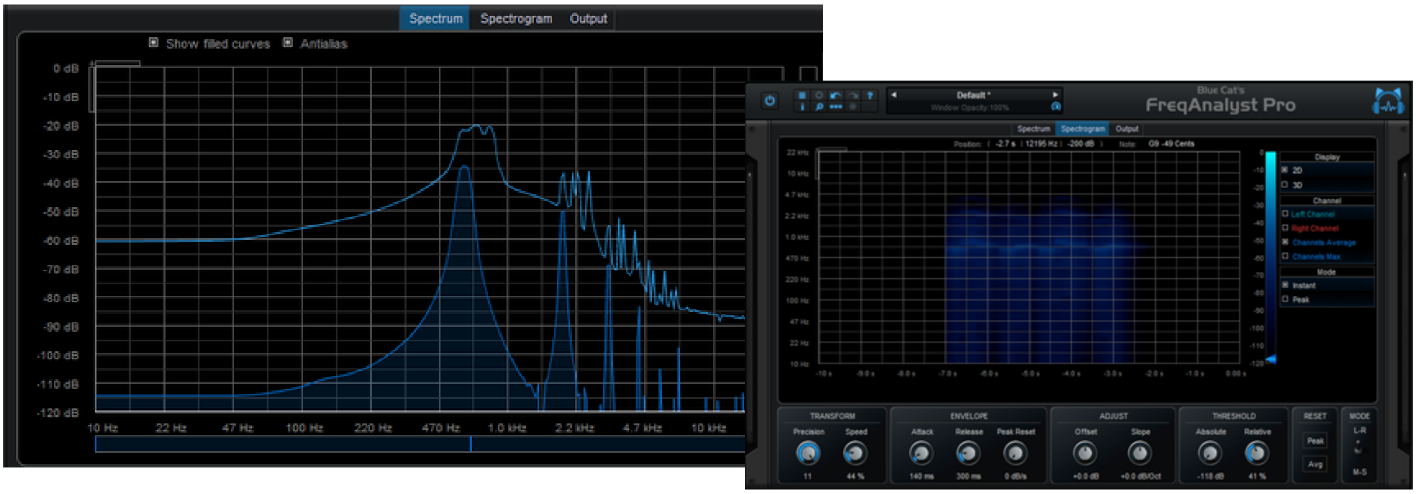
3.1 Freq Analysis:

All of the alarm sounds are within 140 Hz the 2300 Hz range.
The maximum decibel level of -8 Dbfs. Similarly, on the DAW, all the sounds were equalized under a masking condition, which in this case an audio file of a generic ICU obtained online. This is used as the reference to control the frequency peaks for effective use in the environment when the alarms are played from the HMDs.

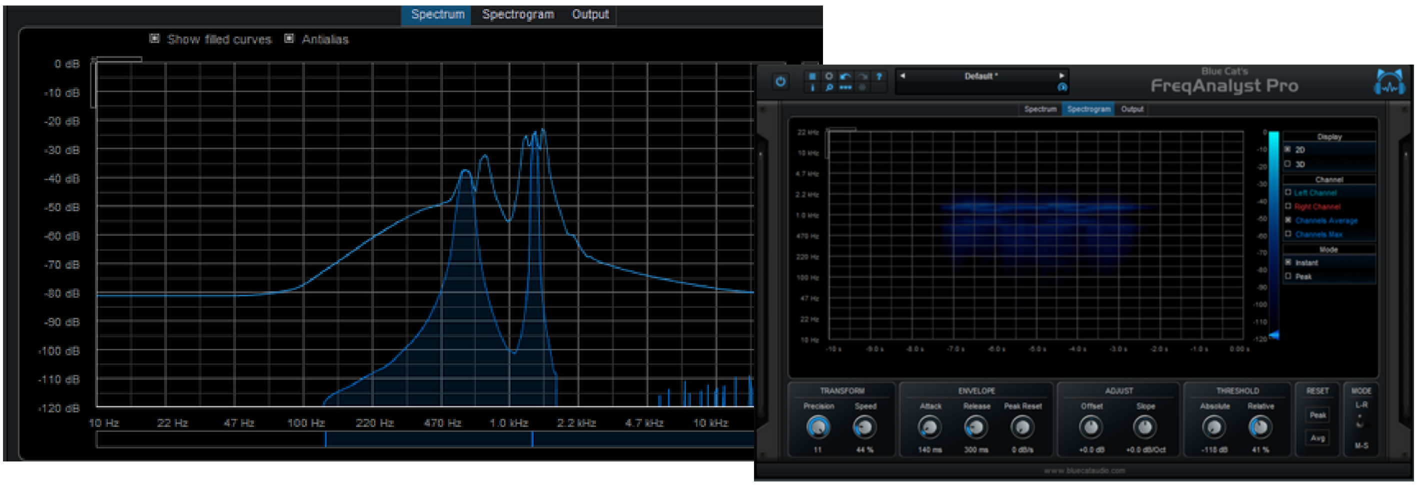
The frequency roll of was done by controlling the amplitude envelope (fig 14), namely the ASDR (attack, sustain, delay, and release). Many of the samples required this process since naturally emulated sounds tend to have inherent reverb in them. Similarly, all possible noise was removed using limiters on the FL studio DAW.

Fig 14. Masked Freq Analysis

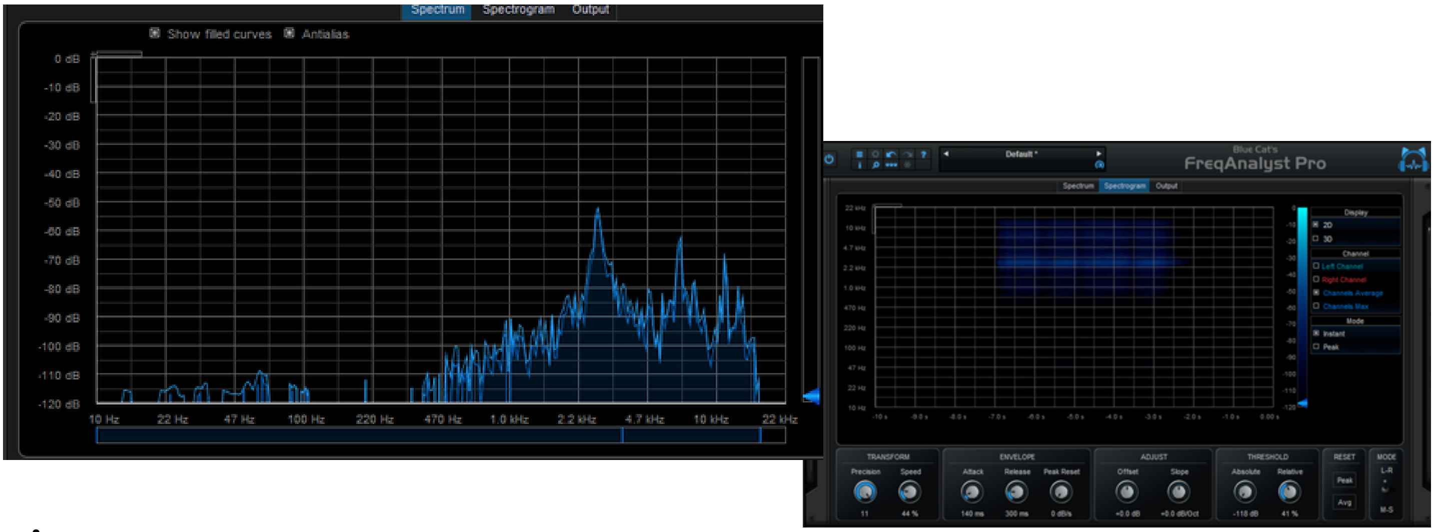
Chime



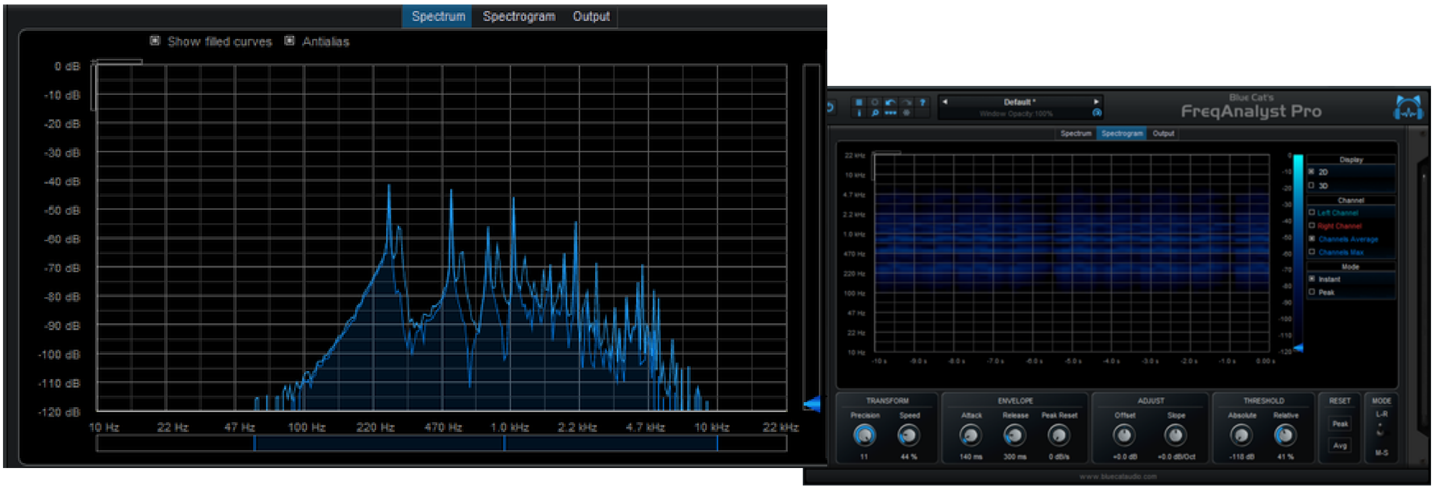
Dial Tone



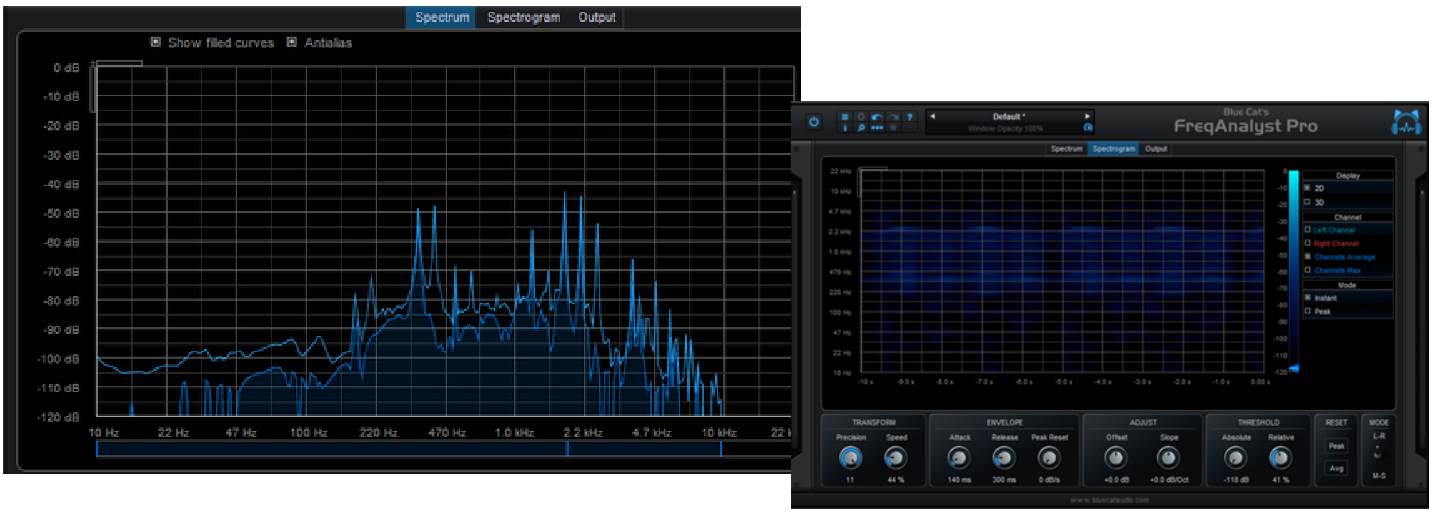
Shaker



Piano A



Piano S



4 The design requirements

Road Achieving Design Goals

To understand if the audible sounds work well in the use case context.

For this, we need to list down the ***requirements****. Let us*

Needs in terms of the sounds used:

- They should be recognized easily in the NICU environment.(It is the sound coming from the handheld mobile device)
- They should be distinguishable in the NICU environment (in terms of sounds from the handheld mobile devices, versus those from patient monitoring devices).
- They must invoke the required response from the user
  - Identify their patient
  - localize the patient's position within the ward
  - The differentiation of sound and grammar for each patient must be well distinguished.
- They should be able to understand the urgency of the event
  - High-priority events must have an apt response
- They should not induce stress or fatigue on repeated use

Wants in terms of the sounds used:

- They should be pleasant in terms of audio parameters of pitch, tempo
- They must be easily learned through usage
- They can be trained in the existing audible alarm space

- They are not be confused with noise
- They must have less impact in terms of the sound parameter of attack and sharpness
- They must be of the right level in terms of sound amplitude within the NICU

Hence let us consider some of these parameters for the purpose of research via testing.

They are parameters of Pleasantness, function, and urgency.

- **Pleasantness parameters (personal taste):**
    - **The test is to determine perceived pleasantness** (ability to listen to sound over a longer period).
- **Function parameters (***requirements***):**
    - **Response time (**on listening to the alarm sound**)**
    - **Distinguishability**
        - **In the environment**
        - **with each other**
    - **Action (Identify the patient)**
- **Urgency**
    - **Level of importance between a High and Mid-Low priority alarm sound**

4.1 Research Test Phase & Methods

Critical audible alarm pleasantness test:

The aim of this test is to understand the perceived pleasantness of the newly designed sounds. This is done to reduce the number of alarm sounds used in the final research test phase for effective understanding of the alarm grammar in its use case (response time and action)

Tools: Mobile Speakers & online questionnaire (M365 forms)
Type of research: Cognitive ergonomics
Test demographics: General population with normal auditory perception.
Method

- First the context is explained.
- Set up alarm sounds on a mobile device
- Classify the alarm sounds by names (Identity)
  - Chimes
  - Dial Tone
  - Lullaby
  - Shaker
  - Piano A
  - Piano D
- They are played one at a time for the auditory training
- They are then played one at a time and are rated for their perceived pleasantness on the Likert scale
- Then they are played in random order and this is repeated 12 times with each user. They will have to indicate the alarm sound name through an online questionnaire

Participants: non-specific
Questions for the Pleasantness test:

Rate each alarm in terms of pleasantness. ("1"– strongly disagree, '7"– strongly agree)

Alarm Identity:

Chimes

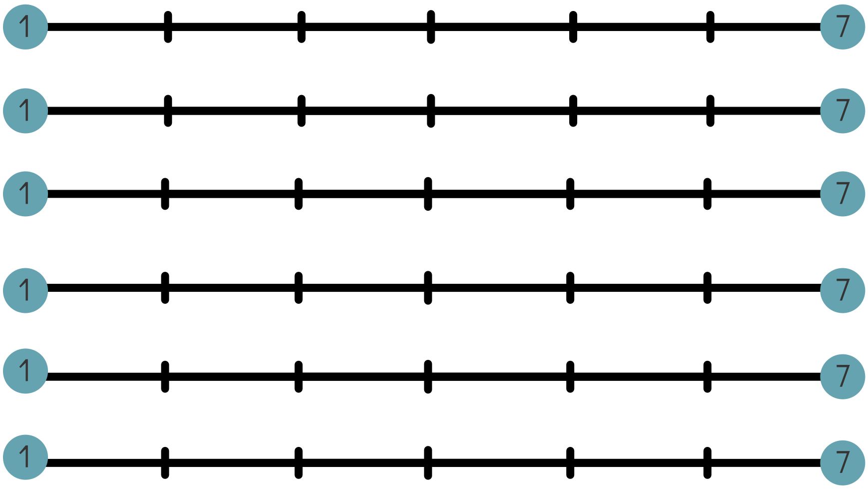
Dial Tone

Lullaby

Shaker

Piano A

Paino S



1: Strongly disagree
2: Disagree
3: Slightly disagree
4: Neutral
5: Slightly agree
6: Agree
7: Strongly agree

Interview Questions (structured):

After an alarm sound is rated on the scale, the following question is asked:

1. Can you describe why you found this audible alarm sound pleasant? and if not, please explain.
2. What type of alarm sounds did you expect?

The interview is converted to a script through which words used are clustered into the parameters of pleasantness and are rescored for their true value

Results:
The rescored audible alarm sounds will be reduced to a maximum of 3 for further study.

Limitation: Presently, due to the scope and time constraints of this project, all tests are done with the general population

Discussion: The results will be further reflected upon in this section

Through the Pleasantness test, the number of sounds will be reduced to a maximum of 3. This will be then used in a simulated clinical context in testing function (response time and action), and urgency.

Function & Urgency

AIM:

A test for the functions (Response Time, Patient identification) and urgency of the audible alarms will be done in a simulated environment at the Industrial Design Faculty. The test will be conducted to understand whether the newly designed sounds fulfill the design requirements.

Test demographics: General population with normal auditory perception.
Method
Type of research: Physical & and cognitive ergonomics
Tools: A mobile audio device, online application, and semi-structured interview

Method:

Set up:

- A simulated hospital environment is set up in an isolated room in the Industrial Design Faculty at the TU Delft
- . A hospital soundscape will be played via speakers.
- An application for testing is prepared for a mobile device and will be kept in the center of the room. The user will perform certain tasks.
- The context is explained
- All the alarm sounds are played twice (high priority only) for training.

Tasks

- The test users are assigned their main patient alarm, buddy alarm, and other alarm (randomized per test)
- They are made to watch a video (distraction task)
- Then a high-priority sound is played for each corresponding test (functionality & and urgency). (This is repeated 6 times)
- The semi-structured interview is conducted.

Results:
This will give us insight on

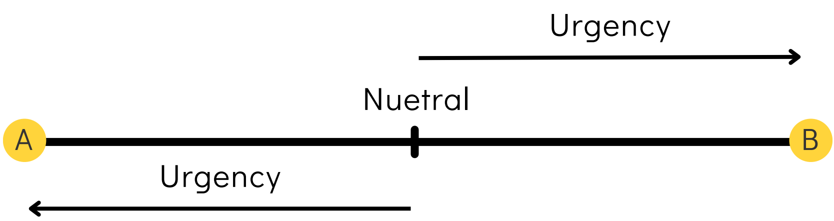
Limitation: Presently, due to the scope and time constraints of this project, all tests are done with the general population

Discussion: The results will be further reflected upon in this section

Urgency test test

The test is to provide sufficient data on whether the high priority and medium priority can be distinguished within one set of alarm sounds. *Please identify which of these sounds are urgent to you.*

Identity: Dial Tone



A: High Priority
B: Mid Priority

Interview questions:

- **What makes the sound grab your attention and why not?**
- **What makes it easy for you to distinguish the sounds in terms of urgency?**

Results
If the user is able to distinguish the urgency level with the existing built, it would

Discussion

4.2 Sampling method

A mixed-method study requires a strong sampling process to obtain relevant data via available resources.

Table 2. The Sampling Process method

Phases	Action	Value
1	Defining target participants	general population with normal hearing
2	Determining participants sampling size	≤20 participants
3	Defining sampling strategy	Convenience Sampling
4	Sourcing participants' sample	Snowball Sampling

The sampling process takes into account theoretical saturation and in this case, using the mixed method requires not only the quantitative data for a perceived pleasantness but also qualitative data. This results in constraints for testing a larger group of participants due to the time constraints of the project scope. Nonetheless, at least 10 interview data would be sufficient for such a test.

The participants in this case for both the tests are the general population with normal hearing, The functional and urgency test was to be done with the nurses post the initial perceived pleasantness test, but due to the latter constraints, this was not possible. The test is set up in such a way that it is an isolated one, hence they will be ample for this research project.

5. Results

5.1 Results of the perceived pleasantness test

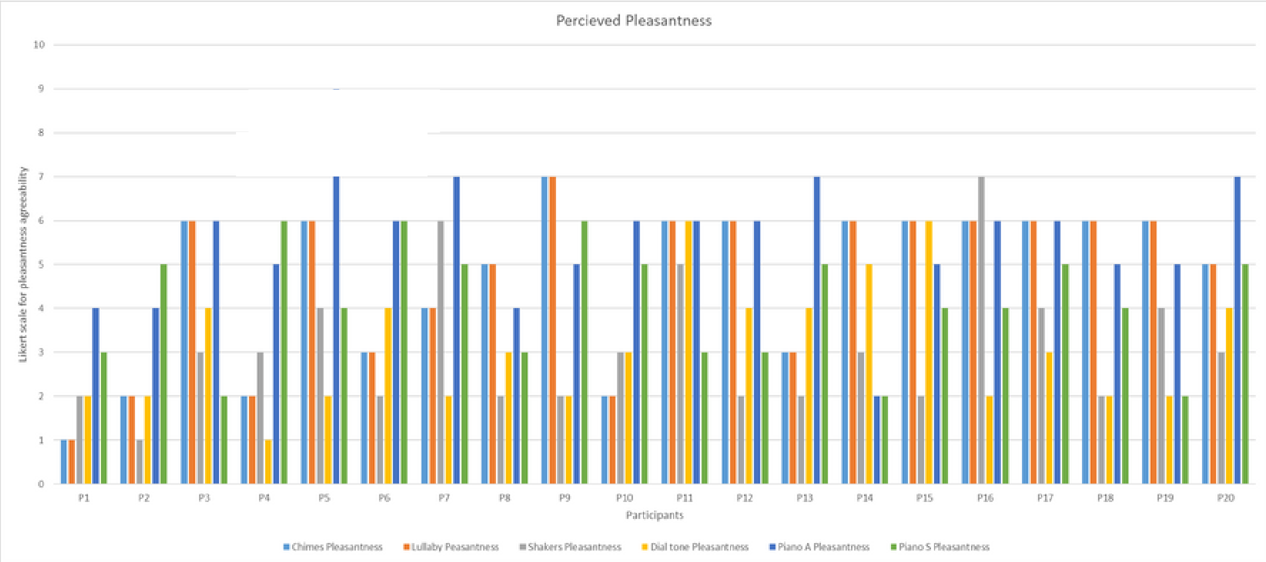


Fig 15. Participants vs Pleasantness Likert Score

Table 3 shows the raw data reforested as a bar chart indicating varying results for each participant. Overall the scale being a 7-point Likert scale requires some validation in terms of its usefulness in understanding the sound quality perceived by the listeners.

Data analysis

The answers are first converted into usable data using Excel and then imported into the SPSS tool for further analysis. For N=20, the data (Appendix F) was first cleaned for missing values and errors. Then the scale reliability is tested assigning the right values to each answer (reverse score is vital since negative answers cannot be used for the scale reliability test). By using Cronbach's alpha analysis score is used to check if the given scale is reliable.

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.512	.442	6

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Chimes Pleasantness	20.60	14.147	.629	.	.221
Lullaby Peasantness	20.60	14.147	.629	.	.221
Shakers Pleasantness	22.20	19.853	.300	.	.449
Dial tone Pleasantness	22.15	22.976	.089	.	.543
Piano A Pleasantness	19.75	20.303	.284	.	.458
Piano S Pleasantness	21.20	28.484	-.284	.	.669

Fig 16 . Participants vs Pleasantness Likert Score

The score is .512 (fig.16) which is not optimal for us to understand individual perspectives of pleasantness. This indicated that the number of participants needed to be increased or one of the questions in the test deviated highly from the expected answer (Piano S).

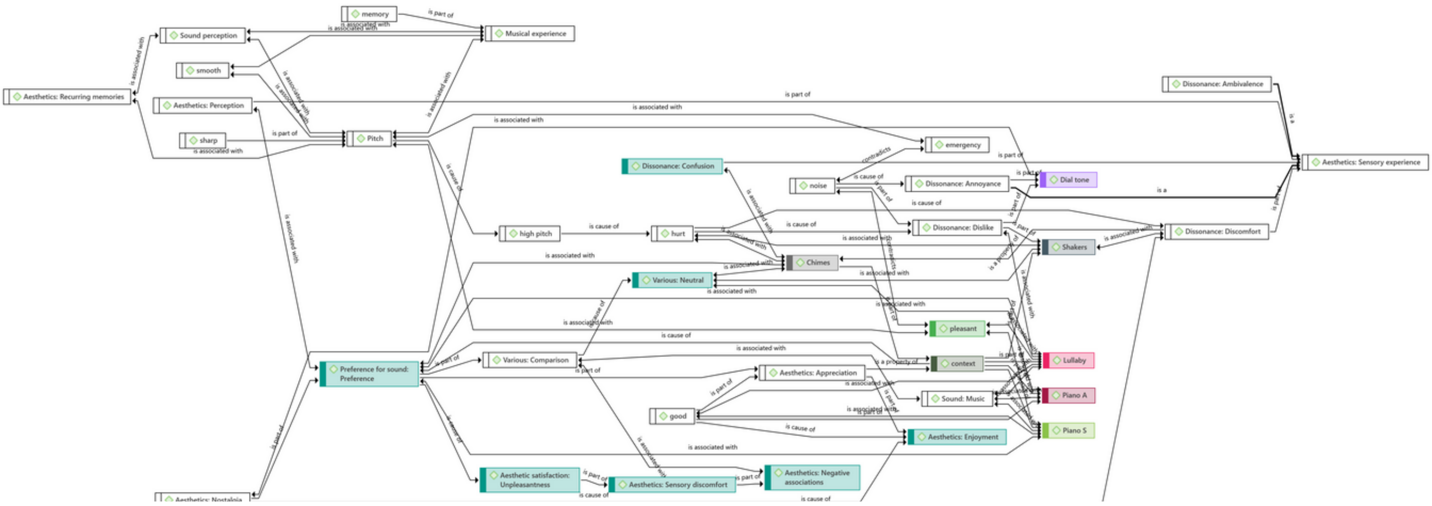


Fig 17. Network of nodes producing themes

The qualitative data analysis process:

- Familiarizing with the acquired data
- Repeated reading of the cleaned transcripts
- Generating code ideas.
- Creating preliminary codes Based on the ideas, generate an initial list of
- raw codes.
- Exploring themes Analyze the broader theme by creating a
- thematic map based on the formulated codes.
- Evaluating themes Review and refine the identified themes to underline the essence of each theme.

- Defining and naming themes
- Further analysis and routinization of themes to narrow down the theory.
- data analysis and association.

All the interview data was converted into the cleaned transcript. Then they were read through multiple times to gain insights to create nodes that would form the starting block for the thematic analysis. An inductive thematic analysis approach was opted for since psychoacoustic parameters were not completely explored in the preliminary research. This also allowed us to look into how the Likert score was influenced by the user's opinion on the particular alarm sound.

The themes that emerged from the data were as follows;

The main crux of the interview gave rise to this overall arching theme called Aesthetics sensory appreciation. Negative association, enjoyment, satisfaction (pleasant, unpleasant), and sensory perception (comfort/discomfort) were some of the main nodes under which many nodes were connected. The nodes were then converted into data points for mixed analysis. Then a mean was calculated for the results,

Item Statistics

	N	Mean	Std. Deviation	Variance
Chimes Pleasantness	20	4.700	1.792	3.210
Lullaby Peasantness	20	4.700	1.792	3.210
Shakers Pleasantness	20	3.100	1.480	2.190
Dial tone Pleasantness	20	3.150	1.388	1.927
Piano A Pleasantness	20	5.550	1.431	2.047
Piano S Pleasantness	20	4.100	1.300	1.690
Valid N (listwise)	20			

Std. Deviation and Variance use N rather than N-1 in denominators.

Fig 18. Mean Statistics for all the alarms

Discussion

Piano A is considered the most pleasant considering it has one of the least deviations and second to it the Lullaby. Piano S is also a good candidate to replace Lullaby. Although thematic association did score chimes low, the fact that it can create an apt response when played grabs the attention of the listener. Hence for the next phase of tests, these three will be used as the main alarms assigned to 3 different patients in the test setup.
Overall both pianos were considered the most pleasant alarm sound.

Limitation

The Likert scale test must have more inputs for better reliability such that thematic analysis is not highly dependent for understanding the pleasantness of the alarms. The test is done with the general population with in a particular region, hence it's still can user more diverse inputs for creating a more robust test.

5.2 Results of the functional and urgency test

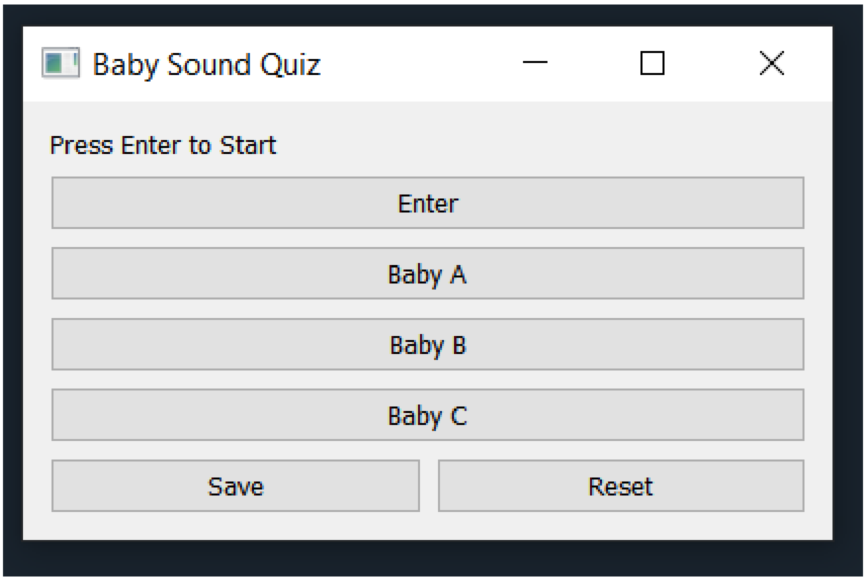


Fig 19. Application game window

The game test

A pygame application was created using Python and related platforms (Appendix B). Initially, a short training session that lasts about 3 min is conducted for N=15 (Appendix G), where each of the alarm sounds is played. The Alarm sounds this time around are named according to the patients they are assigned to and hence Baby A (Lullaby), Baby B (Piano A), and Baby C (Chimes). The users were not given any information about their original names.

Then the application is run, on selecting 'Enter', one of the three alarms is played at random for 8 seconds, and the user clack clicks the answer they believe that the sound is. The answers and the response time are recorded as a CSV file,

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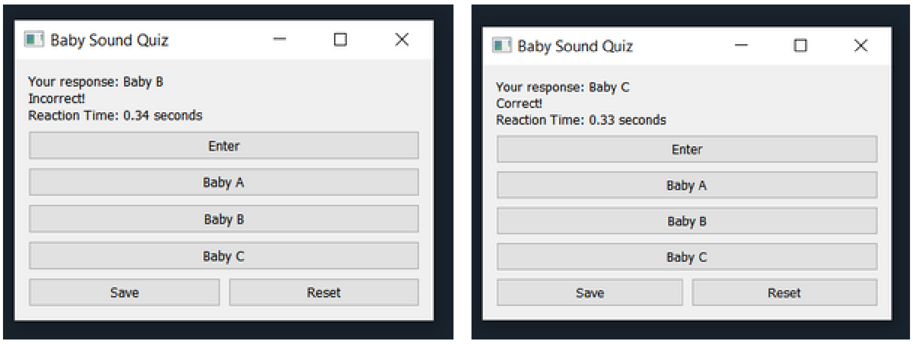

Fig 20. Incorrect and correct identification with response time

Since N=15, repeated 4 times per user, the reaction time is considered independent from the identification response. Below is the overall average distribution of the reaction time per participant. The data was cleaned and then the mean distribution was calculated, Since the data only consists of 2 independent variables, there is no need to check reliability.

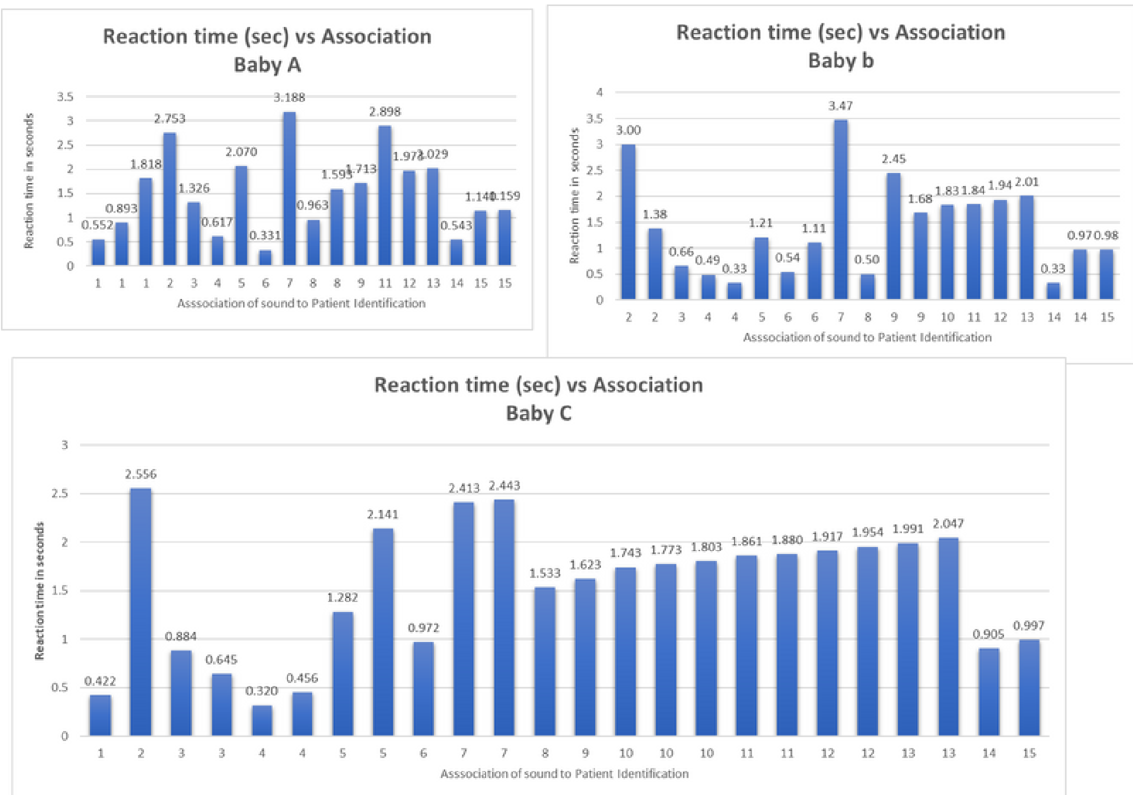

Fig 21. Patient Identification Vs Reaction time in seconds

The answers were converted into CSV data for which the frequency of correct responses was calculated. With 86.9% accuracy in identifying the different patients. Similarly, the mean response time is 1.49 seconds which is way faster and below the 6 seconds recognition during medical operations.

Fig 22. Patient Identification frequency and response time mean

Answer

		Frequency	Percent
Missing	Correct	53	86.9
	Incorre	8	13.1
	Total	61	100.0

Report

	Sound	Reaction
N	61	61
Mean		1.4897799152
Std. Deviation		.79100373601
Median		1.5931199210

Limitation

The response time results are limited to this test setup. To see real-world implications of the sound design, this must be conducted with Nurses at the NICU in order to see their understanding of this whole new alarm library and how its benefits,

5.3 Results for the urgency test

Urgency Test

The test was conducted as a simple verbal question session and the results are inconclusive since many of the users did not identify much difference between the high and medium/low designed alarm sounds. Hence for medium/low priority alarms, the sound design must be changed to distinguish them in a real-time patient event. This could have also arisen since there was no training for the two different event sounds with any of the users.

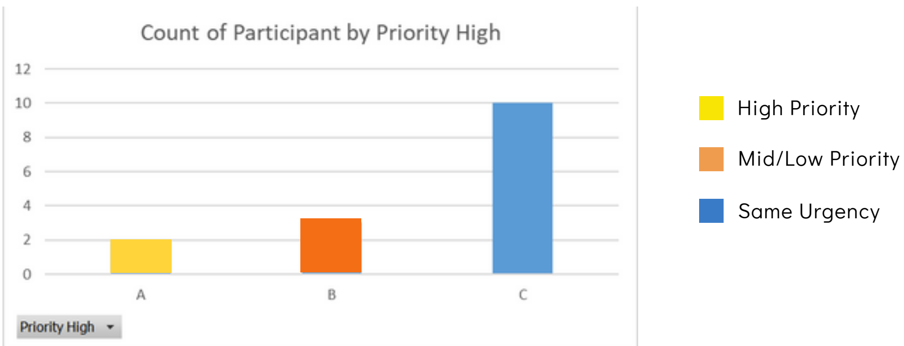

Fig 23. Participant Count Vs Urgency

5.4 Discussion

In the pursuit of designing clinical alarms with an innovative approach, this project employed a mixed-method research methodology, combining quantitative data on perceived pleasantness with qualitative insights. The initial intention was to conduct both functional and urgency tests with a larger participant group, but time constraints within the project scope limited the testing to a smaller scale.

The results of the perceived pleasantness test, using a Likert scale, indicated a need for a larger sample size or potential refinement in the questionnaire, specifically concerning the Piano S alarm. The subsequent qualitative data analysis, employing inductive thematic analysis, revealed overarching themes such as aesthetics, sensory appreciation, and emotional associations.

In the discussion of results, it was found that Piano A was considered the most pleasant alarm, followed closely by the Lullaby. Piano S, despite thematic associations, was not ranked as favorably. These findings guided the selection of three main alarms—Piano A, Lullaby, and Chimes—for further testing in a functional and urgent context.

The functional and urgency test, conducted through a pygame application, demonstrated high accuracy in identifying different alarms, with a mean response time well below the critical threshold for medical operations. However, limitations were acknowledged, particularly the need for testing with nurses in a real-world setting to assess practical implications and benefits.

The urgency test, focusing on participants' ability to distinguish between high and medium/low urgency alarms, yielded inconclusive results. The lack of training for different property sounds might have contributed to this outcome, suggesting the need for more focused training in future iterations.

In conclusion, while the project faced certain limitations in sample size and testing scope, it successfully combined quantitative and qualitative methods to inform the selection of alarm sounds for clinical use. The next steps involve refining the Likert scale test, conducting real-world tests with healthcare professionals, and addressing design aspects for improved urgency distinction. This endeavor stands as an innovative exploration at the intersection of sound design, user perception, and healthcare applications.

5.5 Reflection

The journey of creating a new alarm sound library for clinical use has been a meticulous and creative process, deeply rooted in the analogy of baby toys as the building blocks. This unique approach was chosen for its versatility, offering various material properties and metaphorical associations related to baby growth. The malleability of toy sounds provided a rich source for the hierarchical semantical approach in sound design. This was a new path of design that I had yet to discover,

The ability to justify the design helped one understand the intricate layers of sound design within the medical critical alarms context. The challenges in the sound design process were identified with a focus on reducing the number of alarms from handheld devices while effectively communicating emergency patient events through audio cues without relying on visuals. This led to the development of a semantic network, emphasizing the importance of context, event, and embodiment in crafting meaningful audio cues.

To be able to test the functions such as response time and identification of patients also proved the importance of a good sound design in the NICU setting, and the perceived pleasantness test helped one understand the emotional cognition that could help reduce stress and well use the alarm effectively.

The future of this design project would be aimed at training nurses to respond to the new audible alarm sounds for patient identification without relying on visual cues, which would be a crucial step in improving response times and overall effectiveness in emergencies.

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Link to New audible alarm library:
https://drive.google.com/drive/folders/1MsyPlbsv6OrH2mwwV5iceKhN-Trg1tOT?usp=sharing

Appendix A

Determining the pleasantness of the newly designed Critical Audible Alarm Library.

Greetings to beloved fellow human!

I am Anjay Valiyaveedu, an Integrated Product Design Masters student, and I am conducting a test on determining ***Pleasantness*** of the newly designed audible alarms for my graduation thesis project.

CONTEXT:

The focus of this project is on the sound design of audible alarms in the critical alarm realm for neonatal ICUs at the Erasmus MC- Sophie's Children's Hospital in Rotterdam, Netherlands. The current critical alarm system used in the Neonatal Intensive Care Unit (NICU) at Erasmus Medical Center Rotterdam is the ASCOM's MICIS (medical Integrated Communications and Information System) which integrates all the information streams from various devices into a single platform. Currently, the system is being integrated with an addition of special handheld mobile devices (HMD) which will be used to deliver and send various patient information within the faculty.

There will also be a shift in the auditory alarm database due to the change in alarm standards and alarm devices affecting its perception.

The goal is to create an efficient audible alarm sound library for the nurses at the NICU where the new HMDs can help locate and cater to their patients through effective audible alarms from mobile devices for different patients.

The priority of the new audible alarm is to help nurses locate different patients effectively during an event and effectively respond to the event without visual cues when they (nurses) are mobile in the hospital.

Hi! Would you mind taking around 10 minutes to complete this form? It would be great if you could submit your response by Oct 22nd, 2023. Thank you!

All information is collected will be stored safely on the university-approved server.

* Required

* This form will record your name, please fill your name.

The New Audible Alarms

Six different audible alarm sounds, with two different priorities (High and mid-low), have been created. The Higher will be presented below.

Please indicate whether you find each audible alarm pleasant. (The 7-point Likert scale goes from 1-Strongly disagree to 7-Strongly Agree).

After each audible alarm sound is rated, please describe shortly as to why you found the sound pleasant or not pleasant.

1

Chimes *

Upload file

File number limit: 1 Single file size limit: 10MB Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

2

Please rate Chimes - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	○	○	○	○	○	○	○

3

Lullaby *

Upload file

File number limit: 1 Single file size limit: 10MB Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

4

Please rate Lullaby - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	○	○	○	○	○	○	○

7

Dial Tone

Upload file

File number limit: 1   Single file size limit: 10MB   Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

8

Please rate Dial Tone - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	○	○	○	○	○	○	○

5

Shakers

Upload file

File number limit: 1   Single file size limit: 10MB   Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

6

Please rate Shakers - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	○	○	○	○	○	○	○

9

Piano A

Upload file

File number limit: 1 Single file size limit: 10MB Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

10

Please rate Piano A - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	◯	◯	◯	◯	◯	◯	◯

11

Piano S

Upload file

File number limit: 1   Single file size limit: 10MB   Allowed file types: Word, Excel, PPT, PDF, Image, Video, Audio

12

Please rate Piano S - High Priority audible alarm in terms of Pleasantness

	Strongly Disagree	Disagree	Slightly Disagree	Neutral	Slightly Agree	Agree	Strongly Agree
Pleasantness	◯	◯	◯	◯	◯	◯	◯

13

Please indicate your name

14

Your age group

- 20 - 25
- 25 - 30
- 30 - 35
- 35 - 40
- 40 - 45

15

You Email Address

This content is neither created nor endorsed by Microsoft. The data you submit will be sent to the form owner.

Microsoft Forms

Appendix B

Functional test application code

```
import sys
import os
import random
import csv
from PyQt5.QtWidgets import QApplication, QWidget, QPushButton, QVBoxLayout, QLabel, QHBoxLayout
from PyQt5.QtCore import Qt, QTimer
import pygame
from pydub import AudioSegment
from pydub.playback import play
import time

class BabySoundApp(QWidget):
    def __init__(self):
        super().__init__()

        # Initialize variables
        self.sound_files = [
            "D:\\ANJAY\\Grad\\final stretch\\sounds final\\babya.wav",
            "D:\\ANJAY\\Grad\\final stretch\\sounds final\\babyb.wav",
            "D:\\ANJAY\\Grad\\final stretch\\sounds final\\babyc.wav"
        ]
        self.correct_sound = ""
        self.start_time = 0
        self.reaction_time = 0

        # Create GUI elements
        self.init_ui()

    def init_ui(self):
        # Layout
        layout = QVBoxLayout()

        # Sound buttons
        sound_group_box = QLabel("Press Enter to Start")
        layout.addWidget(sound_group_box)

        # Enter button
        enter_button = QPushButton("Enter")
        enter_button.clicked.connect(self.start_test)
        layout.addWidget(enter_button)

        # Answer buttons
        self.answer_buttons = []
        for sound_name in ["Baby A", "Baby B", "Baby C"]:
            button = QPushButton(sound_name)
            button.clicked.connect(lambda _, name=sound_name: self.check_answer(name))
            layout.addWidget(button)
            self.answer_buttons.append(button)
```

```
        # Save and Reset buttons
        save_button = QPushButton("Save")
        save_button.clicked.connect(self.save_response)
        reset_button = QPushButton("Reset")
        reset_button.clicked.connect(self.reset_test)

        button_layout = QHBoxLayout()
        button_layout.addWidget(save_button)
        button_layout.addWidget(reset_button)
        layout.addLayout(button_layout)

        # Set main layout
        self.setLayout(layout)

        # Set window properties
        self.setWindowTitle('Baby Sound Quiz')
        self.setGeometry(300, 300, 400, 200)
        self.show()

    def start_test(self):
        # Clear the answer buttons and reset layout
        self.correct_sound = random.choice(["Baby A", "Baby B", "Baby C"])
        random.shuffle(self.answer_buttons)
        sound_name = self.correct_sound

        # Display the sound name and play the sound
        sound_group_box = self.layout().itemAt(0).widget()
        sound_group_box.setText(f"Listen to the sound: {sound_name}")

        sound_file = self.sound_files["ABC".index(sound_name[-1])]  # Extract index from "Baby A", "Baby B",
"Baby C"
        self.play_sound(sound_file)

        # Record start time for reaction time calculation
        self.start_time = time.time()
```

```
    def play_sound(self, sound_file):
        sound = AudioSegment.from_file(sound_file)
        play(sound[:6000])

    def check_answer(self, selected_sound):
        # Calculate reaction time
        self.reaction_time = time.time() - self.start_time

        # Display result
        if selected_sound == self.correct_sound:
            result = "Correct!"
        else:
            result = "Incorrect!"

        # Display result and reaction time
        sound_group_box = self.layout().itemAt(0).widget()
        sound_group_box.setText(f"Your response: {selected_sound}\n{result}\nReaction Time:
{self.reaction_time:.2f} seconds")

    def save_response(self):
        # Record response in CSV file
        with open('responses.csv', 'a', newline='') as csvfile:
            fieldnames = ['Correct Sound', 'Selected Sound', 'Reaction Time']
            writer = csv.DictWriter(csvfile, fieldnames=fieldnames)

            writer.writerow({
                'Correct Sound': self.correct_sound,
                'Selected Sound': "Not Recorded",
                'Reaction Time': self.reaction_time
            })

    def reset_test(self):
        # Reset the layout and clear the CSV file
        sound_group_box = self.layout().itemAt(0).widget()
        sound_group_box.setText("Press Enter to Start")

        with open('responses.csv', 'w', newline='') as csvfile:
            fieldnames = ['Correct Sound', 'Selected Sound', 'Reaction Time']
            writer = csv.DictWriter(csvfile, fieldnames=fieldnames)
            writer.writeheader()

if __name__ == '__main__':
    app = QApplication(sys.argv)
    baby_sound_app = BabySoundApp()
    sys.exit(app.exec_())
```

Appendix C

Data Sonification Canvas

1 Use Case: Who are your users, what are the goals and the context of your sonification?

Users

- **Neonatal Nurses**
- **Nursing assistance**
- **Infants**
- **Administraton**
- **Doctors**
- **Communicaiton staff**

Goals

Reduce the number of alarms to be easily perceived with trainable outcomes

increase the effectiveness of communication by the reduced alarms

Context

Location: Sofie Children's hospital, Erasmus MC, Rotterdam, Netherlands.
=At the neonatal ICU

2 Mapping Choices: How do you map data parameters to sound parameters?

Type of Sounds

Digital signals with assigned single-note PLUSATED tunes.

Behaviour

Timbre
Pitch Overtones
ADSR envelope
Temporal cohenrence

Functions

Symbolic is more appropriate in this case. The alarm sound must fit the context while allowing one to recognize its function.

Multi-modality

The alarms are coupled with visual indicators such as lights and a display with values indicating the threshold for each parameter

Analytical

Are you representing hard values from a dataset?

Narrative

Do you want to communicate a message or tell a story?

the data set of indicators from the machines at the ICU must translate into easily trainable alarm actions

The message communicated is that of identification and appropriate action

3 Sonification Approach: How would you position your approach to the sonification?

Causal

The information conveyed is that of the patient identity (not name but the location) and the ability to respond effectively to an emergency NICU event

Semantic

Alarm sounds produced are semantic in nature. Mean while the gap between the alarms, their intensity of tone is also vital to differentiate what they indicate.

Reduced

Will they focus on the sound itself and its inner characteristics?

e.g. when we distinguish the interval between two notes or the pitch of a bridsong.

4 Listening Experience: How do you imagine your users will listen to the sonification?

Appendix D

Project Brief

Personal Project Brief - IDE Master Graduation

TUDelft

Designing critical alarms grammatically for improved learnability — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 16 - 03 - 2023 — 17 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Current Critical Auditory alarms: The current state of critical alarms in ICUs is the presence of multiple alarms (100 +) intensified by poor room acoustics and lack of informative quality. These alarms are a combination of visual and auditory information. The large sets of alarms result in caregivers becoming overwhelmed in response to them. They get desensitized, which can lead to missed alarms or delayed responses, placing patients at risk. This phenomenon is called alarm fatigue. Similarly, the change in critical alarm infrastructure every few years in the hospital facility results in the need for training for the new system, which can also lead to fatigue and confusion among caregivers. Hence, vital actions become slow and the response time lags which also leads to patient health risks. In the past few years, critical alarms used in medical care facilities are being streamlined, based on research and development in this field, to increase the efficiency and safety of both patients and caregivers in the field. It has been evident that there has been a rise in the overall alarms generated by medical devices due to an increase in patient vital information transmitted by these devices. The auditory alarms associated with such a system are usually auditory icons, which are essential for learnability and recognition performance. Learnability could be defined as how easily the user understands the detailed event in a critical alarm system, and hence any shift must in the auditory side of these alarms need to be learnable.

The current critical alarms systems used in the Intensive Care Unit (ICU) at Erasmus Medical Center Rotterdam is the ASCOM's MICIS (medical Integrated Communications and Information System) which integrates all the information streams from various devices into a single platform with a special device called the Ascom Myco Mobile and delivers them to the caregivers. There will be a shift in the auditory alarm database due to the change in alarm standards and alarm devices affecting its perception.

Critical Alarm Labs (CAL) & MICIS (Erasmus MC):

CAL's focus is on the future of alarms and soundscapes in a socio-technological environment, especially with healthcare, and the lab studies alarms for the right point of interventions in the context. Critical alarm systems in the medical field are situated in complex environments where the caregivers' actions heavily rely on the alarms from monitoring devices. CAL has been working with Erasmus MC Rotterdam to achieve the best critical alarm systems for all their users, especially in intensive care. With the guidance of Tom Goos at the neonatal ward in Erasmus MC Sofia Hospital, who is actively researching the development of MICIS 3.0 based on the hospital's needs. The neonatal ICU (NICU) ward is undergoing an overhaul, where each patient would be shifted to single beds and rooms each monitored separately through the MICIS system. With this comes a shift in the auditory alert perception with the devices.

The major research stakeholders of the project will include the CAL team (Critical Alarm Labs TU Delft), and the MICIS research team (Erasmus MC) and the solution will cater to the Neonatal ICU at the Erasmus MC Rotterdam while acknowledging the medical policymakers and manufactures.

space available for images / figures on next page

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The MICIS 3.0 device currently is being developed to provide alerts/ alarms close to the existing infrastructure of the Erasmus MC Rotterdam and provides a mobile device inter-phase for interaction between caregivers. It provides a digital platform through its dedicated app for communicating patient vitals and other related information in the form of visuals and alerts and even can capture and share images. It helps the nurses communicate more efficiently with the doctors, lab workers, and the administration and streamlines the communication flow. With this shift comes constant updates in alarm standards and sounds, resulting in a change in the auditory alarm perception of these caregivers. A large information from patient vitals are converted into signaled outputs for the caregivers which results in a larger complex information alert system. This allows us to build a unique auditory alarm design for the users, helping them be better aware of such vital information from the device through human-centred sound design.

The CAL and MICIS team are working towards refining the existing solution into a more efficient product, reducing the risks in the transition of using the device for caregivers. In this case, the focus will be on nurses handling the MICIS system Through preliminary research, it is seen that there is a possible gap in the current system is in defining the perception of new auditory alarms (alerts from the device) from a stream of patient vitals which is important in bringing out the right actions when interpreted by the caregivers (nurses).
Definition:
The scope of this project would be to map out the existing auditory alarms and design a comprehensible alarm system based on a logical grammar for the nurses at Erasmus MC Rotterdam through sound design of auditory icons (i.e., metaphorical alarms) and earcons (i.e., musical alarms), which would increase the learnability of new alarms (Edworthy et al., 2022) for the nurses at Erasmus MC, reducing the complexity of the information interpretation, in turn, reducing risks when under stress.

ASSIGNMENT **

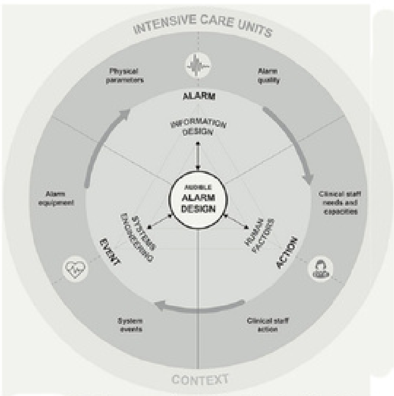
State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Comprehensive alarm sound design for MICIS 3.0
To design a flexible auditory alarm grammar for the MICIS 3.0 in Neonatal ICU Nurses at Erasmus MC Rotterdam, for increasing efficiency in training and learning of the critical alarms based on auditory icons (metaphorical alarms) versus auditory earcons (musical alarms)

The initial phase would be literature/desk research on the MICIS systems, followed by primary research at the Neonatal ICU of the Sofia Children's Hospital, Erasmus MC Rotterdam on the current events and actions. Previous interaction with the auditory alarms by the caregivers will also be taken into account for the design phase, followed by the development of alarms on a digital audio wave platform, where various sounds suited as alarms will be developed and assigned as an output to the related information.
The second phase is to create an alarm sound grammar based on two separate sound design strategies (Fig 2) on stacked scenarios of the context of patient vital information to required action from the caregiver (nurse) and test the learnability of this new grammar. The flexible grammar database of alarm sounds should bring out an intact alarm system which is easy to perceive and efficient even under high-stress conditions. The alarm grammar design will be based on familiarity, novelty and future-proofing.

This is followed by a real-time user test phase where the user's perception versus their cognition of this auditory alarm (Fig.1) grammar (based on icons or earcons), and their learnability time under the quantifiable condition will be done, and post iterations, a final grammar package will be created. The test will be done in a Lab environment where users are made to listen to the new alarm grammar in a forced choice test. This new grammar training data will be analysed ans will let us understand how new auditory alarms impact the ability to learn for the caregivers within their workplace routine. The final design phase will be to implement the grammar into the developing MICIS Software package.

introduction (continued): space for images



Basic design components for audible alarm design at Intensive Care Units.

Hierarchy of needs theory. (Maslow, 1943).

image / figure 1: Basic Critical Alarm Design (Design Framework for Audible Alarms, 2022)

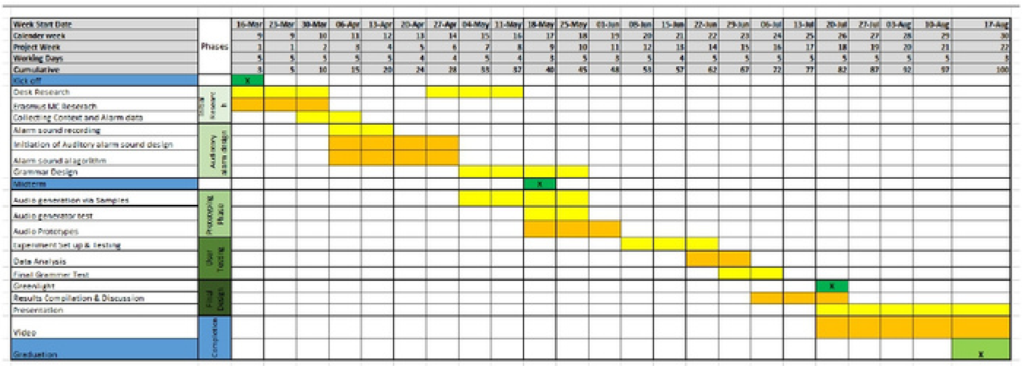
image / figure 2: Auditory-alarm grammar design for MICIS 3.0 training (example)

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 16 - 3 - 2023

17 - 8 - 2023 end date



Off days	
Good Friday	07-Apr
Easter Monday	10-Apr
King's Day	27-Apr
Off Day 1	04-May
Liberation Day	05-May
Ascension Day	18-May
Day after ascension	19-May
Pentecost	29-May

Dates	
Kickoff Meeting	16-Mar
Mid term	19-May
Greenlight	20-Jul
Graduation	17-Aug

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The design of sound around a context for a particular user has always fascinated me, which may vary from foley in entertainment to alarms of products. The focus is on a human-centred design approach which I have previously practised through the IPD master's programme and I would like to combine it with my passion for sound-driven design. A project in this field would help me further develop my skills exclusively related to sound design and related topics of cognition and perception, all of which can be implemented in product design and development of any product with a focus on its acoustics.

The CAL (Critical Alarm Labs) department presents a unique opportunity where I get to work in an exclusive field with experts who have a large experience in the topic of sound, especially in the medical field. This creates a zone of high excellence in terms of learning and implementation when it comes to the design process and its execution. The alarm system approach and design push me to further explore such interaction in the evolving concept of more silent future alarms and also allows me to enter medical design to a small extent. The need for a trainable alarm grammar is also exciting for me, as it would help in streamingly the learnability and eventually the perception of the alarm systems for the caregivers, making it a streamlined process when alarm systems undergo transitions.

I have a great interest in the topics of audio design & branding, cognitive perception and biology. Hence my interest in the sound-driven design topic pushes me to work passionately on a project with such a scope, to not only deliver a product solution that would help me further hone my skills as a designer, but also create meaningful solutions for the developing socio-technology interactive space. Together they form a great motivation in pursuing this project as my final graduation project.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Ref:
Design Framework for Audible Alarms: A Multidisciplinary and Integrated Approach
Sanz-Segura, R., Manchado-Pérez, E., & Özcan, E. 2022 Aug 29.
Edworthy, J., Parker, C. J., & Martin, E. T. (2022). Discriminating between simultaneous audible alarms is easier with auditory icons. Applied Ergonomics, 99, 103609.

Graduation Thesis Project
Masters in Integrated Product Design
Industrial Design
TU Delft

Appendix E

Title:
Critical audible alarm-sound design for handheld monitoring devices in Neonatal ICUs

Authors:

Corresponding researcher; Anjay Valiyaveedu

Responsible researcher; Dr. Ozcan Vieira, E.

Mentors; Dr. Sara Lenzi, T.G.Goos

Research

You are being invited to participate in a research study titled Critical audible alarm-sound design for handheld monitoring devices in Neonatal ICUs.

This study is being done by Anjay Valiyaveedu, an Integrated Product Design Master student from the TU Delft, as part of their graduation thesis.

The purpose of this research study is one of cognitive ergonomics in understanding the effectiveness of the newly designed audible alarm library for Hand-held Mobile Devices for the Nurses of NICU at Sophies Hospital, Erasmus MC, Rotterdam. It will take you approximately 15 minutes to complete. The data will be used for implementing the new alarm sounds for the nurses at the NICU to identify their patients and respond appropriately. The data acquired from this research will be kept online under a university-approved survey. Only the results from this research will be used, whereas no personal data will be used in the Thesis report, its publication, and if used in any further teachings.

We will be asking you to listen to six different audible alarm sounds and indicate each perceived pleasantness on a Likert scale followed by a short interview on the reasoning behind the score. The Task is to fill in an online survey form with the above questions, whereas the interview will be transcribed separately

As with any online activity, the risk of a breach is always possible. To the best of our ability, your answers in this study will remain confidential. We will minimize any risks by only using university-approved online forms and data storage facilities.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. The data will not be removed but stored until further notice in terms of use for thesis & and publication which may go up to a year of storage..

Signatures

________________________ _______________________ _______

Name of participant [printed] Signature Date

[Add legal representative, and/or amend text for assent where participants cannot give consent as applicable]

I, as legal representative, have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

________________________ _______________________ ________

Name of witness [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Anjay Valiyaveedu

Researcher name [printed] Signature Date

Study contact details for further information: [*Name, phone number, email address*]

Appendix F

Likert Data

Participants	Chimes Pleasantness	Lullaby Peasantness	Shakers Pleasantness	Dial tone Pleasantness	Piano A Pleasantness	Piano S Pleasantness
P1	1	1	2	2	4	3
P2	2	2	1	2	4	5
P3	6	6	3	4	6	2
P4	2	2	3	1	5	6
P5	6	6	4	2	9	4
P6	3	3	2	4	6	6
P7	4	4	6	2	7	5
P8	5	5	2	3	4	3
P9	7	7	2	2	5	6
P10	2	2	3	3	6	5
P11	6	6	5	6	6	3
P12	6	6	2	4	6	3
P13	3	3	2	4	7	5
P14	6	6	3	5	2	2
P15	6	6	2	6	5	4
P16	6	6	7	2	6	4
P17	6	6	4	3	6	5
P18	6	6	2	2	5	4
P19	6	6	4	2	5	2
P20	5	5	3	4	7	5

Users	Pleasantness	Pleasantness2	Pleasantness3	Pleasantness4	Pleasantness5	Pleasantness6
P1	Slightly Disagree	Slightly Agree	Disagree	Disagree	Neutral	Slightly Disagree
P2	Disagree	Slightly Agree	Strongly Disagree	Disagree	Neutral	Slightly Agree
P3	Agree	Agree	Slightly Disagree	Neutral	Agree	Disagree
P4	Disagree	Strongly Agree	Slightly Disagree	Strongly Disagree	Slightly Agree	Agree
P5	Agree	Slightly Disagree	Neutral	Disagree	Slightly Disagree	Neutral
P6	Slightly Disagree	Neutral	Disagree	Neutral	Agree	Agree
P7	Neutral	Slightly Disagree	Agree	Disagree	Strongly Agree	Slightly Agree
P8	Slightly Agree	Agree	Disagree	Slightly Disagree	Neutral	Slightly Disagree
P9	Strongly Agree	Strongly Agree	Disagree	Disagree	Slightly Agree	Agree
P10	Disagree	Slightly Agree	Slightly Disagree	Slightly Disagree	Agree	Slightly Agree
P11	Agree	Strongly Agree	Slightly Agree	Agree	Agree	Slightly Disagree
P12	Agree	Agree	Disagree	Neutral	Agree	Slightly Disagree
P13	Slightly Disagree	Agree	Disagree	Neutral	Strongly Agree	Slightly Agree
P14	Agree	Neutral	Slightly Disagree	Slightly Agree	Disagree	Disagree
P15	Agree	Slightly Agree	Disagree	Agree	Slightly Agree	Neutral
P16	Agree	Strongly Agree	Strongly Agree	Disagree	Agree	Neutral
P17	Agree	Strongly Disagree	Neutral	Slightly Disagree	Agree	Slightly Agree
P18	Agree	Strongly Agree	Disagree	Disagree	Slightly Agree	Neutral
P19	Agree	Agree	Neutral	Disagree	Slightly Agree	Disagree
P20	Slightly Agree	Agree	Slightly Disagree	Neutral	Strongly Agree	Neutral

Appendix G

Response time

Participant	Playes Sound	Answer	Response Time (sec)
1	Baby A	Correct	0.552354097
1	Baby A	Correct	0.892566091
1	Baby A	Correct	1.818223333
2	Baby A	Correct	2.753147602
3	Baby A	Correct	1.325706846
4	Baby A	Correct	0.616500318
5	Baby A	Incorrect	2.069671857
6	Baby A	Correct	0.331238838
7	Baby A	Incorrect	3.188452093
8	Baby A	Correct	0.963095145
8	Baby A	Correct	1.593119921
9	Baby A	Correct	1.713219065
11	Baby A	Incorrect	2.898360691
12	Baby A	Correct	1.972835866
13	Baby A	Correct	2.028692243
14	Baby A	Correct	0.543060233
15	Baby A	Correct	1.140404998
15	Baby A	Correct	1.159023791
2	Baby B	Correct	3.000147573
2	Baby B	Correct	1.384386301
3	Baby B	Correct	0.663656721
4	Baby B	Correct	0.488953153
4	Baby B	Incorrect	0.332726735
5	Baby B	Correct	1.211493249
6	Baby B	Correct	0.543060233
6	Baby B	Correct	1.113970926
7	Baby B	Correct	3.473020794
8	Baby B	Incorrect	0.503045578
9	Baby B	Correct	2.453169497
9	Baby B	Correct	1.683194281
10	Baby B	Correct	1.833318199
11	Baby B	Incorrect	1.842504311
12	Baby B	Correct	1.935598281
13	Baby B	Correct	2.010073451
14	Baby B	Incorrect	0.331238838
14	Baby B	Correct	0.972149534
15	Baby B	Correct	0.977642582
1	Baby C	Correct	0.422156743
2	Baby C	Correct	2.556104333
3	Baby C	Correct	0.883961234
3	Baby C	Correct	0.645433201
4	Baby C	Correct	0.319726098
4	Baby C	Correct	0.455952515
5	Baby C	Correct	1.282403945
5	Baby C	Correct	2.140582553
6	Baby C	Correct	0.972149534
7	Baby C	Correct	2.412971226
7	Baby C	Incorrect	2.442996011
8	Baby C	Correct	1.533070361
9	Baby C	Correct	1.623144713
10	Baby C	Correct	1.743243848
10	Baby C	Correct	1.773268632
10	Baby C	Correct	1.803293416
11	Baby C	Correct	1.861123111
11	Baby C	Correct	1.879741904
12	Baby C	Correct	1.916979489
12	Baby C	Correct	1.954217073
13	Baby C	Correct	1.991454651
13	Baby C	Correct	2.047311036
14	Baby C	Correct	0.905304558
15	Baby C	Correct	0.996961375

Appendix H

Urgency

Priority High	Count of Participant
A	2
B	3
C	10

A = High Prioirty
B = Low Priority
C = Equally same

Appendix I

Link to the audible alarm librabry

https://drive.google.com/file/d/1c4M6avsxJ4vA-soIViba4aSf_1GblbCI/view?usp=sharing

TITLE	LAST MODIFIE
Chimes H.mp3	Nov 22
Chimes ML.mp3	Nov 22
Dial Tone H.mp3	Nov 22
Dial Tone ML.mp3	Nov 22
Lullaby H.mp3	Nov 22
Lullaby ML.mp3	Nov 22
Piano A H.mp3	Nov 22