ultimo

Intensive Care Alarm System:

How display can inform and calm visitors at the same time?

Effects of Lighting conditions inside hospital ICU on patient recovery and rest

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Intensive Care Alarm System: How display can inform and calm visitors at the same time?

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Abstract: Literature research shows that visitors are an important part of the support system for the ICU patients however their presence can have a positive or negative effect on patients and clinicians. Introducing a visitor mode in the ICU monitor can improve their impact. For this purpose, it is crucial to understand their needs, preferences and how they perceive the received information. In this research, the effects of different ICU monitor displays on the experience of meaning and emotions are investigated. Current and new displays are shown to 12 participants. They fill in a questionnaire for each display made based on the semantic scale. To gain more insights, the “think out loud” protocol and a short interview are used. The results outline the diversity of the participants' opinion and the reasoning behind them. The comparison between current and new monitors resulted in a more positive response on the new monitors, except for the icon in a stable state. The new monitors are recognised as more peaceful due to the smaller amount of information and the colour. In addition, the participant perceives less anxiety from the monitors. In order to inform the visitors and help them understand the patient status, the amount of information should be limited and present in a simple and clean layout. The majority of participants prefer the displays with an icon, graph and one value among the presented concepts. However, the balance of the suitable amount of information is variable and requires a future study.

Keywords: Intensive Care Unit, ICU, ICU visitor, ICU monitor, monitor display, patient mode

Introduction: Product Experience

This paper describes a study that is part of a concept of the ICU monitor which envision that the displayed content will be changed accordingly to the type of a user inside the patient box. The aim of the study is to measure the visitors' experience of meaning and emotions in microscale towards the content on the monitor display. As a result, a set of design guidelines is formed for creating the visitor mode.

The intensive care is a stressful environment. Not only for clinicians that work there but also, and maybe even more, for patients and visitors that need to be there. The situation itself is stressful. It is a situation where the clinicians deal with life and death and the patients need constant care. The monitor amplifies the stress and anxiety. The constant sounds, alarms cause information overload, clinicians and cause alarm fatigue (Otenio et al, 2007). Not only do the alarms cause stress to the patient and nurses but in addition, it decreases the sleep quality for the ICU patients (Luetz et al., 2016) which is necessary for the recovery (Delaney, Haren & Lopez, 2015).

The visitors; family and friends, play an essential role in that context. They could have a positive or negative effect on a patient (Farrell et al, 2005). On the one hand, the emotional support to patients has positive effects on physiological and psychological outcomes of the patient (Williams, 2005). In other words, the visitors have an impact on the patient's recovery and will to live. On the other hand, visitor anxiety could be transferred to the patient or a nurse. Anxious visitors with multiple questions can interfere with the nurses’ ability to complete their work. For instance, it can result in errors in drug calculations or mixing drips when the nurse is distracted (Farrell et al, 2005).

Involving family members in the ICU is complex and requires balancing visitors' needs for information with the clinician's need to manage the treating process. When a loved one is critically ill, the family members are often in crisis, dealing with the roller coaster of emotions associated with the threat of a serious illness and trying to make sense of a foreign and sometimes frightening ICU environment (Farrell et al, 2005).

Patient's vital sign monitor is one of the main pieces of medical equipment in the ICU. The display of which is usually multi-parameter and has a technical look. This could be a shortage since the level of technology and equipment in the environment can increase the anxiety. The meaning of continuously changing graph and unstable parameters are hard to understand for unprofessionals. However, the graphs still attract a lot of attention. As described by the nurses, visitors "becoming focused on the monitors and asking very specific questions while paying little attention to their loved one in the bed" (Farrell et al, 2005). Therefore nurses spend more time giving information to a family; hence, less time is spent with the patient (Marco et al, 2005).

The Ultimo aims to reduce these feelings and improve the product experience with the monitor. So that the patient could get the full attention. The monitor should empower the nurses and ensure the patients and visitors.

The system itself is working on the background and is hard to see and experience by the user. The system senses who is in the room. Then the system changes the screen based on who is in the room. The workings and effects of the system are being shown to the users through the patient monitor. The change of the experience is therefore designed through the monitor and screen and the experiences in this report are based around interaction with the monitor.

The various levels of experience

Before the new monitor was designed, the current hospital monitors were analyzed. The monitors were analyzed based on the various levels of experience: micro, macro and meta, and on the different areas of experience: aesthetics, meaning and emotion. To be able to fully analyze the experiences of the user, the users need to be determined. Who are our users and what kind of interaction do they have with the product? What is their experience and what is the situation in which they interact with the product?

For this project we determined three main user groups. The clinicians that need the monitor to do their job. The patient which the monitor monitors and the visitors that visit the patient and often look to the monitor for status. Since there will be a new screen on the monitor which is aimed at the visitors. The research focuses on them. What do they need to see and how can the monitor ensure and support them so that they can focus on the patient. However, the clinicians need the monitor to do their job. Therefore the needs and experiences of the clinicians are taken into account to ensure proper workings of the monitor.

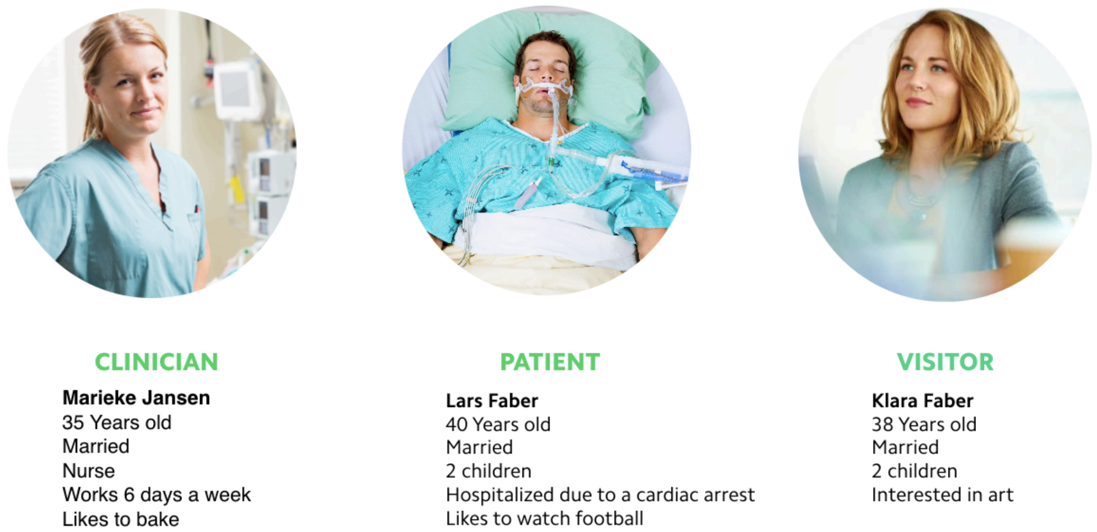

Figure 1. Personas

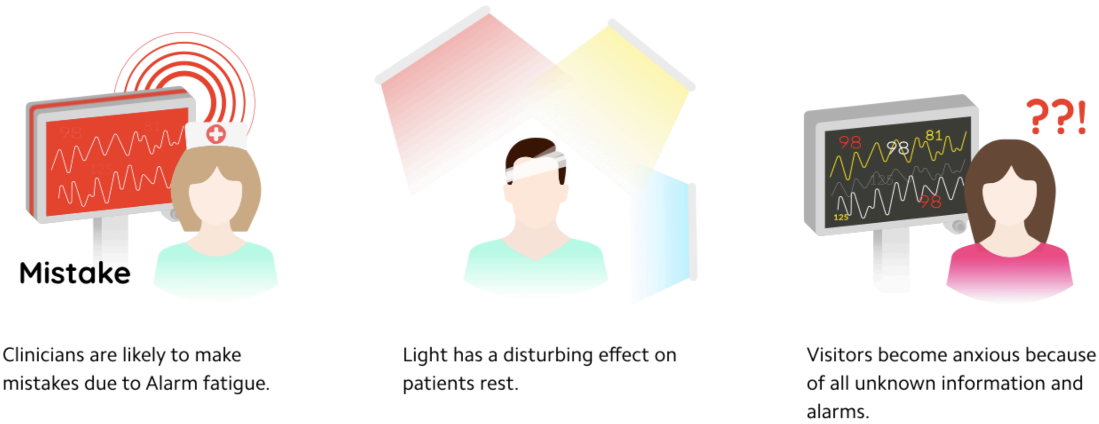

Figure 2. Main users issues

Another thing to keep in mind is the situation in which the monitor is used. The clinicians work in a stressful environment where they need to act on the right alarms from a surplus on alarms. The visitors visit a family member or friend that is in a critical condition, a stressful and uncertain situation. Furthermore, there are two situations in which the interaction differs. One situation is that the patient is stable and nothing is going on. The other one is where the clinicians have to check up on the patient, either because an alarm is sounding, or because they have to do a general checkup like washing the patient or insert and change medicine.

The visitor

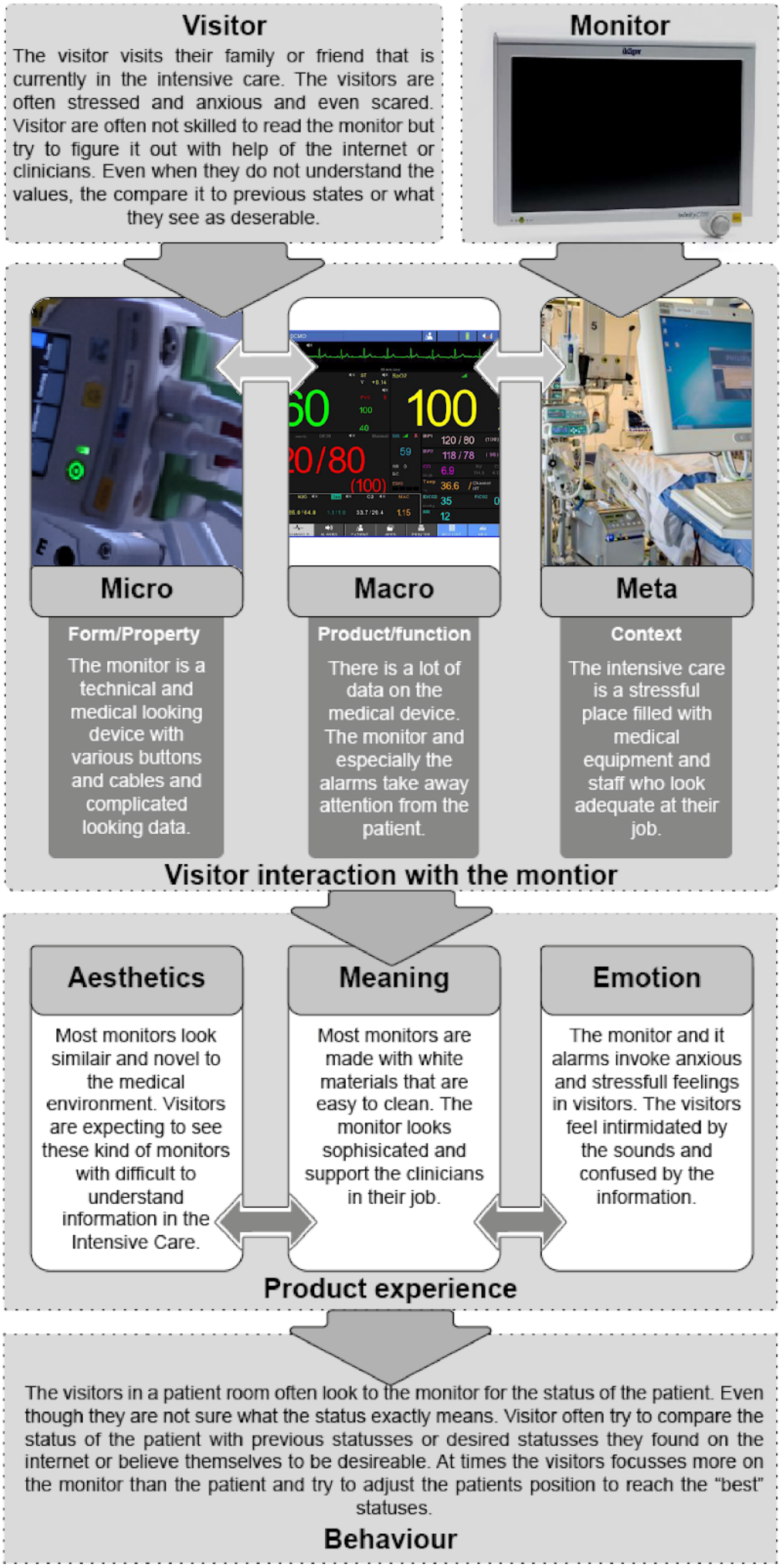

Figure 3. Product experience model for visitors

The clinicians

Figure 4. Product experience model for clinicians

During the rest of the research, the clinicians are taken into account during design but the focus lays on the visitor. The experiences and result are therefore surrounding those of the visitors in the rest of the report.

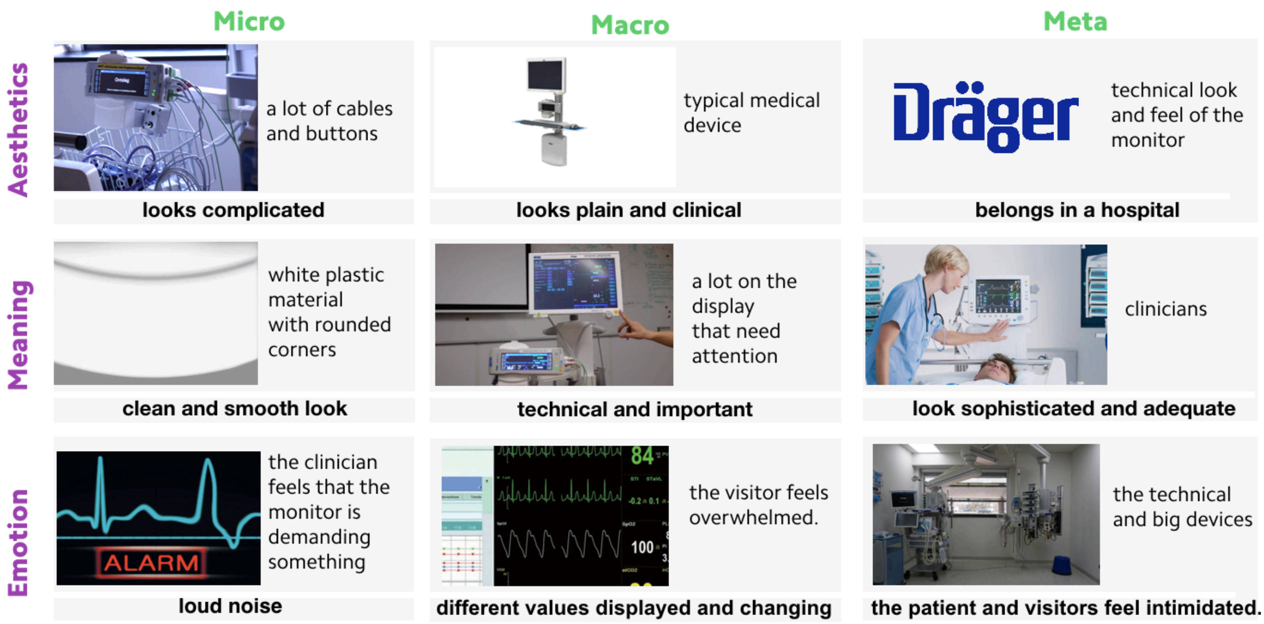

Figure 5. Product Experiences Matrix for the current monitor

To further analyze the visitors' experience with the monitor a human product interactions matrix is made of the current monitor. Where first the technical properties are shown and beneath that the experience of the visitors is linked.

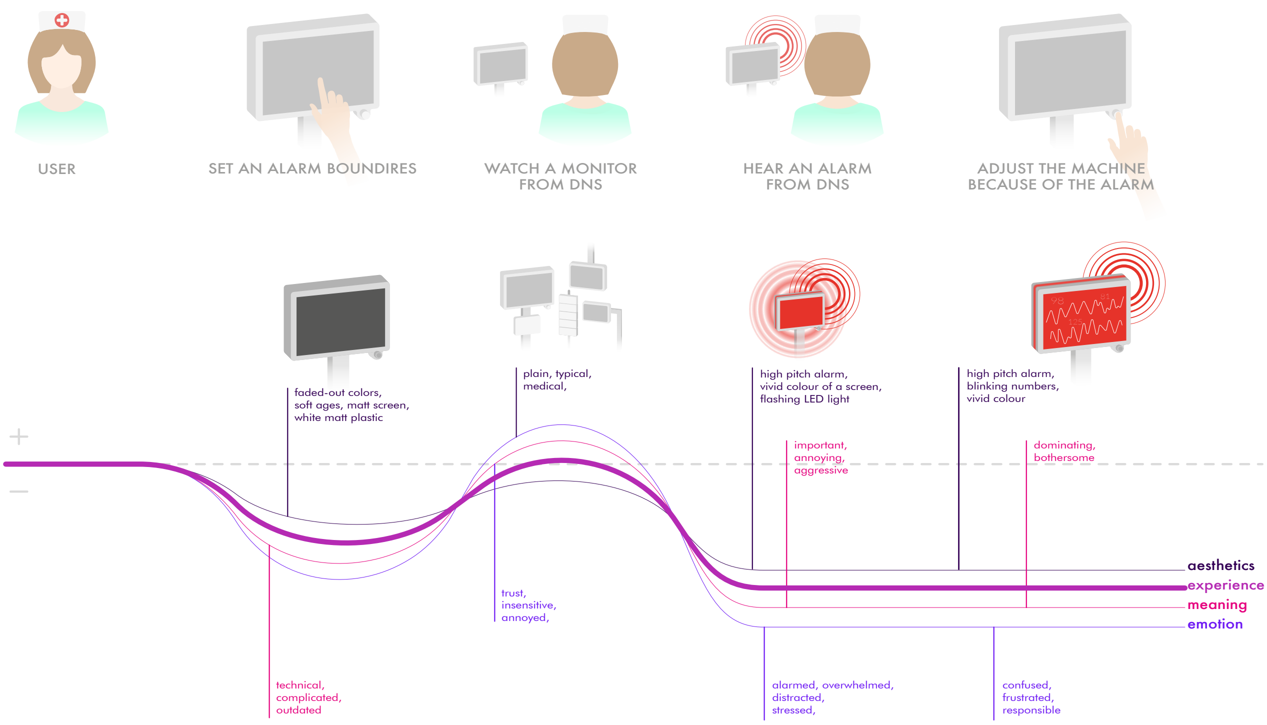

Figure 6. Clinicians experience map for the current monitor

As can be seen, most experiences with the monitor are negative. Keeping the situation in mind, it is not realistic to expect the experience with the monitor to be truly pleasant and positive. This is a result because the monitor will always be related to the situation in which one of their beloved ones are ill. However, the visitors can feel secured by and thankful for the monitor. Secured that their loved ones are taken care of and securely monitored. Thankful that they can see the status and maybe possibly understand it. Therefore we aim to address these positive experiences so that the monitor does not increase the negative feelings in the situation.

Vision

Figure 7. Context of the future ICU

Figure 8. Moodboard for the future monitor

In our vision, the visitor enters the patient room and focuses on the patient. They hear the patient status and what is going on from the clinician. The monitor lets the visitors know that the patient is being monitored and that the clinicians are taking care of them. The visitors do not have to take care of the patient right now, they just have to be there for the patient. The monitor should not confuse the visitors, but give clear to understand information catered to their needs. The visitors should not be alerted by alarms since they do not understand the alarms. False alarms that clinicians easily discard scare visitors. Something is happening with the monitor but no clinician is showing up. When the clinicians do show up due to an alarm or a general check-up, the visitors should be notified. When clinicians enter the room, visitors often have to leave. Visitors should be notified and prepared for that.

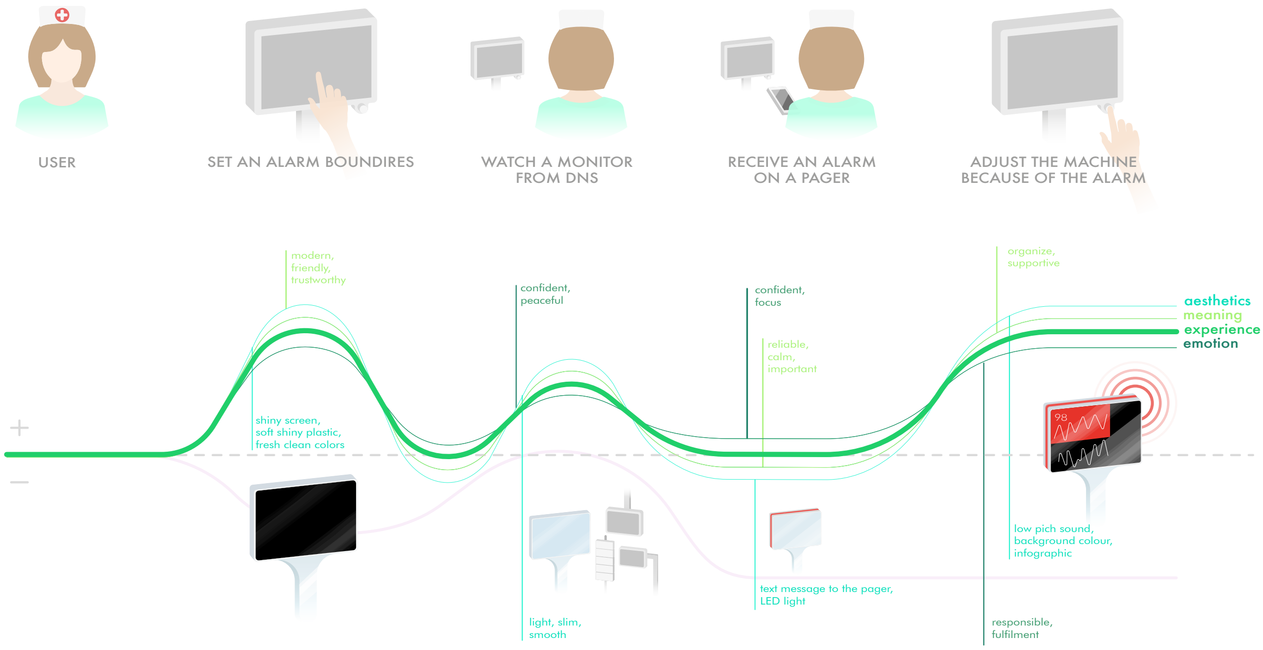

Figure 9. Future experience map

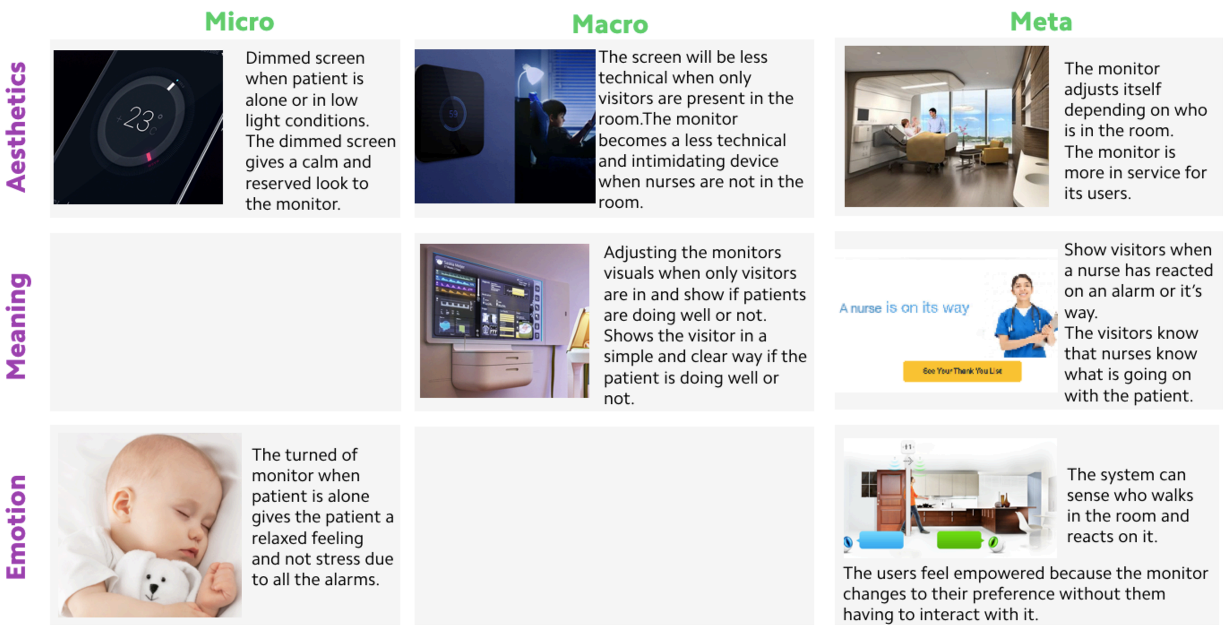

Figure 10. Product Experiences Matrix for the future monitor

With the wanted situation for the visitors determined and a matrix experience on how to reach it in the design, the design can be made. In the scope of the project, the main focus is on the monitor design and the user modes.

Monitor Design

The current monitor looks plain, outdated and typical on both micro and macro level. The aim of the product will be to represent innovation; inspire people, and be an example to the industry. It, therefore, has to significantly embody autonomy and novelty. In aesthetics, it is aimed to balance clean, trustworthy appearance, with less medical aesthetics, to improve the experience. Minimalistic, dynamic forms with big thin screen represent the novelty. In addition, a shiny finish display, silver matte metal and no visible buttons or controls will make the product look sleek and fresh. In order to make the monitor a complete part of the future calm ICU environment, it also has to have a friendly and warm look. Organic modelling, rounded corners and soft white plastic were used to create this feeling.

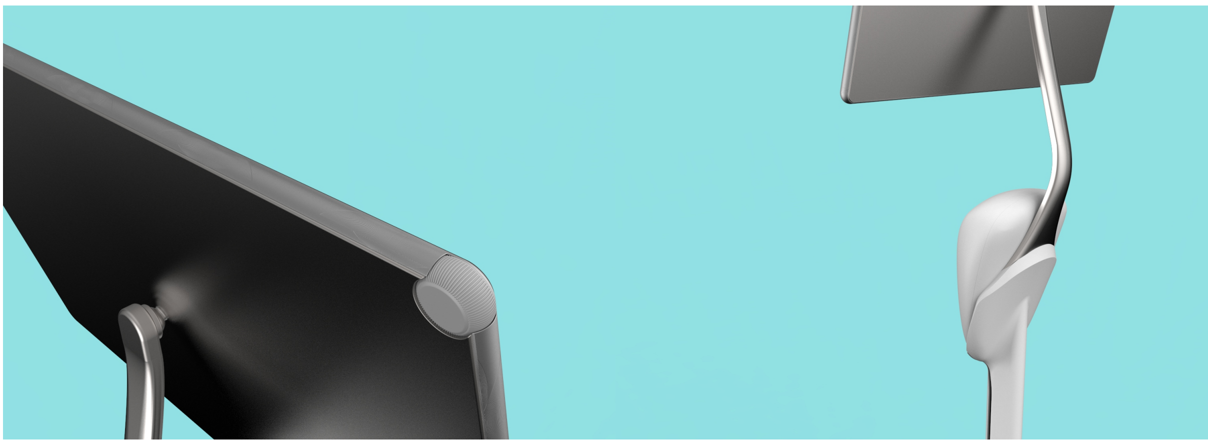

Figure 11. Concept of the future monitor Ultimo
Figure 12. Concept of the future monitor Ultimo details

Visitor mode

The next part of the report is focussed on the visitor mode that can be seen on the monitor screen. As a first step to prepare for the study an informal interview with 6 nurses was conducted at Erasmus MC. Eight display proposals were made and were used as the starting point of a discussion. Four displays presented the Status 1 - stable status and four the Status 2 when visitors should leave the patient box due to an emergency or regular procedure. Nurses evaluated the presented materials and provided suggestions for improvements in the design of the visitor mode. Their judgment was made based on their experience and observations of patients families and friends. Firstly, the opinions about the amount of information varied significantly. The majority of the nurses said not to show anything. This was because visitors worry too much about values. Often it requires clinicians to explain the different values. In addition, when visitors like to know more they come outside of the patient box to talk about the vitals.

However, some of the nurses can see the visitor's need of having something to hold onto, a value to compare. Heart rate was suggested as this value since it is quite easy to understand and explain. Overall, the nurses stated that different visitors have different preferences. Some of them want to see the data and some of them not.

Icons were evaluated as the clear and simple way to communicate with the visitors. The text information in form of the statement “Clinicians are on their way” was recognised as a positive aspect of the monitor in the emergency status. On the contrary, the text, in the stable status, “Patient is stable” evoked a strong disagreement. The fragile status of a patient in ICU cannot be described as stable even when the body vital functions are inside its limits. Based on the clinicians' point of view 6 displays were chosen and improved.

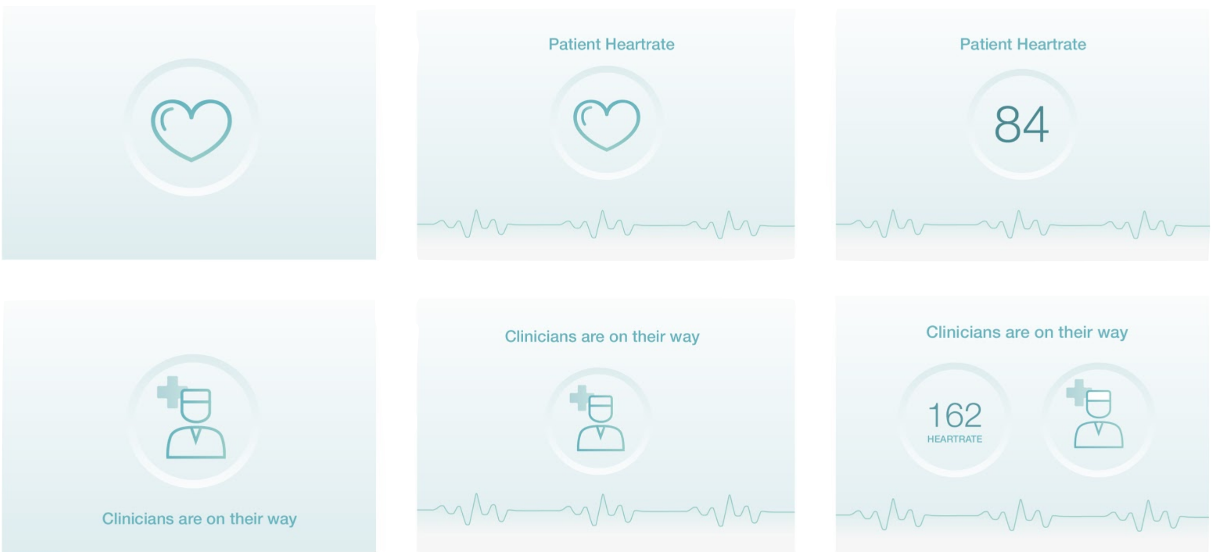

Figure 13. Improved displays

There are still definitely some uncertainties that are hard to determine. What do the visitors want to see? When is there too much or too little information? Would this be different for different situations? Therefore, a research was conducted surrounding these questions.

The research question is stated as: “How can a display both inform and calm a visitor in both a stable situation or when something is happening to the patient?”

To answer the question, it is divided into two sub-questions: “How can a display both inform and clam a visitor in the stable situation?” and “How can a display both inform and calm a visitor when something is happening to the patient?”

Research: Product Experience Measurement

In Erasmus Medical Center, visiting hours are from 11:00 am to 09:00 pm. Examinations and treatment sometimes have to take place during visiting hours and visitors are required to leave the patient room. There are 2 patient monitors, one is in the nurse box where she can see all the data and hear alarms, and the second one is in the patient box.

Family visiting is nearly a daily occurrence in critical care units, yet little is known about the visitors' needs and preferences. Therefore, along with the concept of a visitor mode, the research question is formulated. The research setup is based on the context and focused on how to calm and inform visitors at the same time. We aim to do this by changing displays of the monitor in a patient box. More specifically, with the visitor mode. The visitor mode is the scale of the study and is separated from clinician mode. The visitor mode shows filtered information to visitors.

This research covers visitors’ preference of display content in both stable status (Status 1) and the status where something is happening to the patient or the regular procedure is conducted (Status 2). These are done with both the qualitative and quantitative research method. Insights are gathered and collected for further design. This investigation explores the preferable content of the monitor display and the effect of it on the visitors in the critical care setting.

Method

To test the expected results stated in the introduction, a pilot study was done by recruiting 4 random participants. The study included a questionnaire and the "think out loud" protocol. In order to gain further insights, the participants were questioned afterwards. Based on the result of the pilot study the following method was rewritten.

Participants. A population of 12 international people, consisting of males and females, was gathered to participate in the study. All participants were of an age between 23 to 28 years old. They were students inexperienced with the ICU topic. They were recruited at the Delft University of Technology.

Stimuli. The research was conducted in the Care Lab of the Industrial Design Faculty to mimic a patient room environment. A description of the situation (Appendix F) was read out loud to the participants and a slideshow (Appendix E) of pictures from the hospital was shown. The slideshow included alarms sound. Participants received the written text with the description of the scenario (Appendix G). After gathering some personal data (age, gender) the displays were shown. Two examples of the content on the current ICU monitor and six proposals of the new ones. After each display participants were asked to fill in the questionnaire (Appendix B). The questionnaire was made using the semantic scale. Using a semantic scale in a questionnaire is a simple and efficient method which provides the gradual results for the evaluated characteristics. Participants were asked to think out loud during answering the questions to share the reasoning behind the answers. Afterwards, participants were questioned in order to gain further insights on answers that stood out.

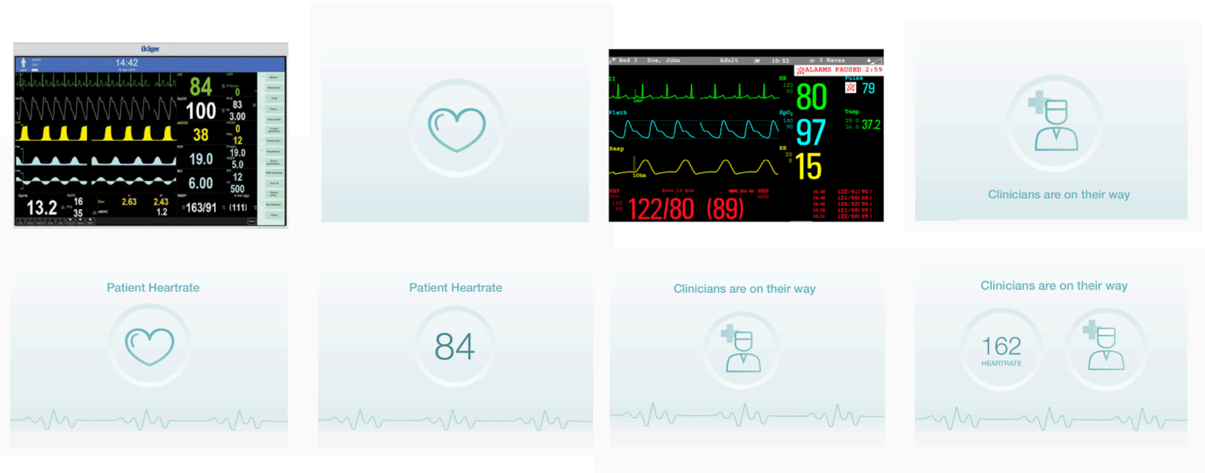

Figure 14. Presented monitors

Apparatus. Apparatus included a TV, displaying the slideshow with the context explanation and studied the content of ICU monitor in the form of pictures, a questionnaire sheet, an A4 sheet of paper, a ballpoint pen, a camera and a smartphone for voice recording.

Procedure. The study took place at the Care Lab which is in the Industrial Design Engineering facility of the Delft University of Technology. The participants took part individually in a study for 30 minutes. They were assigned to one of four groups. Each group had a different order in which the displays were shown, the number was noted on their answer sheet (Appendix B).

The moderator gave an introduction and explained the purpose of the research and how the research would be conducted. Participants were asked if the knowledge gained by the study could be used for further research and if their voice could be recorded.

After this, the moderator read the description of the ICU and the context presentation was shown. Then, a sheet of paper with the scenario and the participant's role as a visitor in an ICU was given to the participant so that they could empathize with it. After the context was explained, the participants were provided with a questionnaire and were asked if they had understood all the questions on it.

The studied material was divided into two parts: Status 1 and Status 2. Firstly, all four screens of one group were shown. Thereafter, the individual screens of the group were shown one by one. Each time the participants were asked to fill in the questionnaire and to use the think aloud protocol. After filling in the questionnaire for all displays, participants were asked to choose the favourite one and give an explanation. Next the same was done with the second group of displays.

Later, the participants were asked for suggestions and improvements to the monitor. Lastly, the participants were asked to give an explanation for some of their answers that sounded interesting to us.

In order to obtain trustworthy results, half of the participants started with the stable state and the other half started with the other situation. The order of the pictures within each display group was also varied.

Measures. All answers to questions were noted in a spreadsheet. Before starting, general data of the participants were written down. This included gender, age, nationality and if the participant agreed that pictures and voice recording were made during the study. Results gained by means of an interview and questionnaire (in English) gave both quantitative (rating from scale) and qualitative (think aloud protocol and interview) data. To process the quantitative results, the Friedman's two-way ANOVA method was used to test the assumptions for each question. To process the qualitative results, the information was organised by the presented display and by the question asked. The focus of qualitative information was on the reasoning behind the answers to the quantitative questions.

Results

Quantitative Results. In general, the answers were spread out on each question and each display. Therefore, no outliers were excluded. Figure 15 shows the answers. Each graph contains the answers to another question. Each colour is another monitor (as can be seen on the top). The graph shows the number of correspondents to an answer value (between 1 and 7). In general the higher the value, the more positive effect on the visitor, only question 4 low answers have a positive effect.

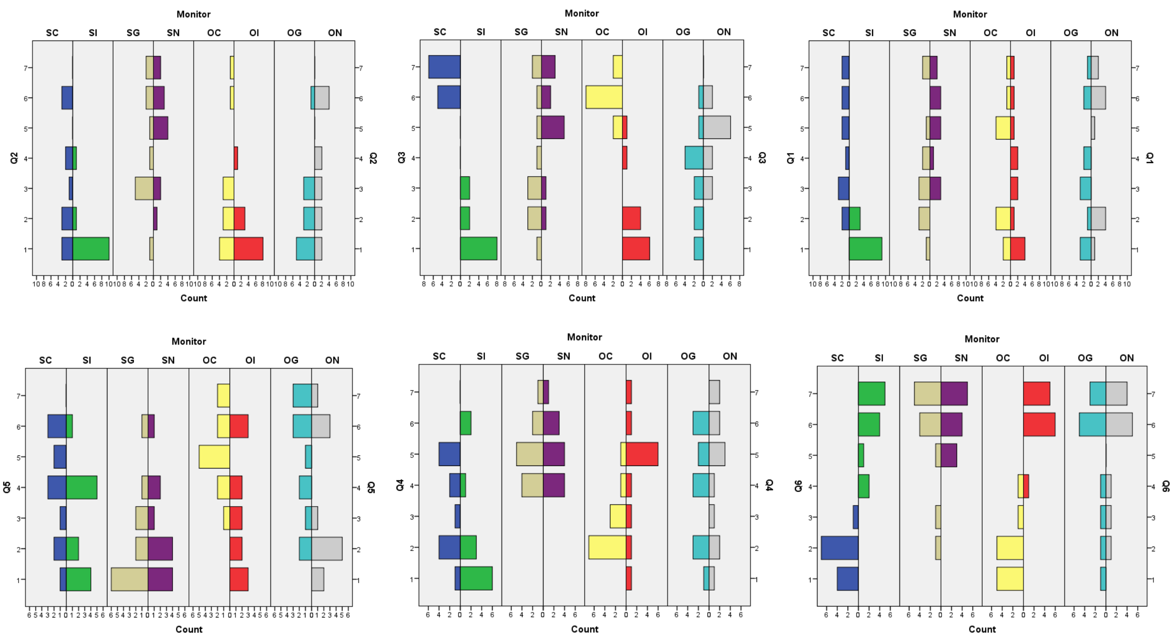

Figure 15. Answers in each graphs

Assumptions

Status 1:

Assumption 1: The stable screen with only a heart icon will have a lower mean rank than the other monitors in the perceived information by the visitor.

Assumption 2: Both new screens with graphs will have a higher mean rate than the current monitor based on the perceived understandability of the monitor.

Assumption 3: The current monitor will have the highest mean rank in the perceived reliability.
Assumption 4: The new monitors will have a higher mean rank than the current monitor based on the thankfulness the participants
Assumption 5: The current monitor will have a higher mean rank than the new monitors based on the perceived anxious of the participants.
Assumption 6: The monitor with the icon will have the highest mean rank based on the perceived peacefulness.

Status 2:
Assumption 7: The current monitor will have the lowest mean rank based on the perceived information.
Assumption 8: The mean rank of the monitor with only an icon will be the lowest regarding the understandability.
Assumption 9: The new monitor with graphs will have a higher mean rank regarding the reliability.
Assumption 10: The current monitor will have the lowest mean rank based on the perceived thankfulness.
Assumption 11: The current monitor will have the highest mean rank based on the perceived anxiousness.
Assumption 12: The monitor with only an icon will have the highest mean rank based on the perceived peacefulness.

Hypothesis
Status 1:
Question 1: H0 Every display has the same mean rank based on the perceived Information given.
Question 2: H0 Every display has the same mean rank based on the perceived understandability.
Question 3: H0 Every display has the same mean rank based on the perceived reliability.
Question 4: H0 Every display has the same mean rank based on the perceived thankfulness. Question 5: H0 Every display has the same mean rank based on the perceived anxiety.
Question 6: H0 Every display has the same mean rank based on the perceived peacefulness.

Status 2:
Question 7: H0 Every display has the same mean rank based on the perceived Information given.
Question 8: H0 Every display has the same mean rank based on the perceived understandability.
Question 9: H0 Every display has the same mean rank based on the perceived reliability.
Question 10: H0 Every display has the same mean rank based on the perceived thankfulness.
Question 11: H0 Every display has the same mean rank based on the perceived anxiety.
Question 12: H0 Every display has the same mean rank based on the perceived peacefulness.

Status 1:

For assumption one and two, there was a statistically significant difference between the screens in stable status as determined by Friedman's test ($\chi2(3) = 24.38$, $p <.05$) ($\chi2(3) = 15.46$, $p <.05$). For assumption 1, it’s proved to be true that the icon screen is significantly worse than the other 3 ($p<.05$) in terms of perceived information. The current and graph ones do have an obvious higher mean, but the mean rank lay close together. Assumption 2 is confirmed to be true since both of the screens with the graph($p<.05$) and screen with graph and number($p<.05$) have a higher mean rank than the icon, but they were not significantly higher than the current one. The one with number scores highest in mean rank and the icon one scores the lowest. The current, graph and number have a high std deviation.

For Assumption 3 The current monitor with a mean rank of 3.75 scores second in perceived reliability. The icon one is significantly lower than current($p<.05$). For assumption four: The current monitor with a mean rank of 2.42 scores third in perceived thankfulness. Once again Icon is significantly lower than graph($p<.05$) and number($p<.05$). The graph and number one do have higher means and mean ranks (3 against 2.4) than the current one but basically the same between them.

Four assumptions 5, null hypothesis was accepted. There was no significant difference between displays($\chi2(3) = 3.09$, $p = .378$), every display has the same mean rank based on the perceived anxiety. The current one is higher, but not that much higher. Difference between graph and current is highest. It goes, current, icon, number, graph. For assumption 6, the monitor with the icon with a mean rank of 2.88 scores third on the perceived peacefulness. There is a significant difference between displays($\chi2(3) = 23.02$, $p < .05$), the current one is significantly lower than the new displays ($p<.05$).

Status 2:
Assumption 8 is proved to be true since The mean rank of the monitor with only an icon(1.75) scores lowest in understandability. The display with an icon is significantly less understandable than the display with a number($p<.05$). For assumption 9, the new monitor with graphs with a mean rank of 2.04 scores third in reliability. There was a statistically significant difference between the displays determined by Friedman test ($\chi2(3) = 28.98$, $p < .05$). The current one scores first on mean rank(3.78) which is significantly more reliable than icon(p<,05) and graph($p<.05$). For assumption 12, the monitor with only an icon had the highest mean rank (3.29) based on the perceived peacefulness. The current one is significantly lower than the other ones($p<.05$).

For Assumption 7, 10 and 11, the null hypothesis was proved to be true. There was no statistically significant difference between the screens in emergency status as determined by Friedman test ($\chi2(3) = 4.25$, $p = .246$) ($\chi2(3) = 6.80$, $p = .078$) ($\chi2(3) = 24.38$, $p < .05$) in terms of perceived information, thankfulness and anxiousness. New display with number scores highest in mean rank on perceived information(3.00) and thankfulness(2.96). It also scores lowest(2,12) on perceived anxiety. The one with icon scores lowest on perceived information(mean rank= 2.08). The current display scores lowest on thankfulness(mean rank= 1.83) and second on perceived anxiety(mean rank= 2.15). All of the displays have a really high deviation. that is the reason none are significant. The full outcome of the test can be found in Appendix K.

As a part of the interview, participants were asked to choose one favourite display for Status 1 and Status 2 however not all of them were able to make the decision. The rank of participants favourite display within each group is shown in Figure 16. Participants prefer an icon with the number and a graph displays in both of the image groups. Although this similarity between the groups the other positions in the ranking were varied.

STATUS 1 (STABLE)		STATUS 2 (EMERGENCY)	
Icon + Number + Graph	7	Icon + Number + Graph	7
Icon + Graph	2	Icon	2
Current	1	Icon + Graph	2
Icon	0	Current	0

Figure 16. Favourite display

Qualitative Results. The conclusion seen in the quantitative data can also be seen in the qualitative data. Opinions were spread out and differ from people to people and from monitor to monitor. Nevertheless, the answers of the participants gave insight in general guidelines for the screen design. Several participants mentioned that they had felt informed and uninformed at the same time by the current monitor. The numbers and graphs gave an impression that communicable information was given even though they did not understand it. Five participants mentioned that they had tried to read the patient status themselves based on the used colours (green-good, red-emergency) and the patterns of the graphs (regular, irregular). Overall, participants felt anxious that the information is not readable and understandable for them.

The understandability is improved with the new screens. However, many suggestions for improvements were given. The minority of the participants missed the other values and therefore a more overall image of the patient status. Others missed a reference value, which value would be normal, or desirable at the moment. In the stable state, the majority of the participants preferred to receive more information and numbers whilst during the other situations more textual information was desired. For instance, what is happening, why is the nurse coming?

This contradiction between feelings, like informed and uninformed at the same time, reoccurs multiple times. Participants were thankful for all the information but also anxious because they don't understand it. However, with no information at all the participants answered feeling anxious as well. Other insights:

- The old familiar monitor screen was valued as reliable because it looks professional and typical (many graphs and numbers). The participants mentioned that the new screens were less reliable due to the small amount of information and simplicity of the layout.
- They felt thankful by new displays because of the feeling that the information was presented so that they could understand it and for emergency status because they knew that clinicians are coming.
- The peaceful look evoked by a cleanness of the presented content and the light blue-green colour of the display.

Overall the new displays were described as more friendly by a majority of the participants.

Discussion

The research provided insights into the diversity of the participants' opinion and the reasoning behind them, instead of generating a solid conclusion. As earlier shown in Figure 15 of the results, the answers are spread out. There was rarely a peak on the mean. However, it can be seen that the new monitor screens receive a more positive response, with the exception of the icon in the stable state. The new monitors are recognised as more peaceful, as can be seen in the sixth question. According to the results received from the first two questions, the current monitors' displays score moderately in terms of informing visitors. However, during the interview participants stated that although they felt informed with a lot of information, they did not understand the information. This means that the feeling of being informed is not equal to the actually received information. The new monitor which showed numbers scored a high value in these two question in the Status 1 (stable). Thus it proved that replacing the full information with limited ones, which are easier to understand, could also adequately inform visitors.

The reliability differs between the various displays. As can be seen, the participants read the current, known monitors as reliable. This could be due to the fact that that they are familiar with the appearance of the current monitor and relate to it as the exemplary. Out of the new displays, the one with numbers score higher on this question, but still not as high as the current ones. By adjusting the appearance of the illustration by adding more medical feelings such as professional looking graph and numbers may turn the displays more reliable.

The majority of participants have a preference for the displays that included an icon, number and a graph. They thought they are well informed by it and it is much easier to understand the patient status compared with current displays. The observation points out that the way the information is presented can increase the feeling of the being informed even though the medical knowledge and level of understanding the values didn't increase. It could be recognised as the guideline for the final display. It could also be a recommendation for a transition between the current display and a future one since the visitors' perception of a patient monitor hasn't changed as of yet.

The majority of the participants like the colour in the new displays and thought they are calm and peaceful. However, the minority of the participants suggested changing the colour during emergency status to reduce confusion. On the other hand, it could result in a higher restlessness of the monitor and the use of for example a red colour could increase the anxiety. This has yet to be investigated.

Conclusions

The results of the user research provided a guideline about what can be changed in the visitor mode of the monitor display. Generally, the new display with text, value and graph performed well in terms of informing and calming visitors. Showing only one understandable parameter with number and graph instead of showing the full data makes the monitor much easier to understand and reduces the overwhelming feeling. Explaining the current situation with text gives a clear indication of patient status and essential medical procedure. This gives the message that the situation is under control.

Light and delightful colour gives the display a peaceful look and make it more calmful. However, the colour used for Status 2 which can be an emergency situation should be more carefully chosen. Using a neutral colour which is different from the stable status can clearly indicate that the situation is changing and avoid confusion. Another drawback of the new display is that reducing the shown parameters and giving the display a peaceful look can make it less reliable than current ones for visitors because people expect the medical equipment to have a technical look. In order to enhance the reliability, the display should add more medical elements inherited from the current displays.

Based on these conclusions, improvements are made for the new displays. The final design manages to keep the professional feeling of the medical device while gives the visitors clear information without causing anxiety at the same time. The displays will be combined with monitor design and software system and are ready for final prototyping.

Figure 17. Final displays' design

Future Suggestions

From this research several design suggestions for the monitor display were derived, which are presented in a Figure 18.

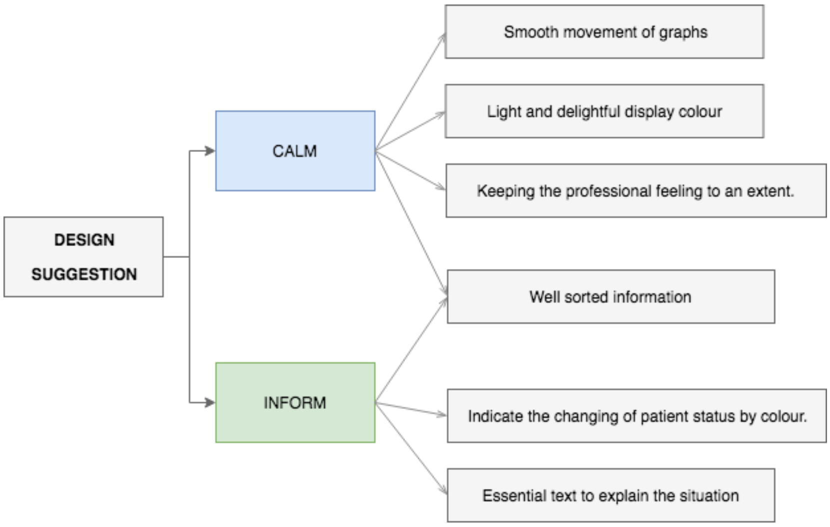

Figure 18. Design Suggestions

There seems to be a fine line between too little and too much information. Furthermore, this line shifts. It shifts not only from person to person but also from situation to situation. Due to the complex nature of the problem the additional research is required. To obtain more reliable results a larger number of participants is recommended for a further research. Furthermore, the participants should vary, with and without the experience as an ICU visitor, and come from diverse education levels. Moreover, there was a change in opinion observed during the test. They went from being informed to uninformed with certain amounts of information in the process of answering the questionnaire. Therefore we recommend extending the duration of the study. It will enable the participants to accustom to the new displays and analyse if, with time, answers are changing. Non-negligible is also the context of the study. The used Care Lab partly mimics the patient box but doesn't depict the ICU hostile environment which can affect the results.

Improvement

The finalised screens were presented to industrial experts who are in this field for decades. They quickly thought it is a radical change in the interface design from the existing design. It was also observed that the interface is too bright as there is a lot of white space. Taking this feedback for being very different bright, the interface is redesigned to darker screens bringing it little closer to the existing interface.

Figure 19. Improved displays' design

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Appendix A / Studied materials

8 displays content presented into two groups:

Group 1, Status 1:

0. Combination of 4 stable status displays
1. Current display
2. New display with static icon/illustration
3. New display with static icon/illustration and heart rate graph
4. New display with heart rate graph and its value

Group 2, Status 2:

0. Combination of 4 emergency status displays
5. Current display
6. New display with static icon/illustration and text
7. New display with static icon/illustration and heart rate graph
8. New display with heart rate graph, its value and text

Effects of Lighting conditions inside hospital ICU on patient recovery and rest

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Effects of Lighting conditions inside hospital ICU on patient recovery and rest

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Introduction

Patients within the ICU often have a lack of deep sleep, or REM sleep, as stated in Weinhouse, G's Bench-to-bedside review from 2009. Which can be caused by different reasons, such as the noise, lighting conditions or internal factors such as stress and pain. (Miller et al. 1976, Swada et al. 1996, Ersser et al. 1999, Raymond et al. 2001). Since plenty of research has been done about the influence of noise and how to reduce this, this paper focuses on the influence of light on a patient's rest in the ICU. The results give insight into how to reduce the patients' disturbance during their time in the ICU.

"Although patients may appear to sleep in a hospital, it may not be refreshing or restorative. Therefore, poor sleep can have serious detrimental effects on health and recovery from illness" (Raymond et al. 2001). An improvement in the lighting conditions would, therefore, be desirable.
In Erasmus Medical Center, lighting conditions in the ICU are regulated centrally and change over time to simulate a correct day and night rhythm. Which is done in the hope that the patient still has a sense of time. Light is an important environmental factor in the regulation of the normal circadian rhythm (as said by Teus van Dam, head technical ICU department of the Erasmus MC on 19th of March 2018 during an interview).

"Current nursing research has given the topic of lighting minimal study. Lighting in patients' rooms is easily controlled by the bedside nurse simply flipping a switch. The potential effect that light has on patients' health and positive outcomes could make this simple act one of great importance." (Dune, 2010)

However, this cycle of day and night doesn’t result in a full, dark, night since the clinicians have to check the patients well being regularly. Furthermore, even when the patient is alone in the patient box the room is still illuminated by several monitors and other equipment that surrounds them.

This research covers the current lighting conditions in the ICU the preferred lighting conditions during sleep and the difference between those in order to develop a vitals signal monitor that better suits the sleeping needs of the patient. The different lighting conditions are measured in multiple ICUs in multiple hospitals in the Netherlands.

Research question
How can we minimize the patients rest disruption regarding the lighting from the monitor inside ICU?

Method
The illuminance of different ICUs during day and night is measured using a LUX meter (model EXTECH HD450).

The measurements are taken at two specific locations inside different patient boxes:

- At the patient's headrest (ideally without the patient)
- Right in front of a working monitor

The measurements incorporate several different lighting conditions:

- During the day and night with all the machines off
- During the day and night with all the machines on
- During the day and night with the machines on and lights on

The night lighting conditions are simulated by closing the blinds and close the door of the patient box since visitors are not allowed inside the ICU during the night. The lighting conditions inside the several personal rooms are also measured during the morning and night aside from the ICU lighting measurements. This is due to the scarce availability of ICUs. These measurements will be used to compare the ICU lighting conditions with the subjects own preferred lighting conditions. These measurements will only be taken from the headrest because devices are preferred off during sleep. Finally, a literature study will be done to further support our findings.

Results

Hospital ICU measurements

Table 1: Daylight illuminance in Erasmus Medical Centre

EMC	Cold light		Warm light	
	Near Head	Near monitor	Near Head	Near monitor
Max	358	425	290	260
Min	279	410	245	241

Table 2 Nighttime illuminance in Erasmus Medical

EMC (blinds down)	Cold light		Warm light	
	Near Head	Near monitor	Near Head	Near monitor
Max	190	292	2.2	4.6
Min	174	290	1.7	4.4

Table 3: Illuminance regarding different monitor modes

EMC (blinds down)	Near monitor	
	Night mode	Day mode
Max	3.2	5.6
Min	3.2	5.4

Table 4: Light measurements in Wilhelmina Children's Hospital

WHC	Working light	
	Near Head	Near monitor
Max	58	72
Min	35	40

Sleep preference measurements

Table 5: Personal light preferences for sleeping

Person	Night min	Night max	Morning min	Morning max
1	0	0	0	0
2	0	0	9.2	19.6
3	0	0	38.2	107.4
4	0	0	34.2	351.15
5	0	0	4.7	79
6	0	0	20.7	174
7	0	0	3.6	68
8	0	0	38	128

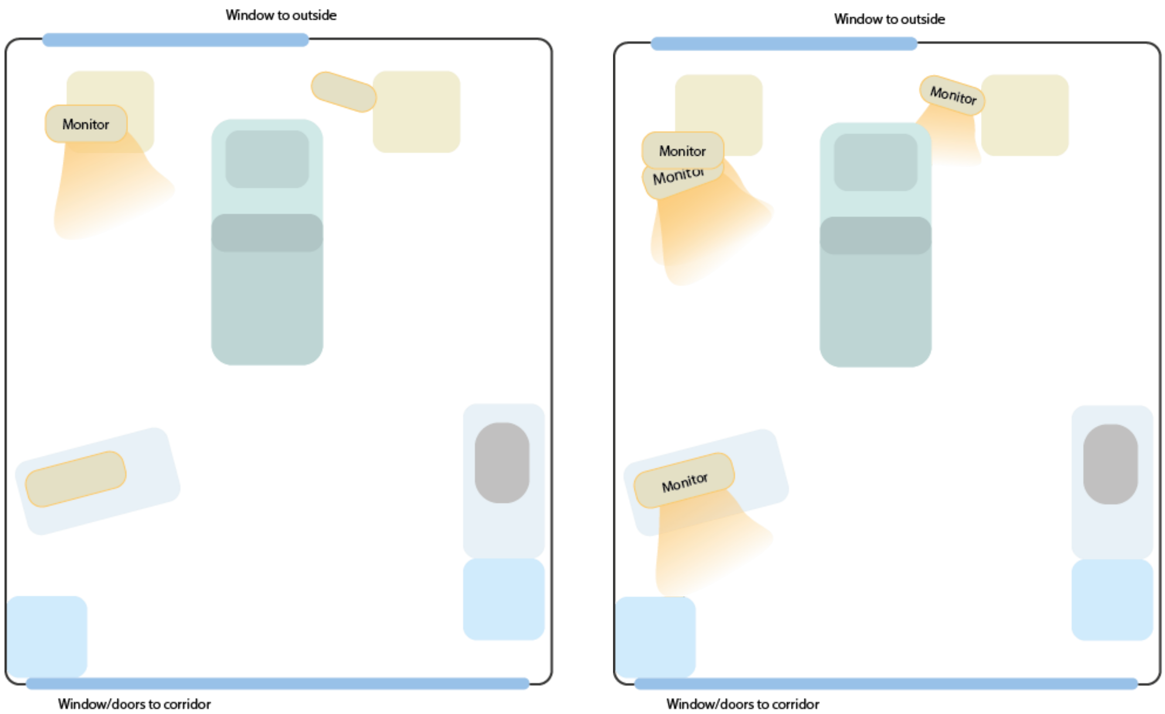
Discussion

Different guidelines for the lighting in the ICU exists. During the night the guidelines indicate that the night light should not exceed 6.5 FC (foot candles) for continuous use or 19 FC for short periods, respectively or 70 lux and 204.5 lux (Guidelines for intensive care unit design, 1995). Other than this, the regulations on lighting conditions focus mainly on the clinicians when dealing with light intensity.

When looking at the gathered results and information, the lighting conditions within the patient box appears to be well regulated, but lack key aspects of optimal patient

The ICU uses bright lamps to recreate the day and night cycle and the difference between day and night settings roughly translates to the measured preferred settings. Without any lights on, the ICU is dark (0-6 LUX) and with the lights on it is as bright as day (241-425 LUX). However, the ICU in Rotterdam showed the usage of a harsh cold (blue) light, which, if used during the night shift, could greatly disturb the patient's sleep. Besides the daylight lamps, the light emitted from the monitors contains blue light. Blue light helps the human body to regulate its night and day mode, using hormones. (It's Okay To Be Smart, 2015). Therefore, the blue light from the monitors interferes with the body's day and night cycle. Furthermore, the brightness of the screen compared to its environment brightness is higher. The brightness of a screen is correct when it is not illuminating its environment like a small lamp and thus has a LUX intensity roughly equivalent to its surrounding (Suzuki, 2000).

Also, within the ICU are many screens. As shown in the picture, the ICU monitor is close to the patients head (top), along with multiple other screens (bottom). According to the research done by Falbe in 2015, this has a negative effect on the patient's sleep.



Since the monitors are close to the patients, the blue light of monitors affects the patients' sleep. The study, therefore, confirms inadequate lighting conditions inside the ICU regarding the positioning of monitors. Reducing the blue lightwaves the monitor emits and, if necessary, replacing them with warm, red ones could be part of the solution (Czeisler, C. A, 2013). The results of the research show that the display brightness of the monitor is higher than its surroundings especially with the light off. And this has to be reduced to fit its environment properly.

The main problem of lighting inside the patient ICU arrizes during the night shift when the clinicians need to be inside the patient box. Clinicians need light in order to do their jobs but this results in irregular room illumination during the patients' sleep. Ideally, the patient's sleep needs to be uninterrupted but the use of current lighting would be disturbing.

Compared to the current values measured the night condition 0 lux is comparable and the warm light condition which would be used when a nurse comes in and takes care of a patient. The working light condition has an illuminance of 58 lux and therefore is still right according to the guidelines. Compared to the bedroom measurements, the conditions are similar to preferred night and morning conditions.

Recommendations

Many factors influence the lighting conditions inside an ICU. The ICU is not only an environment where a patient requires lots of rest but also one where focus and concentration are expected from the clinicians. An overall ideal lighting condition is therefore not easily stated. However, it is possible to change certain parts within the ICU to make it better suited for the patient.

A recommended lighting setup would contain local lighting for the clinicians night shift to ensure both their own visibility/focus/concentration and the patients' rest. This can be partly achieved using a screen that senses the light intensity itself and regulates it accordingly. This is already done in most telephone screens and thus seems to be an easy to implement option.

Furthermore, the screens and room lighting should have minimal blue lighting during the night. During the day, however, the blue light helps the patients give a sense of daytime.

Research improvements

During the research, different possible lighting conditions were measured. However, it was not measured how those different lighting conditions were used during an actual night shift. Which would give more accurate insight into the lighting conditions during a patient's night in the ICU.
Furthermore, we were limited to measuring in two different ICUs. To get more global results the measurements should have been done in more ICUs at a larger scale. This was difficult to do due to the critical situations of the patients and hospital regulations.

Therefore, this research serves as a start for a more in-depth research on the lighting conditions in the ICU and the solutions that are viable within the ICU environment.

When looking at the result afterwards, it is concluded that the measured values were inconsistent with recommendations on Lux values in different environments. like drawing (1000 in comparison with the 350 of the current daylight condition). Therefore, it seems like the measurements taken are not in comparison with the "actual values". However, we were able to compare the different measurements to each other since we used the same conditions throughout the research.

Further research can be done about how the nurses currently regulate the lighting during the night. What percentage of the time the lights are actually turned off. Since the results show that ideal lighting conditions can be achieved in the ICU, this is the part where disturbance could be lowered. With that research, more precise solutions can be found on how to reach ideal lighting conditions during the night without interrupting the nurses work, or giving them extra tasks and responsibilities.

Conclusion

The light of the ICU, in general, should be reduced to a maximum illuminance of 70 lux, as the guidelines suggest and lower whenever possible. Within the current ICU, this is possible to achieve when the lights are turned off. The monitor itself should be designed so that it turns off when not in use, and thus not disrupt the patients' sleep, or at least be dimmed to match the brightness of the environment, which would also be optimal for the nurses . The blue light waves should be suppressed and replaced by warm light during the night to keep the body from perceiving it as day.

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