Designing for the parent-to-infant bonding experience

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Sibrecht Bouwstra

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Designing for the Parent-to-Infant Bonding Experience

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prof.dr.ir. L.M.G. Feijs
en
prof.dr. S. Bambang Oetomo

Copromotor:
dr. W. Chen

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Sibrecht Bouwstra, September 2013

Contents

List of Figures

List of Figures

List of Tables

Abbreviations

ACM - Accelerometer
BPD - Business process design
BPM - Beats per minute
BR - Breathing rate
CFM - Cerebral function monitor
DC - Direct current
DfWB - Design for well-being
DTEM - Diversity textile electrode measurement
ECG - Electrocadiogram
EE - Electrical engineering
EEG - electroencephalogram
ER - Emergency room
FDA - Food and drug administration
FMP - Final master project
FSM - Finite State Machine
HF - High frequency
HR - Heart rate
IBE - Instantaneous bonding experience
ID - Industrial design
IOP - Innovatiegerichte onderzoeksprogrammas
IPCR - Integrale productcreatie en -realisatie
ISO - International organization for standardization
IV - Intravenous
IVF - In vitro fertilisation
KC - Kangaroo care, also called KMC - Kangaroo mother care
MMC - Máxima medical center
MRI - Magnetic resonance imaging
NICU - Neonatal intensive care unit
NIDCAP - Newborn individualized developmental care and assessment program
PCB - Printed circuit board
PWM - Pulse width modulation
QRS - The Q, R and S peaks in the ECG complex
RESP - Respiration
SIDS - Sudden infant death syndrome
SMA - Smart metal alloy
SMD - Surface mounted device

Abbreviations

SNR - Signal-to-noise ratio
SpO2 - Blood sugar saturation level
TU/e - Eindhoven University of Technology
VMK - Vrouw moeder kind
VOC - Vereniging voor ouders van couveuse kinderen

Chapter 1

Introduction

1.1 Background

1.1.1 The Neonatal Intensive Care Unit

When a baby is born prematurely or is critically ill, he or she is admitted to the Neonatal Intensive Care Unit (NICU) where Neonatologists and specialized NICU nurses provide round-the-clock medical care. Babies born before 37 weeks of pregnancy are considered as premature infants. However, when a pregnancy lasts less than 32 weeks of gestation, problems can occur that are related to the immaturity of the vital organs and these babies are considered to be extreme premature. Among the critically ill babies admitted to the NICU, can also be full term baby's that became severely ill during or immediately after birth. According to the Dutch law, newborns from 24 weeks of gestation on are actively treated in the hospital and have the potential to survive, due to today's available knowledge and technologies. Within the unit several levels of care are offered, namely in decreasing level of intensity: Intensive Neonatal Care, High Care and Medium Care. In the Netherlands five to seven percent of children is born prematurely. Among them one to two percent are born within 32 weeks of pregnancy. The number of prematurely born children has increased in the last years caused by the increasing number of twins (which is an effect of IVF and mothers with a higher age) [van de Griendt and Kamerbeek, 2006].

In the NICU the baby receives all necessary medical care to increase the chances of survival. The average developmental outcome of prematurely born children later in life is however a reason for concern. Our belief is that through improving the comfort of the baby (removing negative stimuli) and support of parent-infant bonding (offering positive stimuli) the quality of care in the NICU can be improved. We believe that an entire set of interventions supporting comfort and bonding will improve the developmental outcome of the baby later in life. Therefore, it is our mission to contribute in the form of product/system design to the set of interventions offered. In our research we investigated how to design for comfort and bonding through the process of hands-on design work on two interventions. The thesis is divided in two parts accordingly. The first part is about the design of a comfortable and attractive monitoring system and the second part is about designing a product specifically to support the parent-to-infant bonding experience. In the introduction we describe the living environment of the baby and theory behind the expected positive effect of stress reduction and parent-infant bonding on the developmental outcome of the baby.

1.1.2 The living environment of the baby

Tailored care is provided based on the baby's individual needs. A complete description of the pathologies that occur in the field of neonatal care, would be too extensive to discuss here. Instead, we describe care practices often provided in the NICU, starting with the equipment around the baby. Neonates are nursed in an incubator at their neutral temperature, or in an open bed with a heater above, to help them utilize all their available energy resources for growth, rather than preserving core temperature [van de Griendt and Kamerbeek, 2006]. A weighing scale is integrated into the incubator. On top of the incubator a photo therapy lamp can be found which is used in the treatment of jaundice. Photo therapy results in conversion of bilirubine into water soluble compounds that can be excreted by the body and hence reduces the amount of bilirubin in the blood. To protect the baby's eyes from the photo therapy, special eye coverage is worn. A blanket is often folded over the incubator, to shield the baby from external light sources. Usually the baby is waddled into a snuggle that restricts motion, calming the baby. Nurses often change the baby's position. When a baby is born before 32 weeks of pregnancy there is a chance that the lungs are underdeveloped which may lead to respiratory problems. Therefore, different modes for respiratory support are available to treat the babies appropriately. Another type of tube attached to the baby is the intravenous canula (IV). An IV is inserted in the arm, hand, feet or legs, for the intravenous administration of medication for example antibiotics and pain relief and the administration of nutrition and fluids. An arterial line is similar, although it is inserted in arteries instead of veins and is used to draw blood and monitor blood pressure and oxygen saturation [Center, nd]. Although the baby receives initially most of his or her nutritions through an IV, a naso gastirc tube is placed to provide enteral feeding in accremental amounts. The first period in the life of a prematurely born baby is characterized by uncertainties about the chances of survival and disturbances of the vital functions that the baby may develop. Depending on the clinical course, several additional tests can be ordered, for example x-ray, ultrasound, blood tests, urine tests or EEG/CFM. Problems with respiration, blood circulation, brain and gastro-intestinal tract can be expected. The baby's health is monitored continuously. The monitored vital signs include body temperature, electrocardiogram (ECG), respiration and blood oxygen saturation (SpO2). Temperature is measured with a thermistor integrated into an adhesive foam patch often placed on the baby's lower torso. Respiration and ECG are often measured through three electrodes applied to the skin. Two of the electrodes are placed the on chest, one at each side, and the third electrode below. To measure the oxygen saturation in the blood, a pulse oxymetry sensor is placed around the feet or palm. One side of the sensor emits light, which is read by the light dependent resistor on the other side. The difference between the emitted and the measured intensity of light represents the amount of oxygen in the blood. Additionally, the pulse can also be derived from this measurement. A neonate, especially a premature or dysmature (baby with a birth weight below the 10th percentile) is always at risk of developing a serious infection [van de Griendt and Kamerbeek, 2006] therefore the NICU environment has to be cleaned properly and all persons that are in contact with the baby have to wash their hands meticulously. Concluding, it can be stated that the baby in the NICU is surrounded with technology and requires round-the-clock care, all essential for survival.

Prof.dr. Sidarto Bambang Oetomo (Neonatologist at the Máxima Medical Center Veldhoven (MMC) and part time professor at Industrial Design Eindhoven University of Technology (TU/e), Eindhoven wrote in 2008 in his inauguration speech about his vision to improve the care for prematurely born babies through stress reduction. The field of Neonatology is relatively young and has progressed much since the 1960s, with the result of increasing survival rates. Treatments for respiration problems have improved since the introduction of surfactant therapy and nitrogen monoxide inhalation therapy. For treatment of problems with circulation, such as vessels which won't close, medicines controlling the blood pressure have been a great addition to the spectrum of possible treatments. Much insights have been gained into the nutrition of premature infants improved preparations of parental alimentation have become available. And the advances in x-ray and magnetic resonance imaging (MRI) have improved the diagnostics based on imaging. All these developments in the previous decades have led to improved chances of survival for the extreme premature baby (gestational age below 32 weeks). In Figure 1.1 showing data from dr. Martin de Kleine [De Kleine et al., 2007] it can be clearly seen that the patient populations in 1993 and 2003 had a much lower mortality percentage in comparison to the year 1983. Although this fact can be highly appreciated there is also a drawback of this success. Namely, the number of neonates at risk for poor developmental outcome also increases [Perlman, 2001, Hack and Fanaroff, 1999, Chapieski and Evankovich, 1997]. Follow-up studies indicate that prematurely born infants show more developmental delay compared to their full-term peers. More than 50% show deficits in their further development, such as visual-motor integration problems, motor impairments, speech and language delay, behavioral, attention, and learning problems [Marlow et al., 2007]. Prof.dr. Sidarto Bambang Oetomo pointed out the need to improve the longterm outcome of prematurely born infants.

Medical conditions are potential contributing factors to the longterm outcome. These medical conditions include: chronic lung disease, apnea and bradycardia, transient thyroid dysfunction, jaundice and nutritional deficiencies. In addition, babies are exposed to the hectic environment of the NICU. The premature neonates with an immature central nervous system have to develop in an extra uterine environment, where they are directly exposed to negative stimuli from the outside world, which is in contrast with the natural environment of the womb. The NICU environment is filled with bright light (e.g. phototherapy), noise (alarms) and medical procedures (examination, giving medication or other treatments, nursing and cleaning). In the womb, the baby naturally won't be disturbed with sensors, needles, bright light or unsubdued noise. A redesign of the environment for the premature baby, in which the living environment provides little cause for stress, is believed to contribute

Figure 1.1: Survival rates

positively to the long term developmental outcome of the baby [Bambang Oetomo, 2008] [Chen et al., 2012].

One of the causes of discomfort is the monitoring system. The health monitoring is crucial for early detection of medical problems (e.g. apnea, arrhythmias and hypoxemia) and potential complications (e.g. convulsions). Medical actions based on timely detection increases survival rate and result in a better developmental outcome [Costeloe et al., 2000]. The need for monitoring is apparent. However, the downside of the continuous monitoring is that vital signs are recorded with numerous wired patches on the fragile skin, which is uncomfortable for the baby and additionally unpleasant for the parents to see and impractical during interaction. The main cause for discomfort of the baby by the monitoring system is the painful replacement of the patches. An extreme prematurely born baby has a thin skin, which can damage when a patch is removed. Skin irritation and allergic contact dermatitis have been reported as well [Avenel-Audran et al., 2003]. Additionally, the monitoring system restricts the baby's motions and it can be the cause for loud false alarms when a sensor is pulled accidentally. Until the 1990s doctors assumed that despite crying and motion as response to pain stimulation, new born don't perceive pain or don't remember this pain later on [Schechter et al., 1991]. Currently the belief is that an unborn baby can experience pain from the beginning of the final trimester of pregnancy on [Lee et al., 2005]. Therefore, an alternative for the sensor patches is desired. Indirectly the monitoring system is also the cause for a different type of discomfort. Namely, the monitoring technology being present in the foreground hampers the parent-infant interaction according to an inquiry with NICU nurses [Walker, 1998]. Figure 1.2 illustrates how in practice the wires and cables are connected while the child is being held by the parents. Kangaroo care (KC) is when the baby is transferred from the incubator to one of the parents in a chair to hold the baby skin-to-skin on the chest. Kangaroo care is a method in which exchange of touch, warmth, visuals, sounds and odor takes place. In the 1990s research has shown the beneficial effect of Kangaroo care on the physiology, feeding and growth of the infants. [Charpack et al., 2005].

Additionally, Kangaroo care stimulates the process of forming a bond between parents and infants and it can also be used as a strategy to minimize procedural pain [Johnston et al., 2003]. The disturbances caused by the monitoring system (interruption of sleep and lack of natural communication with parents), all interfere with the babies' normal growth and development [Als et al., 2003].

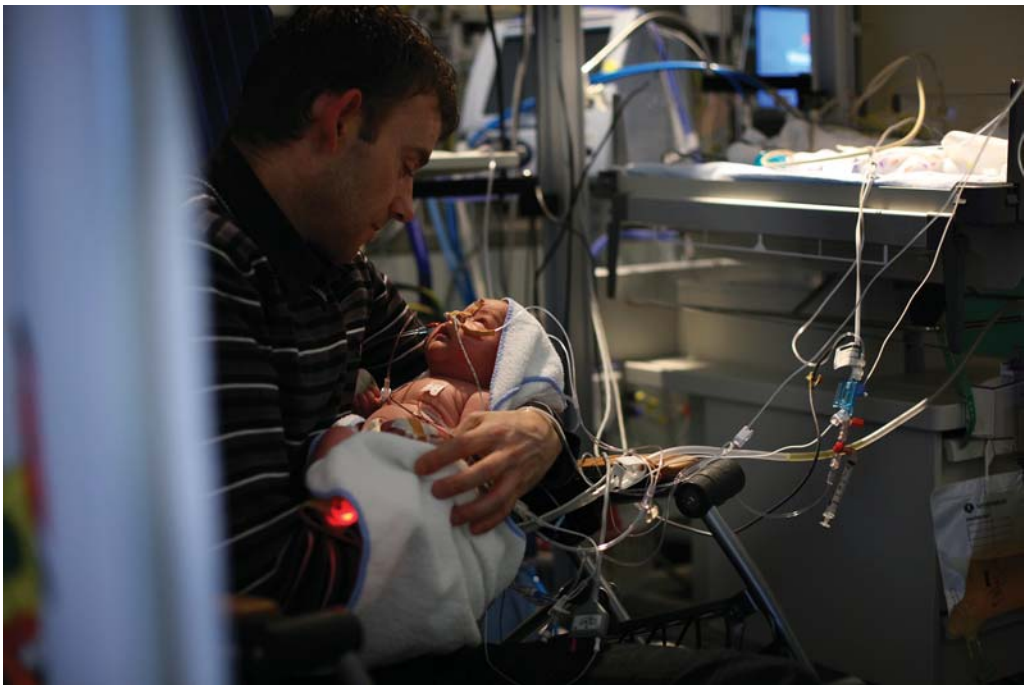


Figure 1.2: Child being held by parent (Photo by Jeroen Broekmans/Asap photography)

Prof.dr. Sidarto Bambang Oetomo envisioned a new monitoring system that contains comfortable sensors and wireless transmits the data. The non-invasive sensors reduce stress for the baby and the wireless transmission enables the parents to fully enjoy interaction with their baby without the physical restrictions of wires. Functionality, reliability and aesthetics are the keywords of the design. In part I of the thesis, the development process of the comfortable and attractive monitoring system called the Smart Jacket is described.

1.1.3 The role of bonding in development

In the design process of the Smart Jacket for usage during Kangaroo care, we became increasingly aware of the beneficial role that parent-infant bonding plays in the positive stimulation of the baby's development. Bonding between the parents and the newborn at the NICU has proven beneficial for the well-being of both. Babies have fewer pauses in breathing, more weight gain, more rapid progress in some areas of higher brain functioning and are discharged earlier [Klaus et al., 1996]:

> "Since newborns are wholly dependent on their mothers or fathers to meet all their physical and emotional needs, the strength and durability of the parental bonds may well determine whether or not the babies will develop optimally [Klaus et al., 1996]."

We explain the connections between bonding and development of the baby's brain though summarizing from the Dutch book 'Het babybrein' [van Elk and Hunnius, 2010] written by scientists from the Radboud University Nijmegen based on research from over the world. It describes the neurological development stages and shows how interaction with parents is involved in the baby's brain development.

Role of parents in positive stimulation

A baby's brain develops according to an interaction between nature and nurture, along a more or less fixed pattern. Most of the brain cells are created during the first four months of pregnancy [Bystron et al., 2006]. Most neurons are formed nearby the developing ventricles, after which the unripe cells migrate to the location where they will perform their tasks [Herschkowitz and Herschkowitz, 2003]. Halfway the pregnancy, most of the brain cells have reached their eventual location and the most important brain structures have taken shape. At that time the neurons only have short synapses, which are not connected to other neurons. Synapses are starting to form after the seventh week and thereby beginning to build the network connecting the brain cells. Once the neurons reach their location, they also start to connect to each other and can produce electrical signals and send them around. The networking proceeds throughout the pregnancy. Most of the synapses, about 80 percent, are formed after birth. For some areas, formation of synapses proceeds until the second year of life. In the phase where most synapses are created, after birth, it has been proven (on rats) that plentiful offering of stimuli leads to a larger brain with a heavier and thicker cerebral cortex. Even their braincells are larger on average and better connected to each other [Greenough et al., 1987]. For human babies a loving stimulating environment is crucial for the creation and growth of their brain. There is a rise and fall pattern [Johnson, 2005]: From the abundance of connections only the most active and useful synapses survive, while unused synapses disappear. Development and progress does not necessarily need to go hand in hand with increase. By having an abundance of connections (of which half won't survive) [Eliot, 1999] the brain can adjust well to the challenges in the environment. All stimuli a baby receives and experiences he undergoes, assure that certain connections are maintained and others are lost. Baby's can for example recognize more tones than adults [Werker and Tees, 2002]. While the baby is in the womb the baby already receives stimuli from the mother such as subdued voices, pounding heartbeat and taste of the umbilical fluid. After birth, parents offer stimuli such as talking, singing, facial expressions, comforting touch, warmth, body odor, massage and gestures. First the brain develops broadly, and later babies become experts in the matters that are relevant for their own environment. Concluding, a well developed bond between the parents and baby involving plentiful interaction and stimulation is essential for the baby's brain to develop and specialize.

Role of parents in stress reduction

Next to offering positive stimuli for brain development, a close parent-infant bond also offers plentiful of comforting presence. The parents namely play an important role in alleviation of stress that the baby can experience [van Elk and Hunnius, 2010]. When a baby repeatedly, for long periods is left by him/her self, the baby will experience chronic stress. Although stress is a natural response enabling alert and correct responses to potential dangerous situations, a long term exposure to a heightened concentration of stress hormones can have negative effects for several organs, including the brain. Research with rats has shown that long-term stress leads to a decrease in neurons in the hippocampus, a brain area involved in storing memories and learning new things [Sapolsky, 1996]. It is assumed that this applies to human babies as well. Loving care for a new born baby is good for the development of the baby in a twofold manner: it alleviates stress and positive stimulation for the brain to develop is provided. In the book 'Het babybrein' [van Elk and Hunnius, 2010] also the mechanism behind this is explained:

> "One of the most important stress systems in the human body is the hypothalamic-pituitary-adrenal axis (HPA-axis). In a stressful situation, for example in fear or pain, this system produces the stress hormone cortisol, which helps the body to release energy for response to danger. During the first months of life this system is accurately set. An important aspect of the precise setting, is connected with the speed in which a stress response is tempered. Based on animal experiments with rats, we know that motherly care practices play a role: If the mother animal often licks and caresses, it stimulates the production of cortisol receptors in the hippo campus and frontal cerebral cortex. If a large number of receptors have been built up, the result is that a stress response will be stopped sooner [Rutter, 1979]. This is how the circumstances early in life impact the capacity to adequately handle stress reactions in future."

Parent-infant bonding and premature birth

In practice and literature it is reported that the bonding process is disrupted in case of a premature birth followed by NICU admission. Several causes for disruption are reported, such as the separation of parent and child immediately after birth, seeing the fragile infant, and giving care tasks out of hand [Klaus et al., 1996]. Studies have shown that NICU admission disturbs the natural development of the interactions skills of parents and baby [Talmi and Harmon, 2003]. Because bonding is disrupted in case of premature birth we see the opportunity to design products, systems or services that support the process of bonding. We set the goal to design for the support of the bonding process between parents and infants during hospital admission to the NICU, leading to positive stimuli for the baby and stress reduction. This is a relatively new design area, because of the shift from the functional medical focus to designing from the perspective of the patient's view. The design context introduces questions about how to define parent-infant bonding, which factors impact the bonding process, what the design space is, which design strategies are suitable and how to measure the impact of a proposed intervention. Our approach to gaining knowledge about how to design for bonding is to learn from hands-on research in a case study. In part II of the thesis the case study of 'Design for bonding' is described.

1.2 Related work

Unobtrusive Neonatal Monitoring
At the start of the Smart Jacket project in February 2008, there had been few projects published about noninvasive neonatal monitoring. Here we shortly describe those projects followed by the most recent developments. Pictures of the designs are shown in Figure 1.3. The Georgia Institute of Technology developed a smart baby suit which measures the vital signs (temperature, heart rate and breathing) and thereby monitors the babies at risk for SIDS [Georgia, 1999]. The University of Gent and the K.U. Leuven [Catrysse et al., 2003] in collaboration developed a knitted belt with smart textiles demonstrating the application of comfortable monitoring using textiles intended for monitoring of children in a hospital environment. The belt was designed to measure ECG using two textile electrodes and respiration using a textile strain sensor. Later the K.U. Leuven published a baby suit for detection of Sudden Infant Death Syndrome (SIDS) complete with ECG sensors, wireless communication and inductive powering [Coosemans et al., 2006]. The University of Tübingen and ITV Denkendorf designed a sensory baby vest for comfortable and invisible monitoring of vital signs of babies, either for application in the NICU or at home [Horter et al., 2006]. The foreseen function is to prevent SIDS or other life-threatening situations for babies. The sensors were integrated into regular baby jumpsuit and can in principle measure the heart rate, skin temperature, respiration and amount of sweating. The European project called Palcom had a more specific focus on design for the NICU and came up with a new concept for an incubator including monitoring. In the NICU case study they conceptualized new technologies that allowed end-user composition and re-reconfigurability, resulting in design solutions [Rullo et al., 2006]. An autonomous dome shaped incubator was envisioned, including bio-sensors, access point, network, a pressure control mattress, web-cams and flexible assembly and end-user composition through an interface. As a follow-up, the Biosensor Belt was created in a collaboration between the Politecnico di Milano and University of Siena. The Biosensor Belt monitors the heart rate, breathing rate, body movements and temperature of new born baby with embedded sensors [Piccini et al., 2008]. The Biosensor Belt is meant to be complemented with a mattress [Marti, 2012].

These projects indicated the potential for neonatal monitoring with textile sensors and wireless communication and encouraged us to design the Smart Jacket specifically for the NICU user scenario. This meant that the jacket had to be suitable for application inside the incubator, as well as during Kangaroo care, and with user focus from the point of view of the parents and babies.

Since 2008 new projects about comfortable neonatal monitoring were released. In 2010 the E-Nemo project was launched. This project aims at stress reduction through the design of a smart monitoring system for in the NICU. The approach to stress reduction is twofold. (1) The monitoring system "has embedded sensors that can measure the critical physiological parameters of the infants in a comfortable, unobtrusive way" [E-Nemo, 2010]. (2) The support system offers active comforting through the positioning of the baby [E-Nemo et al., 2010] and maternal scent dispensation [Croes et al., 2012a]. At the Industrial Design department of the TU/e, Rik van Donselaar performed research about "how the contact pressure distribution can contribute to an assessment of comfort for neonatal monitoring in incubators on mattresses of different material configurations" [van Donselaar, 2011].The University of Rice in Houston, Texas has proposed a monitoring system called BabaLung Apnea Monitor [Alexander et al., 2012]. The system reminds the baby to breath through vibration in case an apnea event (20 seconds without breathing) is detected using a stretch breathing sensor. In case more than 5 seconds pass by without resumption of breathing, the nurses are alarmed through visual signaling. This monitoring system design distinguishes itself based on the feedback loop that acts on the monitoring data without interference of care providers. The Fraunhofer Institute for Reliability and Microintegration IZM in Berlin, Germany developed a baby suit with the aim to unravel the mystery of SIDS. Commercially available sensors for breathing monitoring are applied; their innovation lies in the flexible printed circuit board consisting of stretchable polyurethane [Seckel, nd]. At the Brigham Young University a monitoring sock is developed meant to reassure parents during the night. A pulse oximetry sensor is integrated into the sock, which is used to monitor both the heart rate and blood-oxygen levels. The sock can be expected to be commercially available soon [Brigham et al., 2012]. We conclude the list of comfortable monitoring projects with the design of the Exmobaby Baby Monitor garment by Exmovere Holdings, Inc [Exmobaby, 2010] of which the earliest online publication dates from 2010. The monitor is designed as a pajama which measures ECG, temperature and motion of a baby at home and has the purpose of reassuring first time parents. Innovative about the design is that parents are asked to label patterns in the data transmitted to a PC or mobile phone, which enables the system to predict future emotional and behavioral states. The project is at the time of writing in a beta stage in which prototype kits are being sold.

Products, systems and services for support of bonding

Several services for support of bonding are currently offered in the NICU. As we wrote earlier, Kangaroo care has a positive impact on parent-infant bonding. Kangaroo care was first introduced in Bogatá, Columbia at the Institutio Materno Infantil by dr. Edgar Rey in 1978 because of the lack of incubators, cross-infection and infants abandonment. He could not have foreseen the positive effects on the baby's physiology, as well as the psychological impact on the family. [Charpack et al., 2005]. Through promotion Kangaroo care is currently practiced practically everywhere in the world.

Family Centered Care is an approach to the care which recognizes the family as the main constant factor in the infant's life and therefore the family should be involved in working together with the health care staff right from the beginning on [Shelton and et al., 1987] [Kovacsa et al., 2006]. The family is approached as an integral part of the health care, also when the baby requires intensive care such as in the NICU. The core concepts are: respecting the background of the family and listen to their input to improve the care program and sharing information allowing parents to take part in decision making at the referenced level. The aimed effect is to empower parents in their role of parenting. Family Centered Care has inspired major changes in the NICU's architecture. A new NICU is most often built with the facilitation of Family Centered care in mind. Individual rooms are offered where families can stay over during the night. Attention is being paid to making the family feel more at home and preparing them for the time that the baby will be with them at home. Architects are exploring how to design NICUs and applying design methods such as co-design. For example, in [Holzhauer and Spriggs, 2012] three case studies are described. They reflect

Figure 1.3: Related neonatal monitoring projects

upon the lessons learned in reducing stress in the NICU environment. Including the stress for the medical staff, since the private rooms impact their work flow and overview greatly.

A different way to empower parents is by Video Interaction Guidance (VIG) [Eliens, 2005], which promotes sensitive and responsive parent-child interaction, through the focus on joyful contact. A specialized VIG social worker records interaction moments, such as bathing the baby. Later the social worker and parents together review the recorded movies, in which the parents' natural responses to their baby are pointed out by the social worker. This empowers the parents in their confidence and helps them to promote consistency in interaction. The experience of positive interaction moments supports building the parent-infant relationship.

Newborn Individualized Developmental Care and Assessment Program (NIDCAP) [Als, 2009] is a model that "strives to enhance relationships among the infants, the families and the professionals, who care for them". The idea is that the medical professional are guided by their detailed behavioral observations, in order to provide developmentally supportive care, adapted individually. "Integration of the NIDCAP approach and framework into newborn intensive care reduces the iatrogenic complications of newborn intensive care for infants, parents and staff alike, and in turn enhances the infants' competence, the parents; confidence, and the staff's role satisfaction".

Among the products (Figure 1.4) that (in)directly support bonding are the Kangaroo care chairs and clothing. The chairs are designed for comfort during breastfeeding. An example is the Febromed-breastfeeding chair certified for application in the NICU [Febromed, nd]. The sweaters are designed to position the baby on the chest without placing weight on the arms. The Benjamin Kangaroo Sweater is an example designed specifically for the NICU by Anne-Marie Louwerse which contains mirrors and straps for fixation of tubes [Louwerse, nd]. The bonding process is supported by enabling the parents to see their baby through the mirrors during KC and comfort is supported by positioning the baby and prevention of pulling tubes and wires.

A different approach to bringing parent and infant closer together, is to mediate the contact while the parents are away from the NICU. It is already possible to encounter webcams installed above the incubators in a NICU, which can be accessed online by the parents at home. A concept created by Misha Croes at ID TU/e, called FamilyArizing [Croes et al., 2012b] takes mediated contact even to the next level, by enabling the parents to comfort the baby while they are not physically present. By a webcam it is registered when the baby is experiencing stress, at this point a signal is sent to a necklace worn by the parent, triggering the pendant to move. If the parent 'comforts' the pendant by restricting it's motion, the baby's mattress simulates the comforting touch of the parent by mimicking the 'hug'.

Three other interesting designs that enable parents mediated contact are the following. The Lahav Lab for Neonatal research at Brigham and Woman's Hospital and Harvard Medical School in Boston has developed and tested a maternal voice player for NICU incubators [Panagiotidis and Lahav, 2010, Zimmerman et al., 2012]. The maternal vocalizations and biological sounds are recorded and played back using an mp3 player and micro audio speakers inside the incubator. Studies have shown maternal sound stimulation can improve growth velocity [Zimmerman et al., 2013] and short-term respiratory outcomes [Doheny et al., 2012] in preterm newborn. Although the focus lies on the development of the baby in this study, we also imagine how the system can support bonding by providing the parents with a means to contribute to the care and as a means of intimate interaction. The Mimo is a design by students in the TU/e's User System Interaction (USI) TU/e program [Versteegh et al., 2012] which records the heartbeat of the parent and transfers the maternal heartbeat with a small vibration motor in a pillow to the neonate when distressed as a non-pharmacological method of comforting. In the pilot test it was identified that the Mimo could also potentially support bonding. Another example from the TU/e Industrial Design department about medicated contact is the concept by Michiel Ruben Wolters in which an internet diary application is combined with an object, which allows parents to get to know their baby even when separated and contributing by letting the baby listen to their voice [Wolters, 2012].

We also encountered several incubator designs that address the impact on parent-infant bonding. Elo is a concept created in a master project at the University of Notre Dame [Carvalho, 2009] which is a crib specially designed for visual and physical access for parents to their prematurely born baby. The Jenny [Antonelli, 2008] is a similar concept, with the addition that it aims to create a division between the baby and the environment. The first child-, parent- and nurse-friendly incubator design was however the BabyBloom designed by Heleen Willemsen in 2005. It supports bonding by enabling parents and infant to be physically close. Even when the mother is in a hospital bed the incubator can be rolled over. The BabyBloom also looks friendly and takes the focus away from the technology around the baby. The product is certified according to the ISO standards [Willemsen, 2005].

Figure 1.4: Related neonatal bonding projects

We conclude that in the field of health care programs and architecture design many initiatives have been taken towards support of bonding and these projects are being realized in practice on a large scale. There are however only a limited number of product designs proposed and realized that support parent-infant bonding. The products this far support bonding in various (in)direct manners, such as: offering comfort, reducing stress, making the surroundings of the baby aesthetically inviting, strengthening the parental role and (bi-directional) communication while parents and infant are separated. Our aim is to design a product for support of bonding specifically and in the course of the design process gather knowledge about how to design for bonding. Lessons learned are reflected upon and meant to ease the process of future designs for bonding. For the future we envision that the designs created in the field are combined into a complete set of products that together with the programs and architecture form a NICU environment that supports bonding.

1.3 Objectives of the thesis

Both tracks of design for comfort and bonding are believed to positively contribute to the long-term developmental outcome of the child. We label the responsive interaction between parents and baby, either already within the womb as after birth, as positive stimulation. And impulses that are harsh for the baby and normally not experienced in the womb or after a term birth we label as negative stimulation. Thesis Part I describes our approach to improving comfortable monitoring reducing negative stimuli and Part II describes our efforts in design for bonding supporting positive stimuli.

10 year collaboration between TU/e and MMC

Design carrier 1:
The design of an unobtrusive vital signs monitoring system in the form of a jacket for application during Kangaroo care, which provides comfort for the premature baby and improves the approachability of the baby for the parents.

Research question:
How to design for comfortable neonatal monitoring?

The design for noninvasive monitoring of a premature baby in the NICU, belongs to the scope of the collaboration between the technical University and the hospital. The Industrial Design (ID) faculty of the Eindhoven University of Technology (TU/e) and the Máxima Medical Center (MMC) are collaborating on three tracks: prenatal, pediatrics and training simulation. In the pediatrics track prof.dr. Sidarto Bambang Oetomo is assigned as part time professor at the TU/e's Industrial Design department with the short term goal of improving comfort and with the eventual goal to improve the longterm outcome of prematurely born infants. The MMC and the faculty of Industrial Design believe that the creation of a more comfortable and calm environment can improve the long term development of the prematurely born infant and the design of the Smart Jacket is one of the products envisioned in a whole set of products meant to support comfort and bonding. In the thesis we share the knowledge that we gathered about how to design for comfort through designing a monitoring system. We describe the process and outcome, as well as reflections on the findings.

IOP IPCR Design for Well-being project

Design carrier 2:
A product, system of service that improves co-located bonding between parents and their premature baby admitted to the NICU.

Research question:
How to design for improved bonding between parents and prematurely born babies at the NICU?

Designing specifically for social connectedness between parents and prematurely born baby, belongs to the scope of the IOP IPCR project: 'Developing Transformative Design Strategies and tools to build and measure products and services for social Wellbeing', shortly called 'Design for Well-being' (DfWB). Within the IOP IPCR project the goal is to develop design strategies and tools to support product designers in designing radically new interactive products and services that aim to increase social well-being. These tools and methodologies are aimed to help the industry in making the right design choices when developing a new generation of products that are aimed to enhance social well-being. In the case study of the Máxima Medical Center the following parties collaborated: Industrial design and Industrial Engineering & Innovation Science (IE&IS) which are both TU/e departments and the Industrial Design department (IO) of Technical University Delft (TUD).

The case study about the process of designing products that support the parent-to-infant bonding is a challenging case because we are designing for the ill-defined goal 'parent-to-infant bonding'. It is unpredictable how a design will impact the complex bonding process and there is not yet an instrument that straightforwardly measures a product's impact. Additionally, the NICU environment is a context in which ethics have to be considered carefully when gathering design input or testing. We gathered knowledge about how to design for bonding through designing. We describe the actual designs and encountered design challenges, as well as design process meta-insights of the design process.

Part I

Designing a comfortable neonatal monitoring system

Chapter 2

Smart Jacket design for neonatal monitoring with wearable sensors

Published in [Bouwstra et al., 2009]

2.1 Introduction

Round-the-clock monitoring of vital signs of newborn babies allows taking medical actions based on timely detection. The signals are obtained with adhesive sensors on the fragile skin with individual wires running to external monitors. (Re)placement of the sensors and the large amount of tangling wires lead to discomfort, skin irritation, false alarms at accidental disconnection and interruption of sleep of neonates. Furthermore, parents may feel detached from their baby who is barely recognizable between all the medical equipment, wires and patches. Currently, stimulatory efforts by medical professionals are required to help parents overcome the technical hazards and engage in Kangaroo care. Therefore, the design of non-intrusive alternatives for monitoring of the vital signs is urgently needed.

Recent advances in sensor technologies and wireless communication technologies enabled the creation of a new generation of healthcare monitoring systems with wearable electronics and photonics [Yang, 2006] [Van Langenhove, 2007]. The miniaturization and elimination of wires offered new possibilities in creating comfortable and attractive designs of wearable monitor systems. Smart textiles have been integrated into a garment for ECG and respiration monitoring with wireless transmission [Catrysse et al., 2003] [Paradiso et al., 2005]. Reflectance pulse oximeters attached on the forehead [Mendelson et al., 2006] have been developed. Embedding optical fiber into textiles for patient health monitoring are developed as well [de Jonckheere et al., 2007].

The TU/e started a 10-year project in cooperation with the MMC for improving the healthcare of the pregnant woman and her child before, during and after delivery. The spear head of improving the healthcare of the neonates is to create a calm, natural and comfortable environment. One of the proposed carriers is a baby jacket or mattress, which has wearable sensors integrated for the monitoring of a neonate's vital body functions. So far, various techniques have been developed in isolation. In the collaboration between TU/e and MMC a multidisciplinary network of specialists in sensor technology, medical professionals and signal processing are brought together to and develop revolutionary neonatal monitoring solutions. The new approach can be foreseen to strongly improve comfort and reliability of neonatal monitoring systems, so as to improve the neonate's comfort and quality of life later on, to enhance the parent-child interaction and to alleviate workload of clinical professionals.

2.2 Design process and design context

We envisioned a wearable platform integrated with unobtrusive sensors to replace the currently used adhesive skin sensors for neonatal vital sign monitoring, that can be both be used inside the incubator as well as in the parents' hug during Kangaroo care [Als et al., 2003]. The first step towards the Smart Jacket is the design of a jacket that:

- contains the integration of conductive textiles for ECG monitoring,
- forms a platform for future research, in which wireless communication, power supply and sensors are developed,
- obtains a sense of trust by parents.

Methodologies from the field of Industrial Design are applied in the design process. Neonatal monitoring is a multi-disciplinary area which involves a unique integration of knowledge from medical science, industrial design, sensor technology, electrical engineering and psychology. The iterative process 2.1 began with an information search that included user involvement and gathering of information on unobtrusive ECG monitoring, intelligent textiles and baby clothing design. Requirements were derived from the information search, forming a base for brainstorm sessions which resulted in ideas about technological challenges, functionality issues within NICU and about aesthetics. The ideas were placed in a morphological diagram and combined to several initial concepts. Design choices were made through an iterative process in which technology and user tests provide valuable input for further development. The three aspects technology, user focus and design are strongly interwoven along the process and developed up to the same level of detail.

Based on the information search, the complete design of the Smart Jacket should meet the following requirements:

- support the vital signs monitoring functions
- be safe to use in the NICU environment
- be scalable to include other monitoring functions such as wireless communication and local signal processing

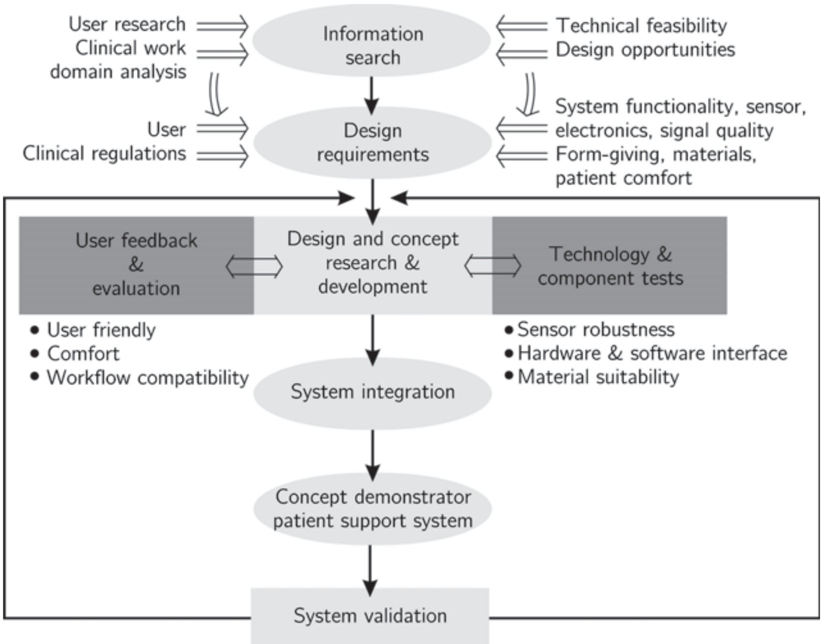


Figure 2.1: Design process model

- support continuous monitoring when the baby is inside the incubator or during Kangaroo care
- gain the feeling of trust by the parents and the medical staff through an aesthetically attractive design
- be non-intrusive and avoid disturbance of the baby and avoid causes of stress
- provide appropriate feedback for parents and hospital staff on whether the system's components are correctly functioning
- non-washable parts must be easy to remove
- look friendly, playful and familiar

2.3 First iteration of the Smart Jacket

A prototype jacket is shown in Figure 2.3. The first iteration is the result of smaller design cycles in which numerous explorations have been made of materials, colors and shape, see figure. 2.2. These designs have been discussed with NICU nurses, baby clothing designers and clinical physicians. Also these prototypes have been part of technical exploration tests conducted with adults as alternative subjects for gaining design insights. The result of the first iteration (Figure 2.3) is open at the front and is partially constructed of an open structure fabric with the purpose of revealing skin for skin-on-skin contact, phototherapy and medical observation. The jacket comes with a hat that contains eye-protection and offers room for the addition of other sensors. The aesthetics are designed to appear as regular baby clothing. The color combination of white and green with colorful happy animals is chosen because it is suitable for both genders and looks cheerful and clean. To assure comfort, care is taken to prevent thick seams and sharp edges, and cotton is chosen for its softness and breathing ability. Figure 2.4 shows a baby mannequin wearing the first version of prototype smart jacket in the Kangaroo care scenario. Furthermore, the dressing process is designed to avoid the stress of pulling the jacket over the head: (1) the baby is laid down on the open jacket, (2) the lower belt is closed, (3) the hat is pulled over, and (4) finally the chest straps are closed. See Figure 2.5.

For the sensors of ECG monitoring, we choose for textile electrodes because these are flexible, non-irritating, lightweight, thin and convenient to be integrated into the inside of the jacket. Two types of materials were selected based on their material properties as textile electrodes suitable for the jacket: silver coated textile electrodes by Shieldex and gold printed textile electrodes from TNO Science and Industry. The silver textile electrodes consists of a knitted structure of a nylon coated yarn with 99.9% silver metal. The nylon consists of 71% polyamide and 29% elastomeric fiber. The gold printed electrodes consist of a thin smooth fiber with a metal print developed by TNO in Eindhoven, the Netherlands.

Figure 2.6 displays the test patches with different versions of silver and gold textile electrodes and a blanket with large silver electrodes. Although in the future application of the jacket, it will contain a miniaturized amplifier with wireless communication, in this stage of development the electrodes are connected to carbon wires. The creation details of the test patches can be seen in Figure 2.7, which also applies to how the textile electrodes can be integrated into the jacket. Three layers of cotton are used, as shown in part (1). The different layers are needed for electrical isolation. On the middle layer, the circuit is sewn with Shieldex silver plated yarn, as shown in part (2). Part (3) shows that the electrode is sewn onto the first layer, stitching through the circuit on the middle layer. The electrode to monitor connection is achieved by carbon wires from regular disposable pre-wired gel electrodes. The ends of the carbon wires are stripped and sewn onto the circuit on the middle layer (see part 4). Finally, the third cotton layer for isolation is sewn to the others (part 5). The gold test patches are created in a similar way to the silver test patches, except that in future applications, the circuit and electrode can be printed in one piece.

In literature it has been reported that dry electrodes, which textile electrodes are, however offer reduced skin contact [Van Langenhove, 2007]. In order to obtain a reliable signal quality, the concept Diversity Textile Electrode Measurement (DTEM) was proposed: The neonate wears the baby jacket that contains six conductive patches that sense bio-potential signals at different positions to perform diversity measurements. The jacket contains 2 sets of the standard 3-electrode lead system: one anteriorly and one posteriorly. This lead system is based on the Einthoven triangle and its leads are constructed as following: derivation I = potential difference between left arm and right arm (LA RA), II = potential difference between left leg and right arm (LL RA) and III = potential difference between left leg and left arm (LL LA). Depending on the way the baby lies or is held, there should always be patches in close contact with the skin because of pressure. If one sensor would become loose from the skin, another sensor could provide a better signal. The system continuously measures which electrode in the jacket has superior contact and chooses the strongest lead for further processing. The concept offers a solution for skin contact, without jeopardizing

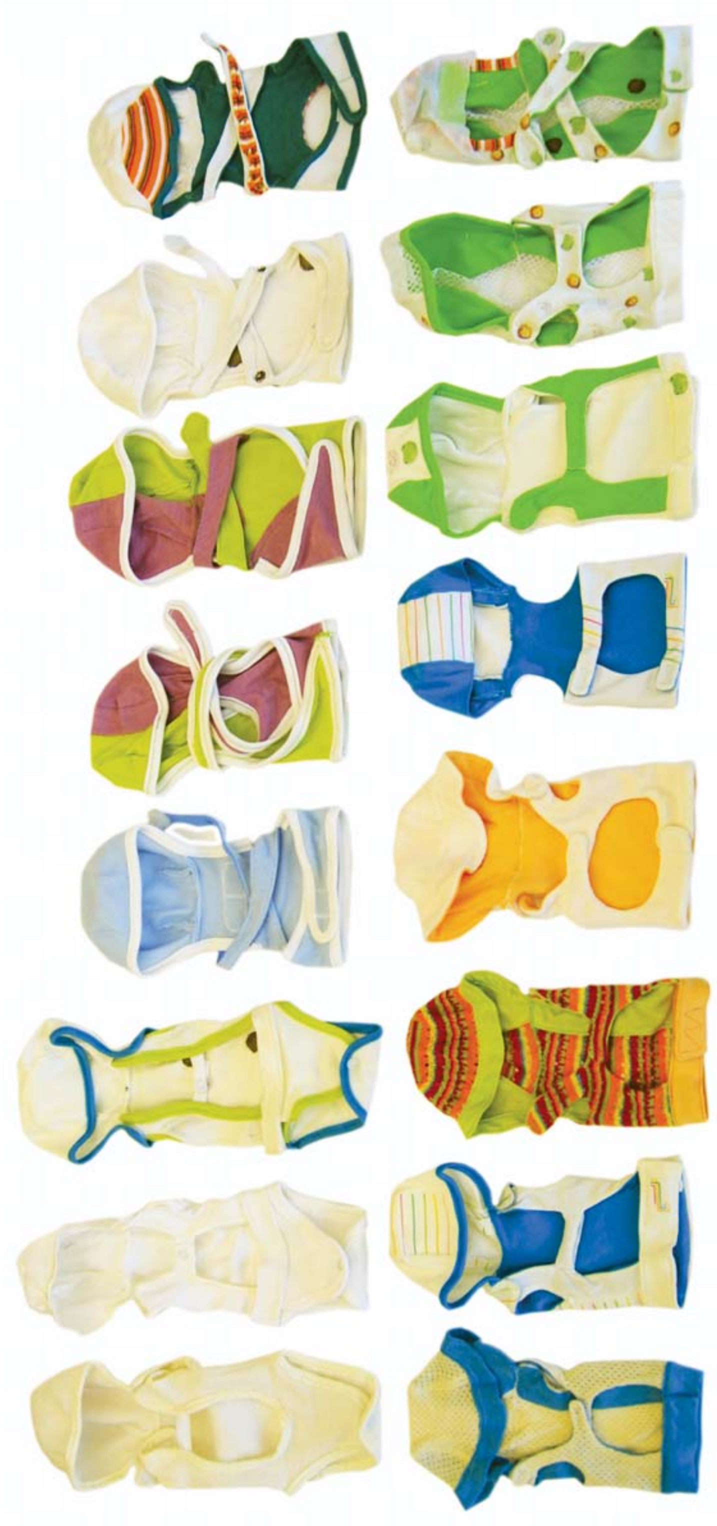


Figure 2.2: Iterative process of the jacket design

Figure 2.3: Prototype Smart Jacket

Figure 2.4: Kangaroo care scenario

Figure 2.5: Stress-less dressing process

Figure 2.6: Test patches and blanket

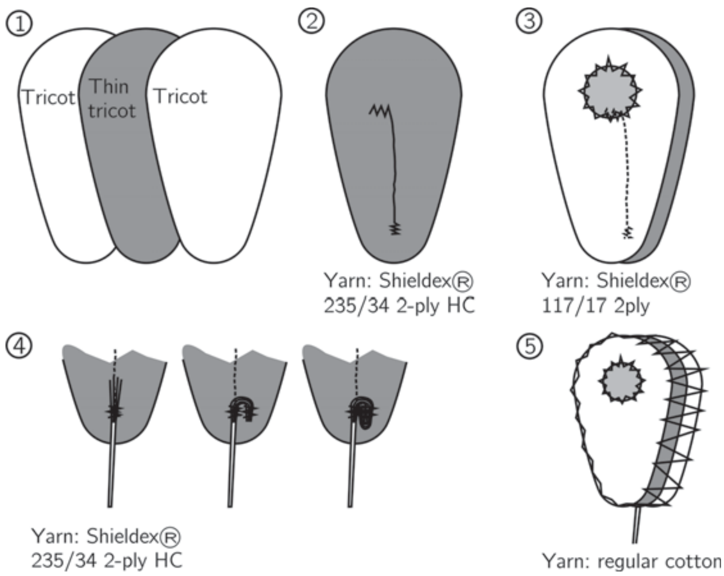


Figure 2.7: Construction of textile electrodes

comfort by tightness. It might also solve the problem of searching optimal electrode locations in the jacket, which varies individually.

2.4 Clinical tests

Several experiments of explorative nature were carried out with neonates in the NICU at MMC. The first test is a comparison of different types of electrode test patches, and the second on wearability of the jacket.

An analysis of risks was performed before applying the Smart Jacket prototypes in the NICU. Together with clinical physicists, hospital hygiene and infection expert and a neonatologist the safety of the monitoring system as well as the hygiene and allergy risks were analyzed. The most critical dimensions were: (1) leakage current which had to meet the CF class 1 standard, (2) hygiene and infection risks, for which the hospital protocol standards had to be met, which consisted of thermo disinfection washing at 60 degrees and cleaning plastics with alcohol and (3) allergic reactions, which was tested by evaluation of a subject's skin after wearing test samples for 48 hours. The prototype stood the CF class 1 and the allergy tests and was cleaned according to hospital hygiene standards.

2.4.1 Pilot study on the feasibility of ECG recording by the Smart Jacket

In this study the quality of the ECG signals obtained by textile electrodes varying in material and size and gel electrodes (3M 2282E) are compared in observations. With the consent of the parents, the textile electrode patches were tested with two subjects: one neonate of 30 weeks and 5 days and the other of 31 weeks and 6 days (gestational age), both admitted in the NICU at MMC (Figure 2.8). The medical ethical committee of the MMC decided that the protocol of the pilot study on the feasibility of the Smart Jacket did not require extensive evaluation and approval according to the Dutch law. The ECG was sensed by three electrodes of one type in regular configuration and the data was acquired with a GE Healthcare Solar 8000M, which is a certified monitoring system for neonatal monitoring. The unprocessed digital data of derivation II was obtained from a network and imported and filtered in MATLAB for the removal of undesired frequencies. We applied a notch, a 2-Hz Butterworth high pass and a 70-Hz Butterworth low pass filter to remove the 50-Hz and higher harmonics, base line wandering and high frequency noise, respectively. These settings were chosen for reviewing purposes of the data at the time. In paragraph Prototype, amplifier and software we discuss suitable filter settings in more detail.

We evaluated the quality of the ECG signals obtained by textile electrodes varying in material, size, and applied pressure, and qualitatively compared it to the golden standard of gel electrodes (3M 2282E). The signals were recorded in series. In two observations, we assessed whether (a) the signals were stable, (b) the QRS complex features could be distinguished, and (c) the signals could cope with movement artifacts. The QRS complex refers to the deflections in the tracing of an ECG, comprising the Q, R, and S waves, that corresponds to the depolarization of the ventricles.

Figure 2.9 summarizes the comparison of different electrodes, by a qualitative rating of the four criteria. It shows that the large silver textile electrodes of 80 mm x 60 mm offered a stable ECG signal with low noise under the condition that pressure was applied by the baby's weight (e.g., baby lied on the mattress with textile electrodes as shown in Figure 2.7). Small silver Balingen electrodes (diameter D = 16 mm) provided a less stable signal than the larger Balingen electrodes (D = 40 mm). During testing it was observed that the small silver electrodes (D = 16 mm) seemed to required a higher amount of pressure applied by finger tops in order to make proper skin contact. The silver electrodes are hypoallergenic and did not change properties considerably after a few washing cycles. The small gold printed electrodes obtained a stable ECG signal with low noise. A little pressure applied by hand was required for the electrode to establish initial contact. After letting go, the contact was maintained. The gold print textile electrodes are not hypoallergenic and lost conductivity after washing, due to corrosion of the metal layer beneath the gold. Therefore, the most promising textile electrodes for the smart jacket are (1) large (D =

40mm) silver plated textile electrodes, and (2) small (D = 16 mm) gold printed electrodes.

Figure 2.8: Test setup recording the ECG with textile electrode patches

Type of electrode	Stability (breathing movements)	QRS complex features	Skin contact	Stability (limb movements)
3M™ 2282E	●●●●●	●●●●●	●●●●●	●●●●●
Gold print D=16mm	●●●●	●●●●●	●●●●	●●●●
Medtex 80mm x 60mm in mattress with pressure of baby weight	●●●●	●●●●●	●●●●	●●●●
Medtex D=16mm	●	●●	●	●
Balingen D=40mm	●●●	●●●	●●●	●●●
Balingen D=16mm	●	●●●	●	●

Figure 2.9: Qualitative comparison textile electrodes

In these explorative recordings we observed that the material, size and pressure greatly influence the signal quality. Because in these recordings more than one of these particular conditions varied, further testing is required to conclude what the optimal electrode design is. Figure 2.10 shows the plots of the recorded measurements of gold printed electrodes and silver Medtex 80 mm x 60 mm electrodes in the mattress when the baby lied still. It shows that the QRS complex is clearly visible from the ECG obtained by both types of textile electrodes, which shows that under these conditions these designs are promising for the Smart Jacket.

The explorative clinical tests show ECG recordings with similar quality of ECG signals recorded with the state-of-the-art gel electrodes. It is found that due to the nature of conductive textiles, the quality of the ECG signal obtained with the textile electrodes cannot exceed that of the gel electrodes as the textiles are 'dry' electrodes with higher skin resistance and have a flexible and elastic structure that causes artifacts. However, since the monitor is used as an indicator of potential harmful events by acoustic alarming, for the screening of heart rhythm disturbances and ECG complex abnormalities and it is not the intention to replace with the present system the more accurate conventional standard ECG for diagnostic purposes, the first results are promising. Although movement artifacts and skin contact quality are the main challenges in ECG recording with textile electrodes, the specific context of neonatal monitoring offers opportunities to solve these problems. Mainly, the skin of the neonate is smooth, the baby makes little movement and is always lying down or being held, by which the baby's weight forms a potential source of pressure. Since we have seen that pressure improves the skin contact, our proposed solution for reliable monitoring lies in the field of signal processing; a smart system that selects the optimal signal from a large amount of sensors. For reliable and accurate signal quality, it is critical to develop dedicated signal processing such as context aware sensing methods and thereby reduce motion artifacts and improve the signal quality of the smart textiles.

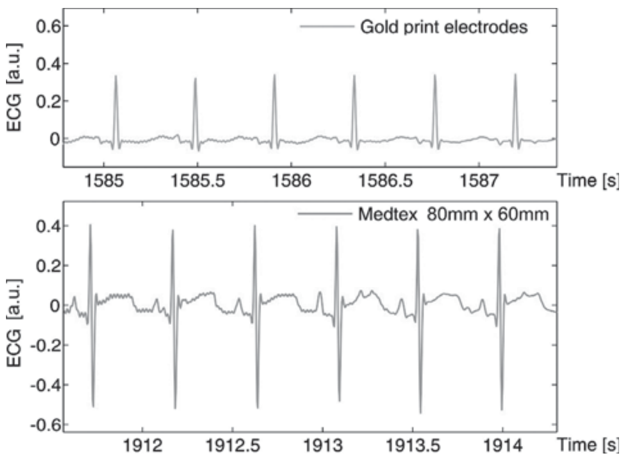


Figure 2.10: ECG's obtained with textile electrodes

2.4.2 Wearability

Apart from reliable technology, the success of the Smart Jacket largely depends on the wearable comfort of the jacket. Tightness is desirable for sensor contact, although it might be in conflict with wearable comfort. Therefore, a wearability test was performed in an early design stage.

A stable neonate of 34 weeks was dressed in the first prototype of the Smart Jacket (2.3) while being filmed. See Figure 2.11. Compared to the stress that was caused when undressing the regular premature baby clothing, the dressing process of the Smart Jacket proceeded smoothly. Only when lifting the neonate, the legs and arms floundered, which can be a sign of distress or simply a search for boundaries. The dressing time took around one minute. We found that the model needed to be more adaptable in size due to large variations in proportions and range of dimensions: as in the NICU neonates can grow from 500g to 2000g and body proportions vary especially when caused by medical conditions. Furthermore, the straps on the chest caused discomfort because they moved up to the chest. This information was valuable for the next design iteration.

Figure 2.11: Wearability test with first prototype

Figure 2.12: Adapted prototype Smart Jacket

2.5 Second design iteration Smart Jacket

In Figure 2.12 the adapted Smart Jacket proposal is displayed. It contains an extremely stretchable fabric that likely ensures adjustability to different sizes and proportions. The hat is kept separate for the same reasons. Furthermore, the straps are designed to prevent them from moving up the chest. This version of the suit was designed with the large silver textile electrodes. The electrodes are sewn to the jacket only on one of the four sides, in order to allow stretch of the jacket without stretch of the electrode itself.

2.6 Conclusion

The first case study describes the design process of a comfortable and attractive wearable monitoring system. In the process was dealt with the the multi-disciplinary nature by developing the 'technology, user focus and design' aspects simultaneously through quick literature studies and explorative tests. The result is a jacket containing textile sensors for ECG monitoring, as a platform to which the wireless communication, power supply and other sensor modalities can be added. For reliability of the ECG monitoring with textile sensors diversity measurement is proposed.

Chapter 3

Designing for reliable textile neonatal ECG monitoring using multi-sensor recordings

Published in [Bouwstra et al., 2011]

3.1 Introduction

In the chapter Smart Jacket design for neonatal monitoring with wearable sensors we observed that there is a trade-off between comfort and reliability: Although textile electrodes offer more comfort, they are less robust due to poor skin contact and sensitivity to motion artifacts. These problems are also described in other studies, such as wearable ECG monitoring for athletics, elderly and (premature) babies [Piccini et al., 2008, Van Langenhove, 2007, Rullo et al., 2006]. Our proposed concept to improve reliability originates from the field of signal processing. It was inspired by the observation that the signal quality is greatly influenced by the amount of pressure applied to the textile sensor depending on the posture of the baby. Therefore, when there is a redundancy of electrodes, there is a chance that there are always electrodes in good contact, which can be selected depending on context. We ask whether a redundancy of electrodes combined with sensor selection based on contextual information can lead to a more reliable and comfortable monitoring system design. The term 'context awareness' is defined in the field of signal processing as:

> "Detecting a user's internal or external state. Context aware computing describes the situation of a wearable or mobile computer being aware of the user's state and surroundings, and modifying its behavior based on this information [Korel and Koo, 2010]."

A relevant example is a mattress called BiSense [Niizeki et al., 2005] which monitors ECG and respiration by selection from redundant electrodes and application of context awareness; electrode selection is trigged by detection of motion. This system, and systems similar to it, faces robustness challenges when applied in the 'real' world. In case of the BiSense, the location of the accelerometer results in false motion detection, there is low correlation between artifact and sensor input and there are problems with accuracy in morphology of the ECG complex. This is where our multidisciplinary approach from the field of Industrial Design could contribute to the creation of a reliable monitoring system, by considering the complete system and exploring the fundamentals on which design decisions are made affecting inter-disciplinary elements.

In this chapter we explore the following question: Is it feasible that diversity measurement in combination with context awareness will lead to the design of a neonatal ECG monitoring system with textile electrodes that meets the standards for neonatal monitoring, and if so, how to design such as system? For feasibility three criteria must be met:

(1) Reliability: At all times there is at least 1 textile ECG signal that is just as good as the signal obtained by gel electrodes (golden standard).

(2) Diversity measurement: The signal quality of the electrodes is not simultaneously affected by a single source of disruption (for example, hand motion on the left, only causes motion artifacts in the signals obtained with electrodes on the left) and depending on context it varies which electrode contains the best signal.

(3) Context awareness: A strong correlation exists between signal quality and contextual information, enabling optimal signal selection based on context.

In this paper the multi-sensory system and experimental design are presented to demonstrate our approach. Clinical experiments with the Smart Jacket prototype on premature babies at Máxima Medical Center, the Netherlands were carried out to measure multi-modal data with textile electrodes, video and acceleration sensors.

3.2 Design of the system for data collection

Data in different modalities was collected simultaneously under various conditions that are common in the NICU. The multi-modal sensors consisted of electrodes as listed below, a 3D-acceleration sensor (ACM) and one video camera, as setup in Figure 3.1. The varying events were sleeping in the incubator in three positions, baby motions and external motions.

- one set of textile electrodes on the back (RA3, LA3 and LL3)
- one set of textile electrodes on the front (RA2, LA2 and LL2)
- one set of gel electrodes on the front (RA1, LA1 and LL1)
- one gel electrode as the reference (RLgel)
- one gel electrode as the GND

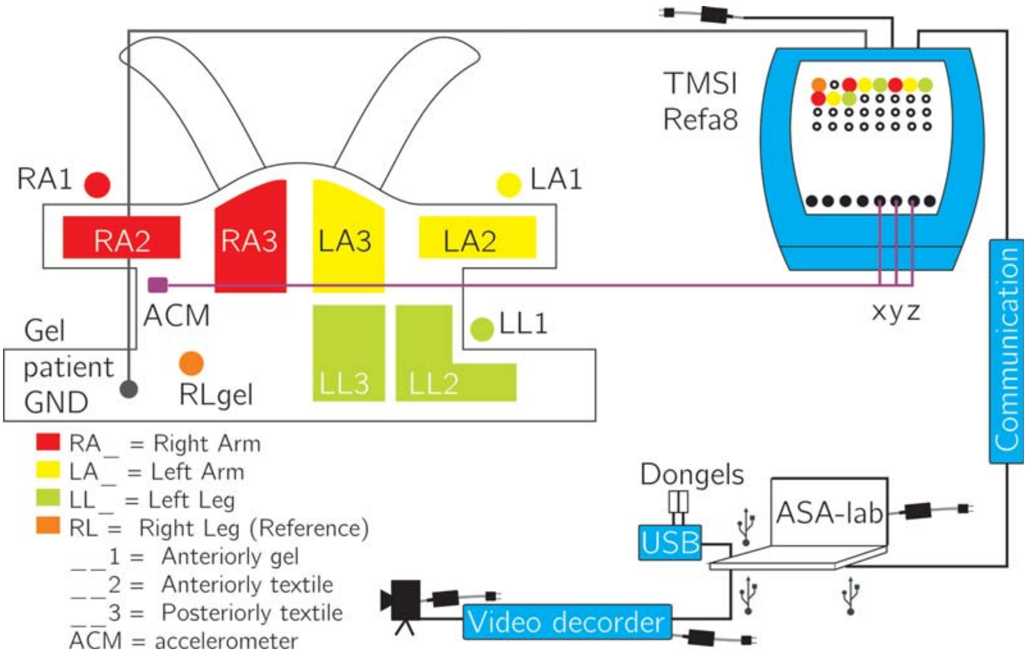


Figure 3.1: Setup of multi-modal data collection

3.2.1 Prototype, amplifier and software

The prototype is an adjusted version of the Smart Jacket with integrated textile electrodes for ECG [Ciani et al., 2008], to which a 3D-ACM from TMSI, Enschede, the Netherlands, is added (Figure 2.12). The new prototype comes in two sizes: M (waist 36-45 cm, 2200-3400 g.) and S (waist 27-34 cm, 1800-2200 g.). Silver textile electrodes are selected for data collection because these are hypoallergenic and did not considerably change properties after a few washing cycles. The electrodes are sized 80 mm x 40 mm because in these dimensions they have previously provided a stable ECG signal with low noise when the baby laid on them. The TMSI Refa8 amplifier in combination with the ASA-lab 4.7.3 software by ANT, Enschede, the Netherlands, was selected, because it enabled the safely collecting and reviewing of multiple unipolar ECG channels, 3D acceleration and video simultaneously. The Refa8 also offers high precision and modest filtering compared to clinical monitoring equipment. Unipolar ECG recording was chosen because it offered freedom in creation of leads (montages). The Refa8 amplifies the individual unipolar channels against a virtual reference (the average of all channels) and since the 'average' is present in both unipolar channels, after montage it is in theory eliminated. The signal quality of the textile channels may be lifted because the Refa8 amplifier uses a principle for common mode rejection that depends on the patient GND's gel electrode's skin contact. The sample frequency was set at 512 Hz based on the Nyquist-Shannon sampling theorem: The sample frequency must be minimally twice as high as the frequency band in which the ECG information lies. The American Heart Association (AHA) [Kligfield et al., 2007] states that "the QRS complex of infants often contains important components as high as 250 Hz" and uses this value for the standards of diagnostic 12-lead recording. Therefore, the sample frequency of 512 Hz was more than sufficient for neonatal monitoring. For the removal of undesired frequencies filters were applied, with carefully selected cutoff frequencies to preserve the ECG's valuable frequency components: (a) a notch filter was set at 50 Hz for use within Europe. (b) For the high pass filter a Butterworth filter with a 1.5 Hz cut off frequency was chosen, based on: "The heart rate in beats (cycles) per minute (BMP), when divided by 60 (seconds per minute) forms a lower bound for the frequency content in Hz" [Kligfield et al., 2007]. The HR of a new born usually lies between 100 BPM and 160 BPM (corresponding to 1.6 Hz and 2.7 Hz) therefore, the cutoff frequency value of 1.5 Hz just outside the heart rate (HR) frequency range is chosen for removal of electrode offset and baseline drift. (c) The TMSI Refa8 amplifier [ANT, 2004] contains a low pass digital FIR filter with a cutoff frequency of 0.27*sample frequency= 138.24 Hz (d) For reviewing purposes in this study, a low pass Butterworth 70 Hz filter was applied.

3.2.2 Subjects and analysis of risks

Data was collected with four prematurely born babies. The recording durations varied from lasting minutes, up to a few hours. Stable prematurely born babies at the pediatrics department were selected as subjects, because neonates admitted at the NICU require certified monitoring that might interfere when connected simultaneously with the Refa8. The babies varied in age from 35 weeks and 5 days to 37 weeks and 4 days and in weight from 1934 g. to 2276 g. Permission was obtained from the parents. A safety analysis of the data collection setup was performed involving clinical physicists, a hospital hygiene and infection expert and a neonatologist. The setups stood the leakage current class 1 CF test, the prototypes had been cleaned according to hospital standards and stood the allergy test [Chen et al., 2010]. Furthermore, a medical staff member was present during the data collection. The medical ethical committee of the MMC decided that the protocol of the pilot study on the feasibility of the smart jacket did not require extensive evaluation and approval according to the Dutch law.

3.3 Categorized results

3.3.1 Morphology alternative electrode locations

For reliable health monitoring the morphology of the ECG must contain complete and accurate information that is interpretable by medical professionals. For diversity measurement it is beneficial to have a high number of channels around the body that flexibly can be combined in montages. Posteriorly ECG monitoring however is unusual, except from in hospital practice e.g. when a baby repeatedly pulls the wires, which is why we looked into its effect on the ECG morphology. The '3-electrode bipolar lead system' (RA, LA and LL, providing I, II, III) is standard in NICU departments. The standard derivations according to the Einthoven triangle are constructed as following: I = LA RA, II = LL RA and III = LL LA. A standard for posteriorly ECG monitoring was not found. Figure 3.2 shows the three derivations collected with the gel electrodes anteriorly (first), the textile electrode anteriorly (second) and textile electrodes posteriorly (third). The textile anteriorly recorded leads highly resembles the gel leads, however the textile posteriorly recorded leads deviate and contain smaller amplitudes. The deviation of the signals recorded posteriorly is most likely due to the fact that electrical signals for the heart activity propagate through the bio-electrically inhomogeneous body tissues and observe the heart vector from a different angle than anteriorly. A method for validation of posteriorly ECG recording is required, because all clinical information may be present nevertheless.

Figure 3.2: ECG morphology

3.3.2 Reliability of the ECG signal

For validation of reliability the aim was to compare the quantified ECG signal properties simultaneously collected by textile leads to gel leads, using the following techniques: A comparison in robustness by calculating the percentage of corresponding (within a tolerance) heart rate (HR) values. Secondly, comparison of the amount of noise, by comparing the signal noise ratio (SNR) [Peters et al., 2006]. The downside of a comparison is that when the presence of the control affects the experiment recording, a quantitative comparison becomes ineffective: In our recordings the presence of the gel electrodes together with textile electrodes caused flat lines. For validation an absolute standard is currently not available for use: Companies methods are not public and the algorithms available are mainly constructed for reliability of HR peak detection in adult ECGs [Kohler et al., 2002]. From plain observation of the measurement data, it is concluded that the textile electrodes generally were less constant in signal strength than gel electrodes, were more sensitive to motion and contained more noise. The ECG signal quality under stable conditions, after selection and filtering, was just as good as the gel electrodes. Based on these observations the textile channels show potential for reliable monitoring.

3.3.3 Signal quality related to context and diversity

We looked for diversity in signal quality, and for relations between signal quality and contextual information. The 3D-ACM on the right chest and video provided contextual information. To gain insight into how single channels are affected by context, ideally the average signal should be removed from the unipolar channels, creating a 'mono-polar' channel. Since the RLgel channel contained little cardiac signal, it was suitable for creation of mono-channels. We reviewed the video recordings together with the mono-polar ECG signals in ASA-lab. The unipolar channels were observed to vary in sensitivity to motion and noise, between electrodes and over time: e.g. a motion event did not affect all textile ECG channels. The 3D-ACM sensor detected motion well that affected the ECG, such as the baby's torso, arm and leg motion. We observed relations between ACM data, ECG measurements and the contextual information, of which the hiccups were a good example. Recognizing hiccups as the cause of an artifact can be used to prevent false alarms. Figure 3.3 shows another usual phenomenon: after a motion event, the signal quality (SNR and sensitivity) changed. Therefore, a 3D-ACM located on the right chest could be an excellent trigger for an electrode selection process. The correlation between signal quality in an electrode location and its nearness to a motion event however was low: Motion caused artifacts in the sensitive channels and not necessarily in the nearest channel to the motion. Posture was not a good indication of local signal quality either: An obvious high signal quality where pressure was expected was not observed. On the video it was unclear whether pressure was actually applied and how the weight of the blanket, arms and the torso affected this. We suggest impedance and/or pressure sensors as indicators for local signal quality, instead of motion or posture.

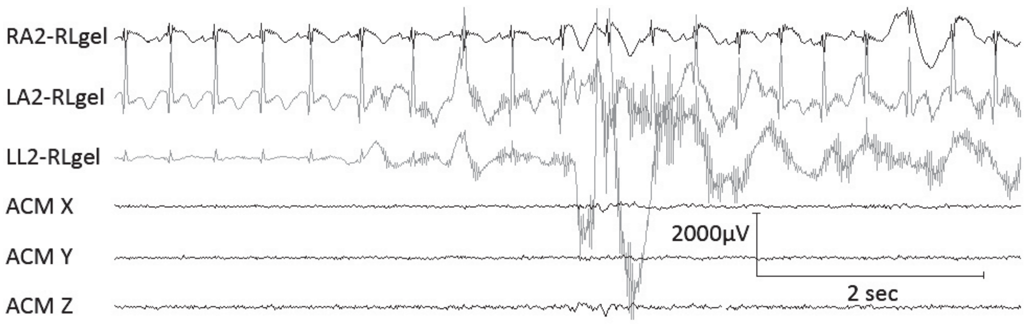


Figure 3.3: Change in signal quality after motion artifact

3.4 Discussion

The strategy to employ an amplifier of the highest quality such as the Refa8 and perform simultaneous measurements was chosen with the goal to avoid all unnecessary amplifier noise and other sources of variation except for the difference between textile and gel electrodes. However, the data contained multiple textile channels with flat lines, which clearly undermined criteria 1: robustness. Most likely the amplifier saturated because large DC offsets existed between the channels (AD convertor range: 300mV). Likely, potential differences between the different types of electrodes and static in the textile-skin contact caused the variation in offsets. A test with the wireless bipolar ECG amplifier developed at IMEC/Holst-Centre with a MATLAB interface developed at the TU/e connected to the Smart Jacket [Chen et al., 2010] demonstrated that the silver textile electrodes did not necessarily cause inadequate skin contact: In measurements on a premature baby no flat lines occurred. In retrospect, the Refa8 appeared to be an unsuitable amplifier for use with unipolar textile electrodes, because it is specifically designed to maintain DC offsets. Ad-hoc solutions for further development we suggest are: bipolar amplification, a wider AD range, high-pass filtering before amplification, one type of textile electrodes and/or coating the silver textiles with chloride. A different approach would be finding the cause for the potential differences to make informed design decisions. Recording ECG, motion and video multi-modally did turn out to provide valuable insight. For the concept of context awareness we propose the use of one 3D-ACM sensor on the right chest for triggering an impedance measurement to indicate the electrodes' individual level of skin-contact and select the best two. The modalities of motion (ACM) and potential difference (electrodes) can be used simultaneously and cause no interference (unlike two electrical measurements).

We could conclude that designing an experiment for comparing an innovative design against a golden standard is more difficult than expected. An absolute standard does not exist yet and using the best equipment alongside the innovative design introduces new problems. Eventually, in the final product when regular patients will be monitored by textile electrodes with an amplifier that can handle large DC offsets these problems could be avoided, but in the validation phase we have to address them. Figure 3.4 shows the essentials of the design process of this complex multi-disciplinary design. Ideally, we would like to have the complete system for exploration and validation to make informed design decisions. However, design decisions are taken already while creating a complete system. Furthermore, there are obvious limitations to the testing of interventions in the NICU. Case specific workarounds and ad-hoc solutions are useful to gain insight, although due to the complex electrical skin contact properties any substitution of testing the complete design in a context close to the real application, won't be representative. Our approach of collecting data before building the entire system, has resulted in the gathering of design parameters as described throughout the paper.

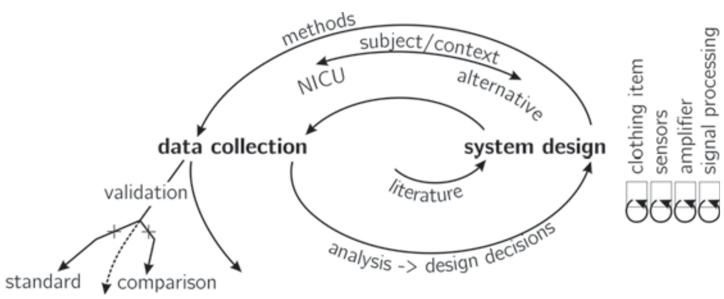


Figure 3.4: Design process complex multi-disciplinary design

3.5 Conclusion

For the design of a comfortable monitoring system for prematurely born babies in the Neonatal Intensive Care Unit, we proposed the concepts of diversity measurement and context awareness to improve reliability. Clinical multi-modal sensor data was collected in the NICU with the Smart Jacket connected to a state-of-the-art amplifier. Observation of the data offered support for justifying the further development of textile electrode systems for this application. We found that the signal quality between sensors indeed varied among sensors and varied over time. We found relations between motion artifacts (signal) and acceleration (context). Furthermore, our explorative system level approach has led to design parameters and meta-insights into the role of clinical validation in the design process.

Chapter 4

Values, competencies and innovation in design for health care: experiences from the Smart Jacket case study

4.1 Introduction

It is our intrinsic motivation to realize the application of the Smart Jacket in the daily practice of the NICU, where the parents and babies can benefit from improved comfort and bonding. In this chapter we reflect on the development process of the Smart Jacket from the initial design steps until the present. We placed the Smart Jacket case study in the context of the latest theory about how to create radically new innovations in healthcare, which lead us to the Value Flow model as a tool to drive the business process development. The objective (1) is to share our experiences with the Value Flow model and its role in the development process, and (2) showing how our design work is not just about form-giving, usability and technology, but sets the direction for the entire innovation process and implementation steps that drive it forward. Our special thanks go out to Prof.dr.ir. Elke den Ouden who contributed to the writing of this chapter.

In [Gardien et al., 2012] a design framework is proposed based on the four economies: industrial, experience, information and transformational [Brand and Rocchi, 2011]. In the design framework they describe the design methods, tools and type of designers belonging to each specific paradigm. According to [Gardien et al., 2012] both the industrial (1950-1979) and the experience economy (1980-2000) are well-established, the information economy is unfolding and the transformational economy is in its infancy. They argue that more value can be abstracted from the market when companies move from one economy to the next, by applying the methods, tools and competencies from that paradigm. The industrial paradigm was mainly focusing on the functionality and quality of the product. User aspects were embodied in the form of ergonomics and form following function. Designers were required to rationally mix the skills of artists, craftsman and, architects and engineers in order to come to solutions suitable for mass production. The experience economy arose because companies needed a way to differentiate themselves between the similar products on the market and people were looking for another source of identity, because religion and other social structures didn't facilitate in that anymore. By experience is meant branding: users were seen as homogeneous social groups who could express their lifestyle through association with products. Ethnographic studies were used to gain insights into the emotional appeal to buy a product, including use of tools such as personas and user scenarios. The knowledge economy paved its way because people could use online communities for expression of their unique identity and sharing content with likewise minded people to gain a sense of belonging. Companies leverage value from the 'user knowledge' offered by the content users place inside the open innovation structures. Where value was first achieved by functionality and later by brand experience, the trend is now to offer products that aim for behavior change, such as health benefits. This requires 'expert knowledge' about the users. And gaining 'knowledge about use' has also become of interest, because the effect of the new adaptive and behavior changing systems are difficult to foresee. Designers need to orchestrate a collaborative open innovation process and to rapidly build interactive products and systems to evaluate them with users. The Transformation economy is about societal value and ethically responsible extraction of market value. Here and there the writers detect that people are starting to appreciate truly ethically produced and traded products. In the transformational paradigm is searched for sustainable solutions that make business sense. Issues such as energy, food and pollution cannot be addressed by one institute. Collaboration between companies, government, academia and local communities are required. Designers must gain competence in envisioning and exploring their aimed changes in society and collaborating with all kind of partners. At this time there are quite a few examples of transformative initiatives, however not yet large scale businesses [Gardien et al., 2012]. A tool can for example be the Experiential Design Landscape [Gent van et al., 2011] in which a new proposition can be proposed, or, a Value Flow analysis in which partners can be brought together to form an ecosystem [den Ouden, 2012].

The Smart Jacket project mainly fits into the information economy, because expert knowledge about the users is necessarily to achieve the desired experience and behavior for the goal of improving the user's wellbeing. The approach applied in the Smart Jacket case study involved consulting a network of scientific experts to learn about psychological and physiological insights into the experience of parents and babies in the NICU. This level of required expert knowledge went beyond what can be achieved applying the research methods for marketing. Designing the Smart Jacket also required multiple iterations of prototyping, testing, physiological data collection and evaluation; an approach in which the users were integral part of the creation process. We share the practical real-life challenges encountered in the case study and which strategies helped to overcome them (case study objective 2).

In practice an innovation rarely fits into one paradigm. Along the process of steering the development towards a producible product with an accompanying business plan, we encountered one of the challenges from the transformation paradigm; the need for collaboration. The Smart Jacket is a product design that cannot be brought onto the market by one organization in isolation. It is part of a larger system, including several organizations and stakeholders, such as hospitals, insurance companies, patient organizations, research institutes and manufacturing companies of electronics, textile and software. The organizations and stakeholders that are involved or affected by the innovation are called the ecosystem [den Ouden, 2012]. Because the Smart Jacket proposition is multi-disciplinary and a radically new proposition in the context of the NICU, where product design has traditionally been mostly medical and technical driven, a sustainable ecosystem is required. An ecosystem would be sustainable when all the partners and stakeholders gain value in a tangible manner, such as financial benefit, or intangible, such as philanthropy and therefore a contributing or supporting the design innovation. In [den Ouden, 2012] the Value Flow method is presented, which is a tool that can be used to design a sustainable ecosystem. We applied this method with our goal of refining the proposition, finding potential partners and exploring their shared values. The core of the chapter is sharing the outcome of the workshop and its effect on the business development process (case study objective 1).

4.2 Initial design stages

The roots of the Smart Jacket project go back to 2006 when TU/e and MMC decided to set-up a strategic cooperation on the area of perinatology. The initiative was taken by Prof.dr.ir. Jan Bergmans of the department of Electrical Engineering. Three groups were formed to develop more detailed plans for the program lines prenatal, delivery, and postnatal. Already in May 2006 the 2nd draft of the 'MMC-TU/e strategic plan on perinatology' contained a paragraph about the Neonatal program line:

> "Key long-term ambitions for this program line are twofold: a) Development of new techniques for non-invasive long-term monitoring of neonates, and b) Development of a neonatal training simulator environment, somewhat akin to the birthing simulator, and capable of both interventional and diagnostic simulations, preferably intermixed for the purpose of training effectiveness. For a), successful initial work has already been carried out in the context of automatic detection of convulsions based on the cerebral function monitor (CFM), and more recently based on video analysis. For b), it is expected that augmented-reality approaches will be very valuable and internationally unique. Eventually b) might also produce spin-offs for ambulatory and at-home settings (e.g. a 'virtual baby' for parental training). For both a) and b), development will be evolutionary, starting with relatively simple pathologies (e.g. convulsions), and gradually proceeding towards more complicated pathologies and medical settings. Involved parties include the EE and ID departments of TU/e (e.g. video, augmented reality, ambient care), the Neonatology department at MMC, and possibly some industrial partners. Required manpower and funding are to be worked out to greater detail."

From this rather imprecise and open ambition, several processes unfolded. One was the formal signing of a more complete TU/e MMC cooperation agreement, the renewal of existing part-time professorial appointments and the new part-time full-professor chair

Pediatric Applications of Ambient Intelligence. The latter chair became to be held by Prof.dr. Sidarto Bambang Oetomo, who also held and holds the position of neonatologist at MMC. 30 May 2008 he presented the inaugural lecture 'High Tech voor de Allerkleinsten' at TU/e. In this setting, the ID department took action to become acquainted with the new application domain and the main mechanisms to do so were twofold:

- the continuation process of the writing of the strategic document into a series of steering board meetings from which ad-hoc working groups were launched to try attracting research funding; also extra visits, joining local conferences, and so on; we could call this a managerial line.
- executing projects of limited duration, working with either research staff or students. Initially most projects focused on delivery and delivery simulation, where ID expertise such as tilt sensors, pressure sensors, 3D modeling could be easily deployed for making (partial) simulators and where the enthusiasm of Prof.dr. Guid Oei and the activities around a freshly established skills lab allowed a quick start.

For the area of neonatal monitoring the start was slower and one of the first students to address the topic was then Final Master Project (FMP) student Sibrecht Bouwstra who began in February 2008 and completed her project in October 2008. She designed the first version of the Smart Jacket. This was the basic idea: to replace sticky ECG electrodes for premature babies by textile electrodes. Already from the very first beginning it was clear that there were two concerns to be taken into account:

- the concern for good signal quality, as expressed by Prof.dr. Sidarto Bambang Oetomo, taking a medical perspective; initially it was not clear whether we would or would not have good signal quality, but we tried to learn about conductive fabrics, amongst others by exchanging information and ideas with the textiles research group of Prof.dr.ir. Lieva van Langenhove of Ghent University.
- the concern for aesthetic qualities and the feedback to the parents. Already in early 2008 assessor Richard Appleby wrote to Sibrecht Bouwstra:

> Looking forward to your graduation project: To what extend will you use aesthetics to communicate what's happening to the baby to tell the parents? How would you help to understand it? Your contribution can be in closing the gap between the hospital and the parent's everyday perception. Advice: make numerous explorations, involve users, try to find out.

The outcome of the graduation project was the design of the Smart Jacket containing textile electrodes for ECG recording, specially for premature babies in the NICU that are stable enough to be held outside the incubator during Kangaroo mother care by the parent. The jacket was designed as an ambulant monitoring platform taking in account the future extension with additional sensors, wireless communication, power supply, signal processing and circuitry. In the initial design stages the focus was on the functional design and technical feasibility, but continuously maintaining a user driven innovation approach. In the graduation project specialized knowledge from various fields was brought together: smart textiles, electrode design, cardiology, material design, ergonomics, tailoring, baby fashion design, signal processing, daily hospital processes and psychology. The design process was highly iterative, based on multiple quick experiments actively involving users and stakeholders on the topics of technology, design and user focus.

At the same time the first version of the Smart Jacket was designed, another ID student, Freek Boesten, developed the power supply for neonatal monitoring during his master project. Afterwards, when Sibrecht Bouwstra joined the IOP/IPCR 'Design for Well-being' project, further research continued along four different lines (see Figure 4.1):

(1) assessing the signal quality of the ECG provided by the Smart Jacket;

(2) adding wireless communication;

(3) adding additional sensors for breathing, temperature and SpO2;

(4) improved understanding of, and design for parent-infant bonding.

Of these lines (1) was continued by Sibrecht Bouwstra and has been reported in [Bouwstra et al., 2011]. The main difficulty was that we tried to measure ECG with both the Smart Jacket and traditional electrodes on the same patients and that (in hindsight) the combination of two electrode types on the same patients, gave all kinds of technical problems. Although the experiments did not unassailable prove or disprove that the signal quality was reliable, we gradually understood that it would be beneficial to skip this type of validations entirely and move to a different amplifier as a complete system including wireless communication the sooner the better. The experiments by ID students Son Tung Nguyen and Roland Coops [Chen et al., 2011] confirmed that with a bipolar amplifier, exclusively textile electrodes and wireless communication, a good ECG signal could be obtained. Later, the students Francisco Piqueras Landete and Marleen van der Wiel succeeded in respectively the creation of a smart algorithm selecting the best signal quality [Piqueras Landete et al., 2012] and an iteration of the electrode design incorporated into the jacket improving skin contact [van der Wiel, 2012].

In line (2) the wireless communication for the Smart Jacket was integrated in sequential projects by Son Tung Nguyen, Roland Coops, Yiwei Wang and Yening Jin. Contacts with the Holst Center were established for the collaboration in which the students explored the application of Holst Center's miniaturized and low-power ECG module including amplifier and wireless communication. Software was developed and the range, module location, and safety for the baby were all documented and carefully considered in their designs [Chen et al., 2011].

Regarding the various signals we tried to obtain (3), the work of student Idowu Ayoola on the SpO2 and teamwork by Sietse Dols, Karlijne Schoot, Hanneke Hooft van Huysduynen on the temperature sensors was published in [Chen et al., 2010]. The breathing was particularly interesting because traditionally the same electrodes are used for both ECG acquisition as for breathing rate measurement. Traditionally the breathing is measured through an impedance measurement, which requires an active sensor sending a small current through the body and requiring a low transient impedance. Because the transient impedance of textile electrodes is higher than gel electrodes and we preferred a passive measurement, and we looked for other sensors. The work by Yves Florack in which he applied knitted

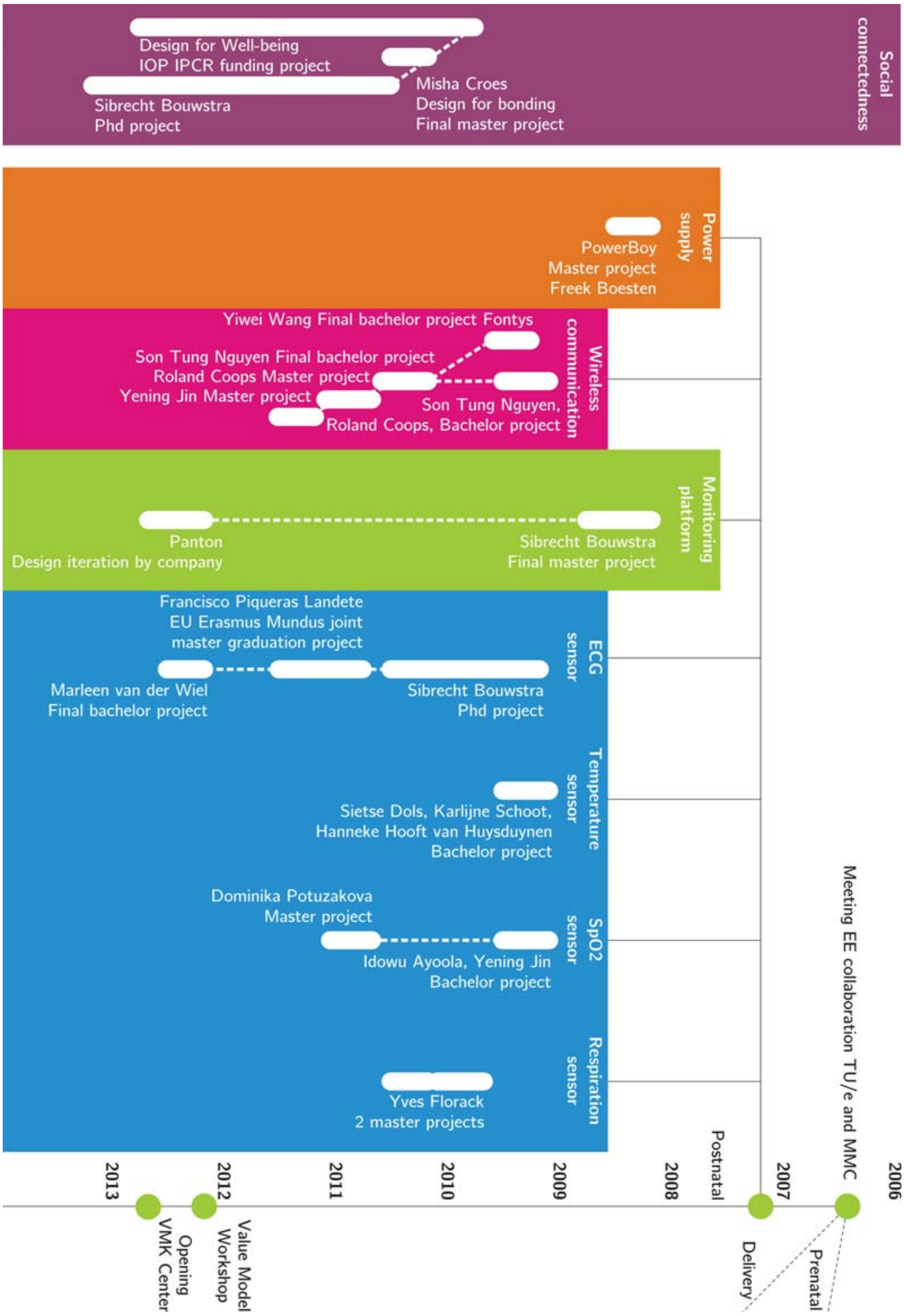


Figure 4.1: Design development of Smart Jacket from 2006 to 2013

conductive fibers was considered very promising [Florack, 2009]. The work on the SpO2 sensor by Dominika Potuzakova has been published in [Potuzakova et al., 2011].

Regarding (4), this was very much in the heart of the DfWB project, whereas sensor development was not, so compliance with the project goals meant that pure sensor research gradually came to a halt (although students continued exploring SpO2 and ECG). The good thing of the DfWB project goals was that new relevant areas could be explored, such as the theoretical design framework for bonding reported in [Bouwstra et al., 2012a].

But the combined effect of doing these four lines of research was that the introduction of the Smart Jacket in the practice was not getting nearer at all. Although it is not uncommon at a University that the most important finding of research is to identify the need for more research, we felt not satisfied. The number of ideas and partial solutions to be integrated was even increasing, rather than becoming simplified. We were pushing the boundaries for finding innovate solutions for each research line. Next to the technical challenges, we identified the need for new validation methods of reliability, comfort and bonding. Rather than waiting what would happen, or compromising the objectives of the DfWB project we decided to take actions to push forward toward real-life usage of the Smart Jacket. We worked as a team, in which most actions towards business development were undertaken by Prof.dr. Sidarto Bambang Oetomo. We noted that the main steps to be taken were engineering, design and business steps, not really research. And we noted that the University is not the typical party for running businesses. Although the University will support start-up and spin-off companies through its TU/e Innovation Lab, in our case we felt that neither Sibrecht Bouwstra, nor Prof.dr. Sidarto Bambang Oetomo, nor Prof.dr.ir Loe Feijs, nor dr. Wei Chen would become business (wo)man. Acquiring a valorization grant was also not the right way ahead, for that reason. Instead we decided that involvement of parties from the external world would be essential. In any case it was essential to understand better how a Smart Jacket, its production and its further development would have to be paid for, protected, and become a viable and sustainable solution. Two action lines developed in parallel: a) a search for funding that without academic objectives and b) to involve internal and external parties.

The action line a) was successful: unexpectedly Chiesi BV (pharmaceutical industry) offered funding to further develop the Smart Jacket which resulted in a donation (we come back to how that was used later, because this is where line a) and b) come together again). For action line b) we decided that it would be essential to extend the scope of the cooperation and involve more Business Process Design (BPD) specialist (we worked already with BPD in the DfWB project on bonding and instruments for bonding). For the Value Flow analysis, we asked Prof.dr.ir. Elke den Ouden and together we organized a workshop where we invited various stakeholders. This is where our earlier efforts to keep in contact with various parties and essentially the embedding of TU/e in the local network paid off.

4.3 The Value Flow workshop

4.3.1 Setup

The Value Flow workshop called 'Smart Jacket - Value Model workshop - from prototype to product' was a co-reflection session with stakeholders. We discussed the pro's and con's for five user application scenarios, and subsequently redefined three propositions that were valued most. Next we created three network diagrams called Value Flows for each of the chosen propositions, by identifying the relevant stakeholders and the values flowing between them in the categories 'products and services', 'financial', 'information' and 'intangible'.

For the one day workshop the following parties were invited and accepted to join:

- Director of the design agency Panton
- Three NICU nurses from the MMC Veldhoven NIDCAP workgroup
- Neonatologist from the MMC Veldhoven
- Representative from Philips
- Three representatives from the VOC: one director, one chairman and one editor of the VOC magazine
- Designer of the BabyBloom (company Babybloom Healthcare)
- Designer of the Benjamin Kangaroo Sweater (company Babybloom Healthcare)
- Four TU/e researchers: one professor, one assistant professor and two Ph.D. candidates

The participants were invited at the TU/e to join in with the scheduled activities during the workshop:

- A welcome by Prof.dr.ir. Elke den Ouden, including discussing the goal of the workshop and brief round of introduction of participants
- An introduction by Prof.dr. Sidarto Bambang Oetomo of the Smart Jacket
- An introduction by Prof.dr.ir Elke den Ouden of Value Flow modeling
- The workshop to create Value Flow scenarios for the Smart Jacket
- Discussion on the pro's and con's of the scenarios

4.3.2 Outcome

In the workshop five applications of use were identified. The summaries are presented here and in Figure 4.2 an example of one of the application areas is provided.

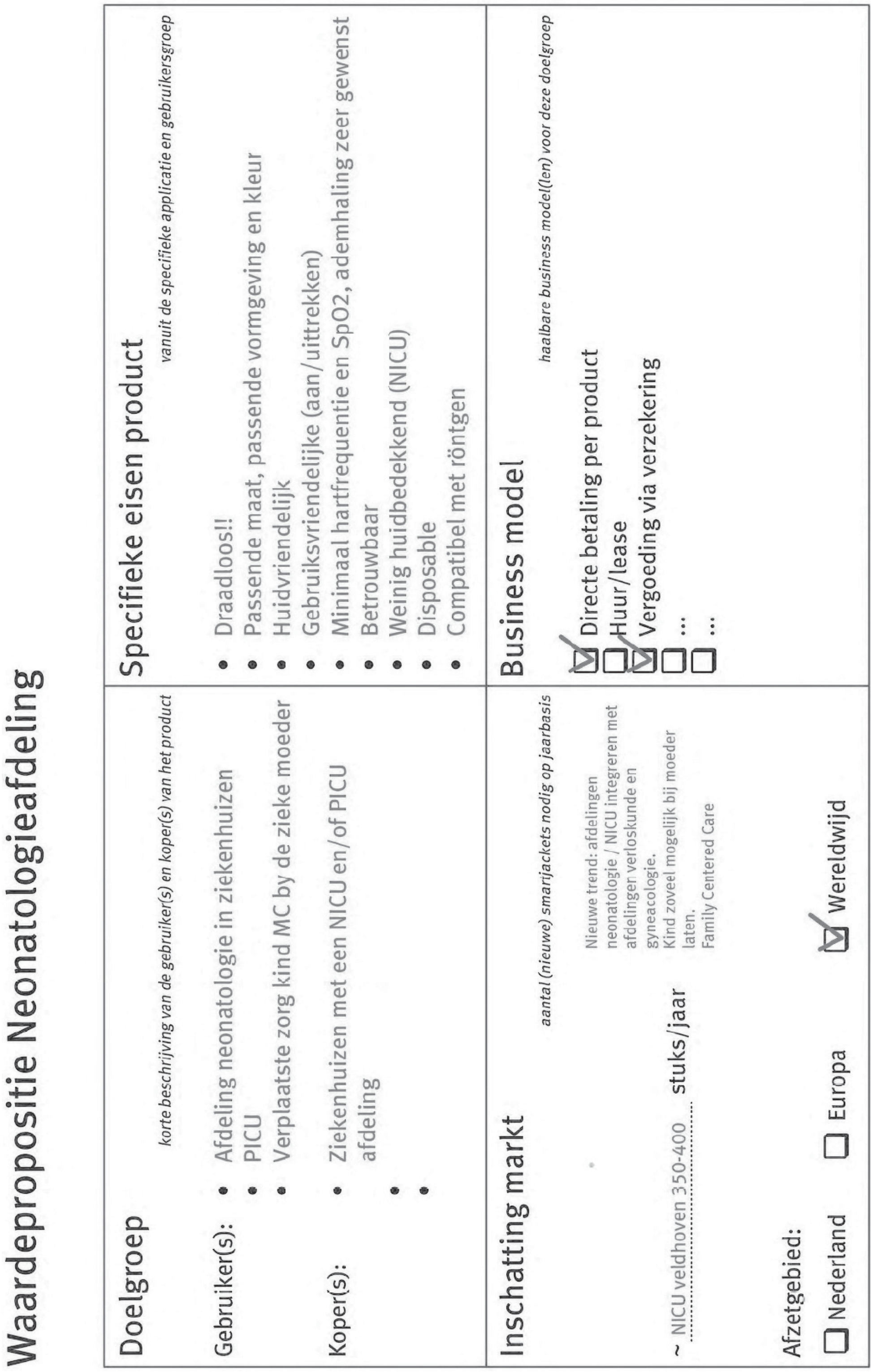
i Neonatology department

ii Pediatric ward

iii Maternity ward

iv Healthy discharged prematurely born baby

v Babyphone+



Waardepropositie Neonatologieafdeling

Doelgroep	Specifieke eisen product
korte beschrijving van de gebruiker(s) en koper(s) van het product Gebruiker(s): • Afdeling neonatologie in ziekenhuizen • PICU • Verplaatste zorg kind MC by de zieke moeder Koper(s): • Ziekenhuizen met een NICU en/of PICU afdeling • •	*vanuit de specifieke applicatie en gebruikersgroep* • Draadloos!! • Passende maat, passende vormgeving en kleur • Huidvriendelijk • Gebruiksvriendelijke (aan/uittrekken) • Minimaal hartfrequentie en SpO2, ademhaling zeer gewenst • Betrouwbaar • Weinig huidbedekkend (NICU) • Disposable • Compatibel met röntgen
Inschatting markt *aantal (nieuwe) smartjackets nodig op jaarbasis* ~ NICU veldhoven 350-400 stuks/jaar Nieuwe trend: afdelingen neonatologie / NICU integreren met afdelingen verloskunde en gyneacologie. Kind zoveel mogelijk bij moeder laten. Family Centered Care Afzetgebied: ☐ Nederland ☐ Europa ☑ Wereldwijd	**Business model** *haalbare business model(len) voor deze doelgroep* ☑ Directe betaling per product ☐ Huur/lease ☑ Vergoeding via verzekering ☐ ... ☐ ...

Figure 4.2: Result application area Neonatology

Application area (a) Neonatology department

Figure 4.2 shows the discussion around the Neonatology department for which the Smart Jacket originally was designed. It was suggested that for the target group, the PICU can be grouped with the NICU. And that the jacket would also be applicable to the scenario in which the mother is ill and the baby is transferred to the mother's department in the hospital. Hospitals that run a NICU and/or PICU are the potential buyers in this case. It was predicted that in the MMC Veldhoven in the Netherlands about 350-400 jackets would be needed per year. The market could be worldwide through, especially because there is an increasingly support for Family Centered Care. The business model could be based on direct payment for the product. Indirectly the health insurance could cover the costs for the Smart Jacket as a part of the complete care package. The possibility of creating a business model and design around a disposable jacket was mentioned as a viable option. The main design requirements expressed in the workshop were that minimally heart frequency and SpO2 must be included and breathing is desirable. The wish for the jacket to be compatible with x-ray was also expressed and other focus points: wireless, fit, attractive aesthetics, skin friendly, usability friendly (dressing), reliability, and skin coverage.

Application area (b) Pediatric ward

While brainstorming about the application of the Smart Jacket in the Pediatric ward, it was identified that the monitoring system could play a role in the transfer from a High care unit in a specialized hospital to a Pediatric ward locally to the parent's home. It is noted that 'medical daycare centers' present a similar user scenario as the 'Pediatric ward'. As potential buyers the following parties were identified: hospitals, transporters, medical insurance companies, or the parents themselves. The specific product requirements for the Smart Jacket in this application are that the product must meet the standards and norms for reliability and safety for professional medical equipment. The size of the market is estimated around a couple of hundred per year within the Netherlands, though it is foreseen by the workshop participants that it could be marketed throughout the developed world.

Application area (c) Maternity ward

The Maternity ward as an application area triggered discussion about what the value of introducing the Smart Jacket would be, when it is offered to be worn during a short hospital admission and from discharge on. The benefit for the parents could be similar as for the consumer market Babyphone+ application; providing parents with comforting feedback about their baby. However, it should be stressed that there is no medical indication to monitor babies at the maternity ward. Therefore the smart jacket could be launched as a consumer product. Whether there is a medical indication for the need for monitoring of healthy babies at the maternity ward was point of discussion. Usually the severeness of the illness determines where the care is provided, and generally the babies that require monitoring are cared for in a department other than the Maternity ward. A special requirement for the user application, (either consumer or professional), is that the Smart Jacket may not be causing an increase in workload for the medical professionals in the Maternity ward. It is estimated that the market for such a product would be a couple of hundred per year in the Netherlands, and was foreseen to be applicable to the rest of Europe and the USA.

Application area (d) Healthy discharged prematurely born baby
In the application area of the 'Smart Jacket for healthy discharged babies', it was proposed that value lies in supporting the parents in the transition from the hospital to home. Currently parents are faced with the experience of suddenly carrying the full responsibility for the baby's health, without access to monitoring data which they became accustomed to. The benefit was identified that parents would be supported in getting used to the new situation, and build faith in the stability of the baby's health. A different perspective to this user case was that parents should be allowed to get accustomed to caring for the baby in a regular way by the time the baby is brought home. The Smart Jacket could leave the impression that the baby is not healthy enough to be fully released from the hospital and create ground for worry. On the other hand, in some cases prematurely born babies do have to be re-admitted due to medical problems, for which early detection could be beneficial. This application introduces a new challenge, namely that the Smart Jacket, certified as a medical device, needs to be accompanied with perfectly clear use and interpretation instructions and training. As potential buyers were identified: the parents themselves, the Maternity ward or a company that rents out medical equipment such as 'Welzorg'. A market of 4000 jackets per year in the Netherlands was foreseen, and it could be marketed across Europe. The standard business model in which the Smart Jacket is sold complete with amplifier, monitor screen and software could be applied. Instead, in this application area it could be foreseen as well, that the electronics would be leased and a multiple textile jackets accompanying one electronic system could be sold.

Application area (e) Babyphone+
In the user application of the Babyphone+, the Smart Jacket is marketed as a gadget for parents of healthy babies. It would be designed for parents that seek of a gadget that provides a feeling of safety for their baby. The emphasis would lie on the smart jacket as novelty, instead of a medical device that can detect signs of an imminent life threatening event. In the workshop it was foreseen that young parents would buy it themselves at a (web)shop or baby products store, or that their family and friends would buy it for them as a present. The main specific product requirements in this user application are that the Smart Jacket should be aesthetically appealing and enable connection to a smart phone or other monitoring equipment such as a babyphone. The potential market in the Netherlands for the Babyphone+ application was expected to be large. It was foreseen that worldwide distribution has potential.

After a discussion the two application areas (i) NICU and PICU and (ii) High Care and Medium Care + transport, were defined to continue Value Flow modeling with during the second phase of the workshop. For those two applications the jacket was expected to bring most added value. The third selected application area was the commercial scenario of (iii) a gadget for parents that seek reassurance, because it seemed worthwhile to explore the possibilities of such a potentially large market. The summaries are presented next for each application and in Figure 4.3 one example of a Value Flow model is provided.

i NICU and PICU

ii High Care and Medium Care + transport

iii Gadget for parents that seek reassurance

Value Flow (i) NICU/PICU

The Value Flow model in 4.3 for the NICU and PICU business scenario shows that the 'financial flows' were expected to run mostly outside the hospital (producing, design and distribution companies). The connections to the hospital were expected run through the purchasing department, which in turn would request funding from insurance companies. Inside the hospital structure, the values that are in-tangible, services and information are exchanged. Likely the purchasing department has to be convinced of the added value that the product brings to the hospital. The added value could be PR as suggested, however, a stronger case could be made if scientific proof was offered of the (in-)tangible benefits such as comfort, bonding and/or a more efficient work flow for medical professionals.

Value Flow (ii) High Care and Medium Care including transfer

The value flows around the 'High Care and Medium Care including transfer' is similar to the 'NICU and PICU' Value Flow model. The role of product certification and quality management came up as a responsibility for the designers. Furthermore, it was identified that a suitable business model should be developed for the specific case in which the baby is transfered in an ambulance to a different hospital.

Value Flow (iii) Gadget for parents that seek reassurance

From the Value Flow model created around the scenario of 'gadget for parents that seek reassurance', the role of grandparents, siblings and babysitters that care for the baby while the parents are away was identified. Also the importance of commercial advertisement became apparent, for example through baby magazines as an efficient means to reach the potential buyers. It was also identified that the value 'information flow', could be important especially between parents and the (regular) health checks with maternity care, clinic, general practitioner or ER. For this user scenario the non-tangible values were described as 'love and confidence'.

Concluding, the participants at the workshop expressed that the application in the NICU/PICU offers the most intangible value of well-being. However, financial value is much higher in the 'gadget for parents that seek reassurance' consumer application. The potential market for professional medical monitoring devices is not nearly as large as the commercial market. In order to make it worthwhile for investors, we chosen to aim for the consumer market and meanwhile offer a specialized version for the professional market. For the professional market, the design must pass FDA procedures, CE and ISO norms. Proof of (in)tangible benefits is desirable as well, because it could help to convince stakeholders, especially hospitals and insurance companies. We have chosen to continue the development of a Smart Jacket that measures heart rate and SpO2 and transmits these modalities wireless, because those functionalities were identified as essential for the NICU/PICU application scenario.

4.3.2. Outcome

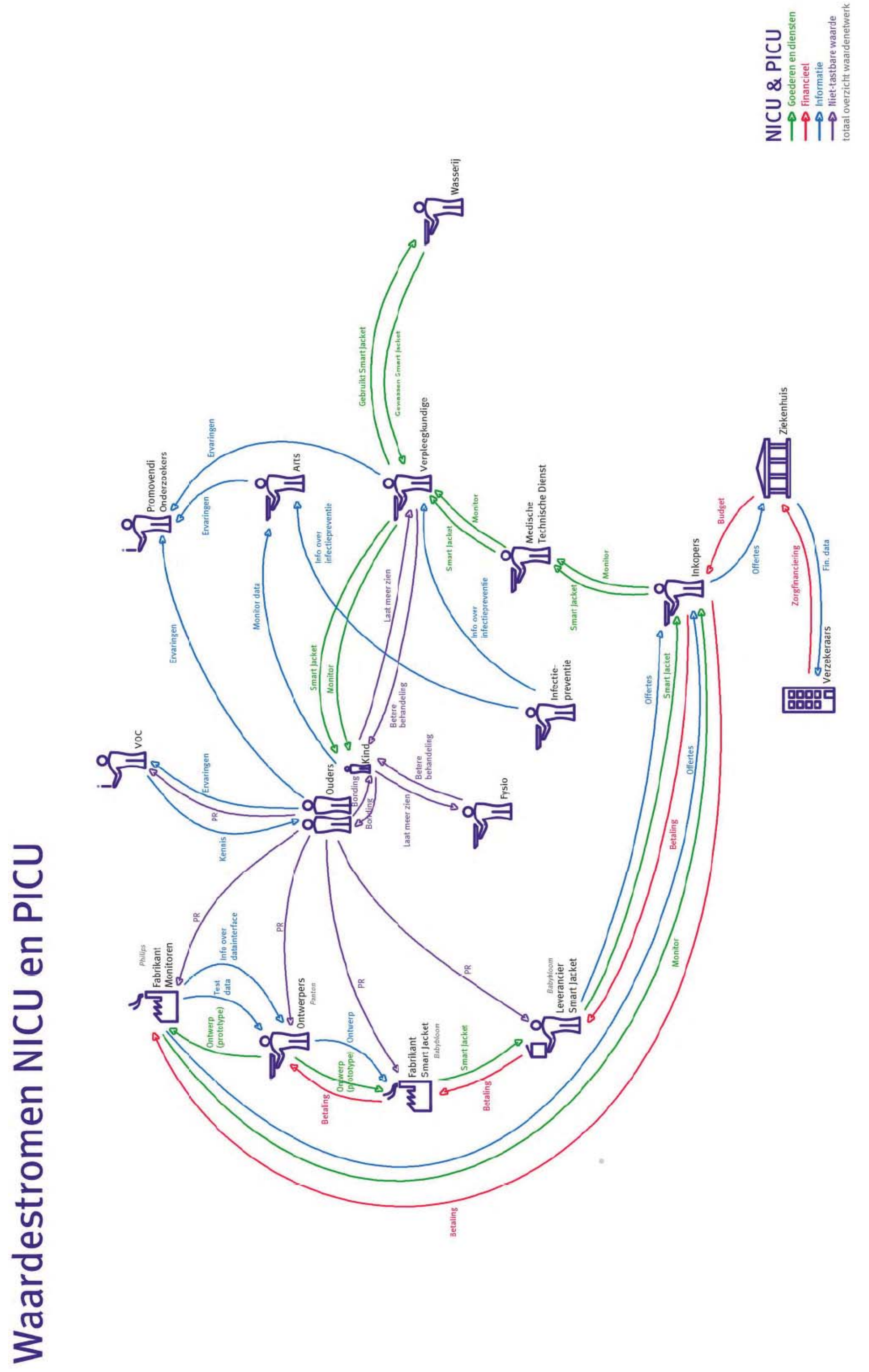


Figure 4.3: Result Value Flow NICU/PICU

4.4 Subsequent steps

One of the effects of the workshop was that we learned to know the medical design company Panton much better. Also the Neonatal product development company Babybloom was identified as a party who could manufacture the product. With the money acquired in the mean time from the fund, the task was given to Panton to take the graduation work of Sibrecht Bouwstra as starting point and try to add a wireless module and at the same time prepare for production. The following documents were provided to Panton:

- Graduation report: Smart Jacket, 2008, Sibrecht Bouwstra, FMP, ID, TU/e
- BSN 2009 article [Bouwstra et al., 2009]
- EMBS 2011 article: [Bouwstra et al., 2011]
- Draft of the EMBS 2012 article: [Piqueras Landete et al., 2012]
- Website: www.smartjacket.id.tue.nl
- A prototype of the Smart Jacket

At the workshop the topic of IP protection was brought forward. The case of intellectual property (IP) protection for the Smart Jacket is as following. The Smart Jacket is an example of a new proposition where the combinations of existing technologies (existing patents technologies on may have to be licensed) and the functional form giving are innovative. Therefore, the idea can be protected with model protection. Model protection describes the aesthetic features of the design (details in shape, colors and materials) and up to a certain point the functionalities that follow shape. A criterion for model protection is that the design has to make a significantly different impression compared to the current alternatives. The Smart Jacket's features have been carefully described and are filed for model protection at the Benelux Bureau for Intellectual Property.

In August 2012 Panton delivered the new prototype of the smart jacket in combination with a microprocessor/amplifier (Figure 4.4). This device generates ECG and respiration signals that are transmitted wirelessly to a tablet PC. The design of this prototype yielded an important improvement in the functionality of the Smart Jacket: (i). flat lines in ECG recording were not encountered anymore and (ii) the respiration signal was included. As we had anticipated, some of the earlier problems we struggled with, had vaporised. This confirmed our judgment that it was essentially not to take it as a University research project, but ask for regular design and engineering.

An unexpectedly essential driver in the Smart Jacket project was the opening of the Vrouw Moeder Kind (VMK) center of the Máxima Medical Center in Veldhoven. On the 20th of September 2012 a new hospital wing was opened by H.K.H. Princess Máxima the present day queen of the Netherlands [MMC, 2012] (Figure 4.5). The event played a driving role in preparing a functional demonstrating prototype for this day. It inspired the step to create the new iteration with Panton, and meanwhile setting up a student project on the topic of reliable monitoring. The student project was performed by Marleen van der Wiel. She successfully designed a mechanical solution for improving skin contact of the textile electrodes in the Smart Jacket [van der Wiel, 2012]. The results of both parallel lines were presented the opening of the VMK center, including a mini-exhibition of innovations for the NICU and symposium and press event by Philips.

Figure 4.4: Smart Jacket iteration by Panton

Development did not stop here. A student SpO2 sensor project was launched, because from the workshop it followed that this modality is essential for the application of the SmFprof art Jacket. Furthermore, a study in collaboration with the Amsterdam Medical Center (AMC) in which clinical data will be gathered over a longer period for the assessment of reliability was setup. The future step is to setup a complete consortium. Together with parties that are interested in taking part of the consortium, we plan to organize a new workshop in creating a complete Value Flow model including all the consortium members, and documenting their individual benefits, as described in chapter 6 in [den Ouden, 2012]:

> "The method has proved to be valuable in enriching value propositions, but also in gaining commitment from the different business actors to make the investments required for implementation. The visualization of tangible and intangible value flows enables the balancing of value across the different parties to ensure sustainable value for all."

4.5 Conclusion

The methods and competencies applied in the case study's design process mostly fit into the information economy. Through the academic approach to investigate and explore, interesting new design areas were revealed, such as context aware sensing for reliable monitoring, new ways of integrating various sensors, wireless communication and power supply comfortably and the notion that design can play a role in parent-infant bonding. This approach of pushing the boundaries for innovation on all research lines however did not bring us closer

Figure 4.5: Opening VMK by H.K.H. Princess Máxima the present day queen of the Netherlands (Photo by John Peters Fotografie)

to our goal to realize the Smart Jacket in practice. We needed to redefine the proposition to a version which represents the essence of what the stakeholders in practice desire and which companies can produce. We realized that the business process of the Smart Jacket could benefit from design methods and competencies for collaboration belonging to the transformational economy. The Value Flow workshop enabled us to focus on a more specific application area and find opportunities for collaboration with experienced business parties. We chose for two application areas: the professional 'NICU/PICU' and the commercial 'gadget for parents that seek reassurance', because then the values of well-being and financial value can potentially be balanced. The MMC opening has in hindsight been an unexpectedly effective driver, because it was a great stimulant for taking decisive actions towards a functional prototype.

Part II

Designing a parent-to-infant bonding support system

Chapter 5

A theoretical framework for parent-to-infant bonding design at the NICU

Published in [Bouwstra et al., 2012a]

5.1 Introduction

The current interventions described in Related work and the Smart Jacket offer different ways of supporting bonding: improving the parents' comfort while being in the NICU, making the interaction more aesthetically inviting and bi-directional communication between parent and infant while separated. Designing for changes in the social patterns in the NICU is a relatively new design area, since traditionally the focus has been on medicine and technology. We foresee that design for bonding offers a number of challenges: the question of what 'bonding' exactly is, what its determinants are and how the level of bonding is measured. This requires a new design approach.

The goal in the second case study is designing a product that stimulates and/or supports parent-to-premature infant bonding in the NICU, and meanwhile gaining insights in the design process on how to design for bonding. As designers we require a framework in order define the design space and identify the determinants for bonding and later on for validation of the design. In this chapter the literature search is presented, with a framework as result, along with the insights about its consequences for the design process.

5.2 Setup literature study

The literature is found through PubMed and google scholar using the following search terms: parent/mother/father-to-infant/child/newborn/prematurely born baby (and the other way around) followed by bonding, attachment or dependency, NICU, measurement, questionnaire, maternal, parental and infantile bonding. Most publications about the 'tie' between parents and babies origin from the field of psychology and are a combination of behavioral studies, interviews and self-report questionnaires [Klaus et al., 1996, Bialoskurski et al., 1999, Ainsworth, 1969, Condon and Corkindale, 1998, Robson and Moss, 1970, Bowlby, 1969, Muller, 1994, Nagata et al., 2000]. Also research has been performed in the field of neuroscience [Uvnas-Moberg and Petersson, 2005]. Apart from scientific arguments we also gained a personal understanding by conducting interviews with parents and nurses at the NICU MMC, reading the support group's magazine called 'Kleine Maatjes' and blogs by parents.

5.3 Design framewok

In Figure 5.1 the framework is presented. We combined the findings into one design framework that forms a theory about bonding between parents and their babies. In section (c) the two directions of bonding are shown. In some literature the terms bonding and attachment are interchanged, however generally the direction from parent-to-infant is called 'bonding' and from infant-to-parent 'attachment' [Klaus et al., 1996]. The circular section (a) illustrates that bonding is a 'feeling state', partially expressed in behavior, which takes place under certain pre-conditions. The timeline in section (b) shows the span of experiences involved.

As Ainsworth defined, attachment is mostly physical and driven by proximity seeking [Ainsworth, 1969]. Parents also have a conscious experience of the bonding process. For the parents bonding seems to be experienced as a feeling state ('love') [Condon and Corkindale, 1998, Bowlby, 1969] that grows with experiences of physical stimulation. According to Uvnäs-Moberg bonding is, at least partially, triggered by hormones that are released when the parent receives stimulation from the infant, such as touch and warmth. Over time the release of the hormone, oxytocine, can be conditioned for other triggers such as sound, odor and likely even thoughts and associations [Uvnas-Moberg and Petersson, 2005]. This is why in Figure 5.1 bonding is constructed of physical and psychological items, in which the reciprocal physical interaction triggers feelings of bonding. We selected the compact list by Robson [Robson and Moss, 1970] which describes purely the feelings of bonding, purple in Figure 5.1. Based on our interviews, we add feelings of 'being meaningful and purposeful', 'unique for each other' and 'happy anticipation about the future'.

The feeling state of bonding is often expressed in bonding behavior. Examples are: 'the mother smiling at her infant', 'eye-contact' and 'non-willingness to leave the infant' [Klaus et al., 1996]. Behavior studies in which the video recorded interaction between parent and infant are coded are usual practice to screen for bonding disorders and for use in research. It is found however that the feeling state of bonding is not always expressed in behavior

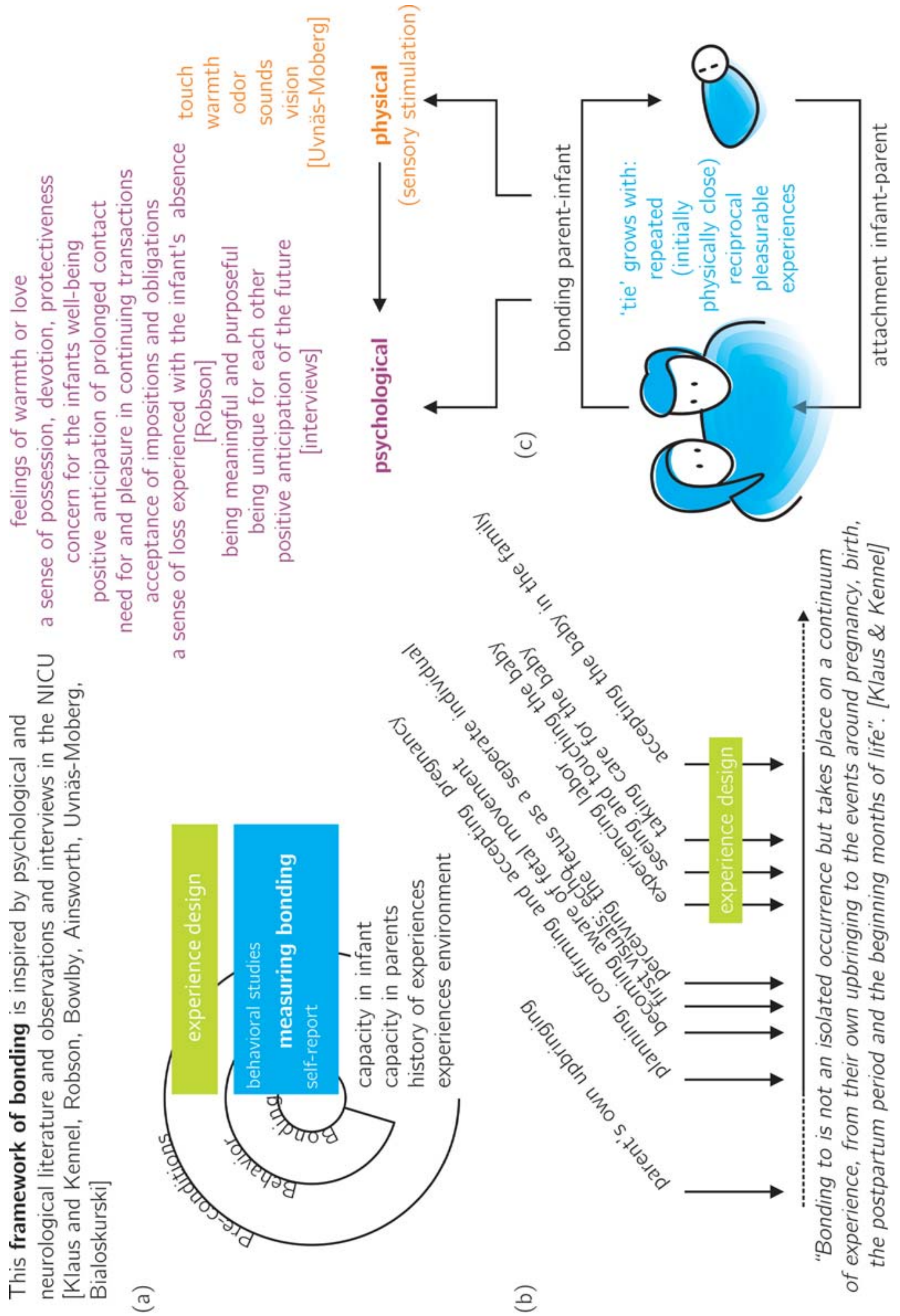


Figure 5.1: Bonding design framework

[Ainsworth, 1969]. The behavior could be held back although the feelings are there, due to pre-conditions such as privacy.

In section (b) of Figure 5.1 the other dimension of bonding is summarized, namely time. Klaus and Kennel [Klaus et al., 1996] came with the notion that the forming of a bond is impacted by experiences going back as far as the parents' own upbringing to the point where their infant is accepted into the family. The existence of a sensitive period for when this contact must be established was not supported.

In literature a wide spread of pre-conditions are reoccurring that may positively or negatively impact bonding between parents of prematurely born babies [Klaus et al., 1996, Eliens, 2005, Bialoskurski et al., 1999, Ainsworth, 1969, Condon and Corkindale, 1998, Robson and Moss, 1970, Bowlby, 1969, Muller, 1994, Nagata et al., 2000, Uvnas-Moberg and Petersson, 2005]. We could fit them into four groups: capacity in infant, capacity in parent, history of experiences and experiences of the environment. According to Bialoskurski [Bialoskurski et al., 1999] the formation of a relationship between a mother and her new born infant should be considered as an individualized process which is multi-factorial.

> "Parent-infant bonding has certain recurring characteristics, but is not fixed or uniform. The setting, circumstances, the family's history, and individual differences affect its course. Bonding is not instantaneous or predictable [Klaus et al., 1996]."

The bonding process also appears to be flexible in nature.

> "It appears that there are numerous built-in human systems that tie the mother and father to their infant so that the development of the relationship seems almost fail-safe [Klaus et al., 1996]."

Some of the pre-conditions appear to directly impact bonding and apply to all the parent-infant dyads. These determinants are required for growth of the bond, blue in Figure 5.1: 'repeated (initially physically close) reciprocal pleasurable experiences' [Klaus et al., 1996, Nyqvist et al., 2010, Eliens, 2005, Bialoskurski et al., 1999, Ainsworth, 1969, Condon and Corkindale, 1998, Robson and Moss, 1970, Bowlby, 1969, Muller, 1994, Nagata et al., 2000, Uvnas-Moberg and Petersson, 2005]. Probably other pre-conditions (such as the stress, privacy, comfort) indirectly impact those determinants. The difference between bonding with a healthy a term infant and prematurely born infant admitted to the NICU lies in the pre-conditions: the separation from the parents, the fact that mothers of low birth weight infants have more psychological distress than mothers of a term born babies and a greater strain is placed on their parenting role [Singer et al., 1999]. Despite the complexity of bonding, there are a few self-report questionnaires that measure the level of bonding for parents of prematurely born babies [Condon and Corkindale, 1998, Muller, 1994, Nagata et al., 2000].

5.4 Discussion and conclusion

We propose the framework in Figure 5.1 providing a definition of bonding, and its determinants for designers who design for bonding , being aware that the combination of findings is not necessarily proven. However, it provides a starting point for the design process and enables to make decisions on the design approach. Later on, the resulted designs can be used in experiments to provide new insights and the framework can be updated accordingly. We assume the following:

$$\text{pre-conditions} \rightarrow \text{experience} \rightarrow \text{bonding} \rightarrow \text{development infant}$$

We suggest that the design opportunities lie in the pre-conditions for bonding, because these are the things we can change and design for. We propose to design for the 'experience' [Hassenzahl, 2010, McClelland, 2005], because it is not one single determinant that will guarantee bonding, but it is a highly unpredictable complex combination of pre-conditions. Considering that bonding is affected by experiences over a life-time, we suggest to limit the time line from 'going through labor' to 'taking the infant home'. This way the design space is limited to the period while they are visiting and/or admitted to the hospital where the experience can be designed.

Philips has developed the 'Experience Design Method' [Parameswaran and Raijmakers, 2010, Kozlov et al., 2007], which guides the gathering of design input and design/measure of the entire experience, instead of just one usability aspect. This experience includes the patient's personal view, the effect of the environment, the encounters with medical staff and the flow of experiences before and after use of the product/service. The core of Experience design is the inquiring of user experience and the creation of experience flow-charts and personas.

The framework based on literature functions as a starting point for the design process. The designs can support future research into the determinants for bonding. In the next chapters the design process according to the 'experience design' method for parent-infant bonding at the NICU using the framework for bonding is described. This includes interviews with parents about bonding and the creation of experience flows.

Chapter 6

Experience flows as the basis for design inspiration

Published in [Bouwstra et al., 2012b]

6.1 Introduction

The case study 'design for bonding' offers the opportunity to design a product/service specifically to impact bonding, starting the design process with this goal in mind. The proposed design process (Figure 6.1) for the case study is fairly traditional (literature search, gathering user design input, design phase 1, gathering stakeholder's feedback, design phase 2 and a validation). In this chapter we describe the search for the design opportunities and inspiration: how do parent experience bonding in the NICU and what kind of design intervention(s) could effectively support this?

Based on the design framework illustrated in Figure 5.1 and selected approach in Section 5.4 resulting from the first step in chapter A theoretical framework for parent-to-infant bonding design at the NICU, the second step is gathering the user's experiences, creating experience flows and analyzing the data. In this chapter, we describe the gathering of the bonding experiences and distillation of the design opportunities, which are likely to have a large impact on the experience of bonding. The NICU forms the Experiential Design Landscape for this case study [Gent van et al., 2011]. Practical outcomes, such as design guidelines are shared, as well as reflection on this phase of the design process.

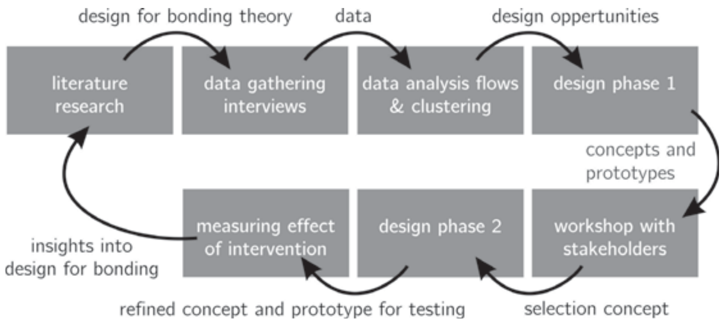


Figure 6.1: Design process case study design for bonding

6.2 Setup and methods

The choice in method for collecting user data for experience design depends on what is suitable specifically to the case study. As part of this case study, we chose to conduct interviews with parents about their experiences and feelings towards their infant related to the environment, while the experience is fresh in their mind. Interviews were transcribed and coded, forming the basis for the experience flows. Initially, personas based on the interviews would be created in order to design for a type of parent. However, as explained in the discussion, a creative clustering session was found to be more suitable.

6.2.1 Interview design

Five mothers (together with the fathers) were interviewed about their bonding experiences during the time their child was admitted. Three of the interviews have been held by a designer and two by a social scientist. The interviews were semi-structured, in order to give the parents room to freely introduce themes relating to bonding, and on the other hand to have topics on hand to maintain the interview flowing. In all interviews the parents were asked to describe their experience of bonding along the journey through the hospital; from giving birth, to being in the NICU/High Care for several weeks. The questions asked were about how the parents felt about the atmosphere, the interaction with the medical staff, first impressions, what they did, and how it influenced the way they felt towards their child. We asked what supported and what held them back in different stages and places. Examples of questions asked:

- How would you describe the bond with (name)?
- What has strengthened the feeling of the bond?
- Was there something holding you back from entering the NICU?
- What was a good experience you had in the NICU?
- Did you perform care tasks? If so, which care tasks?

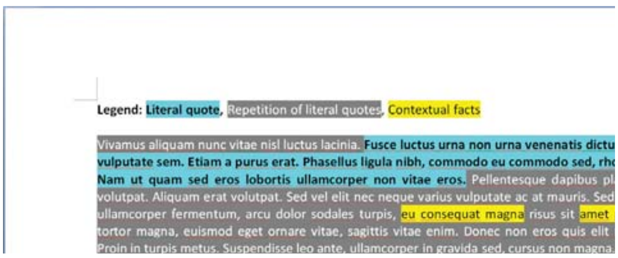
The interviews lasted from 45 minutes to 1.5 hour and took place in the family room in the Máxima Medical Center, Veldhoven, in the Netherlands. The interviews were audio recorded, literally transcribed and names and places were replaced.

6.2.2 Participants

The parents included in the study had one or more babies admitted to the NICU or High Care department. The criteria for selecting the participants were that the baby was in stable health at the time of the interview and the parents had spend a few weeks in the NICU to be acquainted to the rhythm. In order to gain a broad picture, the parents differed in whether they were first time parents, were a single parent, stayed in the Ronald McDonalds house or their child had temporarily been transferred to a specialized hospital. The experiences of both mothers and fathers were included because the study is of an explorative, inspirational nature with a low number of participants. Four participants were native Dutch speaking and one participant was non-native English speaking. The quotes have been analyzed in their original spoken language.

6.2.3 Experience flows

In the experience flows, the interviews are presented with the goal of providing an overview of how the parents' feelings towards their child developed throughout the medical journey. In order to create the experience flows, distillation of factual data about places and procedures, and quotes about bonding experiences, from the transcript was necessarily. The transcripts were color coded, as in Figure 6.2. Factual data was marked yellow (regular black text). Literal experience quotes were marked blue (bold black text).



Legend: **Literal quote**, Repetition of literal quotes, Contextual facts

Vivamus aliquam nunc vitae nisl luctus lacinia. **Fusce luctus urna non urna venenatis**
vulputate sem. Etiam a purus erat. Phasellus ligula nibh, commodo eu commodo sed,
Nam ut quam sed eros lobortis ullamcorper non vitae eros. Pellentesque dapibus
volutpat. Aliquam erat volutpat. Sed vel elit nec neque varius vulputate ac at mauris. Sed
ullamcorper fermentum, arcu dolor sodales turpis, eu consequat magna risus sit amet
tortor magna, euismod eget ornare vitae, sagittis vitae enim. Donec non eros quis elit
Proin in turpis metus. Suspendisse leo ante, ullamcorper in gravida sed, cursus non magna.

Figure 6.2: Coding transcripts anonymous sample

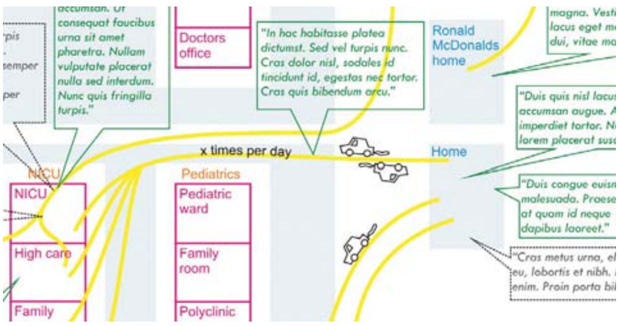


Figure 6.3: Experience flow anonymous sample

Parents repeated certain ideas within an interview, therefore in order to maintain the manageability of the data, the most representative quote was selected and the repetition marked in gray (regular white text). This ensured the entire transcript was considered. Since the questions were open, parts about the interviews about non-related topics were left unmarked, such as medical details about the baby or the delivery. In Figure 6.3 the elements for the experience flows drawn in CorelDRAW are shown. It contains the institutes, departments and rooms, with the journey as a yellow line running through. Along the journey the selected experience quotes are positioned in text balloons.

6.2.4 Creative clustering

An open coding clustering session was held to start the discussion about how parents experience bonding, what the design implications are and point out design opportunities. The session was held with another designer and a computer engineer, both new to the topic of bonding, in order to gain a fresh view and stimulate creativity. In a span of a few hours the designers created clusters on post-its until all the quotes could be placed. The discussions were documented. Afterwards, the clusters were organized in more detailed clusters of which the conclusions are drawn. The five experience flows together contained too many quotes for clustering, namely 253. Therefore, the quotes most relevant to bonding feelings or activities were selected, which brought the number down to 144. The quotes were given a symbol specific for the interview ($\star$, $\wedge$, $\circ$,$*$ and $\bullet$), in order to be able to differentiate the original interviews when they were mixed in clustering.

6.3 Results

The coding of the interviews resulted in five experience flows, with a variation of medical journeys including contextual facts, activities and feelings related to bonding. The clustering exercise resulted in an extensive report containing conclusions for each cluster of quotes. Here the summary is presented in themes, each conclusion accompanied with one representative quote.

Separation after birth - Several mothers felt empty seeing the baby only shortly directly after birth. They wish to be with their child as soon as possible, but realize that medical care for themselves and the baby is required which they don't want to disturb.

> $\star$ "At the time it was just important to deliver her and connect her as quickly as possible to all contraptions", "So the period directly afterwards was a little strange. Perhaps also a little bit empty"

NICU environment - Parents are overwhelmed during the first impression of the NICU. They are attracted by a homely design, however feel it is not appropriate for a medical environment.

⋆ "It all went so fast and I actually can't remember it all too well"

∧ "The moment I entered I definitely noticed it is only for premature babies"

◦ "You know that he requires a lot of support and that just does not go well with a blue crib with a bell on it"

Baby's fragile health - Parents report that in the beginning they struggle with the fear of becoming attached to the child that they might lose. For the interviewed parents this fear diminished over time as the baby's health stabilized. In time they could participate more and the baby became more responsive.

∗ "I went through a lot of emotions, not wanting to get too attached to the child, certainly during the first week, weeks, I think. Because, well, you don't know how long he will be around"

⋆ "earlier he was connected to the CPAP" [continuous positive airway pressure], "and then you do require some help with all these tubes. Now he is only connected to the lowflow" [nasal prongs], "and we can do it ourselves", "She is getting stronger and stronger. You develop a stronger connection. We can do more with her, and she responds more and more"

In case of a premature birth it can be too overwhelming being confronted with the baby's fragile health. Instead of being on top of everything, parents sometimes choose trust in the care provided. Or, sometimes, parents observe or participate as much as possible, thereby obtaining a sense of control. Parents react differently to live-stream of information. There is a large difference between whether the news is positive and whether the parents are in a position to act on it or not.

• "I am almost more at ease while I am there, observing what is happening. Opposed to while being away and having to maintain faith"

◦ [About witnessing the fragile moments] "it makes you feel insecure and wonder Oh, will he pull through?'"

• "You record the good times on film", "therefore the videos that you have are fun to watch"

⋆ "That you can see her [on a live-stream], that is much more intense. It makes me realize I can't be with her 24 hours a day"

> ∧ [about a NICU webcam] "So let's say maybe if I was at home, and I could see she is awake, I could rush here and maybe we could play together"

> • [about monitor alarms] "You can only review the past hour or so", "but it does give you the feeling that you are updated on what happened during your absence"

Participation in care - Mothers expressed their wish to participate in care. It strengthens their parental role. Yet with the fragile health of the baby they feel insecure, especially in the beginning. If the staff can do a non medical task such as changing diapers faster or better, they rather give it out of hand.

> ∗ "then you actually have the feeling that there is something that you can do." [When she is excluded, she feels] "Less like a mother"

> ⋆ "it is not that you can just go ahead and pick her up, and hold her to your chest. No, there is always a preceding action. You have to notify them how it is going, or ask if we can do this?"

A premature baby requires much rest, which often leaves the parent sitting next to the incubator. Parents want to actively contribute, have a reason to be there. They talk and observe, bring personal items such as a scent cloth or toy, read something, write in a journal or take a nap.

> ◦ "The fact that you may not touch him, that was a bitter pill to swallow"

> • "'Well enjoy', 'Oh', I contemplated, 'Enjoy what?', I am lying here staring at a box"

> ∗ "Of course there isn't all that much you can do next to the incubator. And yet there is. Having the feeling, of yes, I do love you, I am there for you. That. And I think that applies the other way around as well"

> • "then I just look at her for a moment and continue reading. Then I do get the feeling of being there"

> ◦ "You really want to take the pain away from the little guy", "You feel so helpless, powerless"

Getting to know each other - Parents learn along the way to interpret the signs of the baby, which differ from a full term baby. They use the monitoring data to get to know their child. They compare the monitoring data to their observations for confirmation.

⋆ "You can see whether he is comfortable or not. However, the first days you are not so aware of all these things. It comes naturally with Kangaroo care and caring for him. Then you just start to notice things"

• "Sometimes you mix it in your head", "And you do look at her, but look for confirmation in the monitor as well", "Am I right? Or do I know that already? Or am I not seeing it correctly now."

Parents are insecure about whether their child responds differently to them than to the medical staff. Three mothers mentioned that the baby recognizes them, but others strongly doubt it. Explanation about how the baby interacts and behaves supports parents. They notice that the child looks for them when hearing their voice. It motivates parents when they notice that they can calm their child.

∘ "are you responding to me, or do you also do that when a random nurse opens the door?"

∗ "It is purely his eyes, the fact that he opens them when I am speaking to him. And I can see he does not do that with everyone. You do notice that"

• "I don't feel that she, when I am sitting next to her, is thinking 'Oh, that's my mother again'"

∗ "It is very strange that you although you don't know him at all. I am here twice a day, I have never had him with me for 8 hours, but these nurses, they are in his presence the entire day"

• "That give me something to hold onto, 'Oh, so when she does this, she may actually recognize me'", "when she does this with her eyes and they are quite capable of making a connection"

⋆ "Kangaroo Care is important. If you notice that he is calming down, his breathing improves et cetera, then that feels very good. Then you really want to pull him close. It has a positive effect"

Kangaroo care physical contact is experienced as very positive. It has however limitations, such as not seeing the baby's face, not being able to smell or give a kiss.

• "It is a special feeling. However you do miss lifting your child, or holding her pleasantly against your shoulder. Or yes you hold her, but that is all"

◦ "I had him on my arm", "and thought 'wow'". "'Oh, my baby!!.' Then I was studying him so intently, when I had him really right in front of me"

Monitor system - All parents look at the monitor, but with different intensity. It is not sure whether parents always interpret the data correctly. The monitoring requires professional interpretation and does not predict the future. The sensors of the monitoring system are in first instance restraining parents from interacting, however with support of the medical staff this is overcome. The fragile health of the baby has the main impact.

∗ "At some point, you are just sitting there [pretending to watch the monitor] even though your child is lying over there"

◦ "I would for example see his saturation drop, and would think: 'Oh, there he goes. How often would he do that a day, and how harmful would that be and"

• "I think that I am a bit clumsy, but that is also caused by maneuvering your hands through these holes", "And in addition there are all these wires, which tend to intimidate you a bit."

∧ "Very small. Really. Very small. So sometimes and I must be frank, when I come here and I look at my baby and then I begin to cry"

Spending time in the NICU - Parents spend different amounts of time next to the incubator. If the parents can participate in care or perform Kangaroo care they tend to stay longer. Also when they arrive at the right moment. Planning (with the medical staff) is important.

• "I reckon that I sit there each day for 6 hours watching her"

◦ "Then you just lie on your bed and you can look at him. That's all fine, but after fifteen minutes or half an hour, you have seen enough", "And you are aware that he mostly benefits from rest, rest and more rest"

∗ "Now it easily happens that you are applying Kangaroo care for one and a half hours. And then there is care before and after. At first you were only sitting in front of the incubator, and as a result your stay is shorter"

∧ "sometimes, lucky, I try to be in time", "Maybe she is then awake"

∗ "Here you arrive at a convenient time and often his diaper has been changed already. Or sometimes you are in luck that you arrive on time and can do it together"

For the parents days are filled with being at the NICU, traveling back and forth, pumping breast milk every 3 hours, caring for the children, house, eating, working and sleeping. A parent that spends much time at the NICU might benefit from more relaxation. Especially the days after birth, the mother needs to focus on her own recovery. Parents that spend little time, might benefit from being supported to stay longer. Some parents go home with a good feeling and are able to rest. Other parents worry and call in often.

∧ [single mom] "I am with another child, really I try to manage the time to come here also"

◦ "You are recovering from a caesarian and everyone tells you: 'Make sure you get some rest as well. Because once you have your child at home, you will also want to be a mother that can care'"

⋆ "I am not going home with the idea of all the things that might happen. I mean, I do trust everything here"

◦ [recommended by a nurse] "It is so pleasant. Just being at home with your child and husband. I don't have to go to my child, because I know he is in the right place"

• "If you call, you are again afraid of what they might say. You would almost consider not to call. But then you cannot sleep, so that does not work either"

∗ "It was also not pleasant when I was not around, when I was at home. I felt guilty and wanted to be there"

∧ "I think of her every day, every minute, every hour"

Trust in care provided - Staying updated is of main concern to the parents. Parents notice the difference in communication styles between hospitals when they are (temporarily) transferred. If the communication is inadequate, parents can start to worry at home. Relying on the care provided is sometimes difficult. Most parents put their faith into it or say they simply have to and meanwhile keep a close eye on things.

∧ "I should know what is going on with my daughter"

∗ "Every time that you're there, they would approach you and tell you about things that have happened and how he was doing"

⋆"You would spot a note and then you would think: 'Hey, this says something about morphine'. That was not exactly shared with me, so in turn you would ask 'Did he receive morphine', and only then they would explain"

◦ "Yes, and when I would lay in bed at night I would think 'Yes it went well today', but yes, did it really go as well as they said it did?", "Would they be doing something with him?"

• [about a nurse of which the mother feels she does not know her child well enough] "If I wouldn't be here now, you would consider this as normal"

◦ "Here they are the experience experts really, here are the people who know about what could happen to your child"

6.4 Discussion

The interviews showed the complexity of how the feeling of bonding develops over time, and the highly intertwined processes affecting parents in an individualized way. Parents expressed contrasting thoughts about needs, e.g., that some parents would want to see their child live via a webcam at home, and others would find it confronting to be faced with the fact that they are away from the child at that moment. These contractions, also within individuals, result in a fine line to walk when designing an intervention. The interviews also show that pre-conditions affect each other: when e.g. the mother has comfort, the baby relaxes in turn, resulting in higher responsiveness when the baby is in an alert awake state. The design opportunities are therefore tied closely together; as soon as a concept emerges, it is easy to imagine how another opportunity is affected as well. It is unpredictable which pre-conditions will have the largest impact on the experience of bonding, because it is such a complex individualized process. The proposed opportunities therefore are not a guarantee, and user tests with prototypes are required in order to gain insight into the actual effect of the intervention.

6.4.1 Design oppertunities

We identified the following design opportunities:

- Health info is being used to get to know the baby: do parents interpret correctly?
- Parents sitting next to the incubator wanting to contribute while the baby needs to rest.

- During Kangaroo care not being able to really see or interact as parents would 'normally' do.
- Helping parents to feeling more secure about the baby's ability to distinguish between parent and medical staff.
- Health info; the balance between wanting to know everything all the time, and resting with peace of mind.
- Planning and being 'in luck' of arriving at the right moment for care tasks or interaction.
- Care info: wanting to know everything that was done with baby. Trust in care while away.
- Recording the good moments to re-live at home.
- Wanting to see and be with the baby right after birth.

The three design directions selected as the most promising to proceed the design phase 1 with are:

i Specific monitor design for parents as a means to get to know their child.

ii Supporting a meaningful and active contribution while sitting next to the incubator.

iii Supporting the acknowledgment of the difference the baby knows between parents and medical professionals.

These three opportunities are well represented in the interviews and are likely to affect the experience early on, right from admission. Also, they support co-located bonding.

6.4.2 Design guidelines for bonding experience

Based on the literature research, the experience flows and clustering sessions, the following design guidelines were formulated:

1 The intervention must positively affect the experience of bonding under which the bond between parents and infants grows: 'Repeated (initially physically close) reciprocal pleasurable experiences'.

2 The intervention may not be obtrusive; parents must have the option to use (certain functions within) the intervention.

  a The amount of information the parents receive about their child's health status must be adjustable according to their personal needs.

  b The privacy settings must be adjustable to the parent' personal needs with privacy ensured in all settings.

3 The intervention may not restrict the parent' autonomy, but rather support a higher level of autonomy.

4 The intervention must be safe.

5 The intervention may not introduce opportunities that negatively affect bonding, such as stimulating the parents spending less time at the NICU with their child.

6 The intervention may not rely on intensive instruction or support by the medical staff, unless it is saving time by optimizing time consuming in another tasks.

7 The intervention may not cause any discomfort for the baby, which conflicts with the goal of improving the developmental outcome by reducing stress.

8 The intervention may not stimulate the parents to wake the baby or provide stress when he or she needs to rest.

9 It is preferable that the parent' focus is pointed towards the baby than away.

10 It is preferable that the intervention stimulates natural interaction between parent and child.

6.4.3 Benefits and challenges of experience design

Conducting interviews while the parents are in the middle of the experience, resulted in spontaneous reactions. We noticed that the topic of bonding had not been considered extensively yet by the parents, because health had been of their main concern. The downside introducing the heavy topic is that it resulted in emotionally intensive interviews. It faced parents with the undesired situation. Nurses reported that it lingered with parents, even days after. Asking the parents in a later stage likely causes less stress, however probably provides more socially desired answers.

At first the goal was to create personas in order to design for a certain 'type' of parent. However, five interviews were too few in order to build stereotypes. Although in the clustering session indeed certain ideas were repeated, 'sets' of these responses did not repeat in the five interviews.

The ordering of the data in the form of experience flows in this case study did not result in additional insights. Perhaps the scope was too large. We do expect that the rich experience flows will be useful later on for concept scenarios. Once the concepts are there, it is interesting to imagine how the intervention would impact the experience flows and in which stage. Would these parents use the proposed concepts in different ways? The experience flows contain the complete story with personal insights in an organized way, opposed to the generalized clustered data.

6.5 Conclusion

The bonding process between parents and prematurely born babies is important for the well-being of both, however in practice the process is hampered due to separation, fragile health of the baby and parents having to rely on the care by medical professionals. Designing for the support of bonding experience, raises questions about the definition of bonding: how bonding can be effectively supported through design and how to measure the impact of such an intervention. In the case study 'designing for the parent-to-infant bonding experience' we explored how to design for such a complex, flexible, individualized process. In this chapter we described the search for inspiring design opportunities that are expected to impact the bonding experience, through conducting in-depth interviews about bonding experiences of parents with a premature baby admitted to the NICU. Five interviews resulted in five experience flows and thematic conclusions derived from a creative clustering session. The interviews illustrated the complexity of how the feeling of bonding develops over time, and the highly intertwined processes affecting parents in an individualized way. We identified three design opportunities and a set of design guidelines, which form the inspiration and focus for the design process. The three resulting opportunities are: (I) specific monitor design for parents as a means to get to know their child, (II) supporting a meaningful and active contribution while sitting next to the incubator and (III) supporting the acknowledgment of the difference the baby knows between parents and medical staff. We conclude that user experience tests with prototypes are required in order to gain insight into the acceptance and effect of the intervention(s) on the bonding experience.

Chapter 7

Concept development: designs that support the bonding experience in the NICU

7.1 Introduction

How to design products that support bonding between parents and prematurely born babies in the NICU? In the case study about this question we have so far created a theoretical design framework [Bouwstra et al., 2011] as described in Chapter 5 and gathered design inspiration and guidelines [Bouwstra et al., 2012b]. Having arrived at the creative phase of the case study, the question can more specifically be defined as: what concept is likely to impact the bonding experience? A brainstorm session was organized and resulted in a multitude of ideas. The objective is the generation of a concept that impacts the bonding experience positively.

7.2 Concept development

7.2.1 Brainstorm

The setup of the brainstorm was traditional. Two Ph.D. candidates at the Industrial Design department of the TU/e were involved in the idea generation. They had previously joined the creative clustering session of interview data about this topic in Creative clustering. Therefore, they were informed about the user scenario, however could approach the brainstorm with an open mind. The program for the brainstorm was as following:

- Going through the brainstorm rules [Terhurne and van Leeuwen, 2002]
- Presentation of the problem definition:

- The goal is to design an intervention in the NICU that supports co-located bonding from parent-to-infant.
- Bonding can be supported by creating: repeated (initially physically close) reciprocal pleasurable experiences.
- The three design directions
  - (I) Specific monitor design for parents as a means to get to know their child.
  - (II) Supporting a meaningful and active contribution while sitting next to the incubator.
  - (III) Supporting the acknowledgment of the difference the baby knows between parents and medical professionals.
- The design requirements Design guidelines for bonding experience

- Idea generation technique called brain writing [Terhurne and van Leeuwen, 2002]
  - Participants each receive a A3 paper with one of the three design directions.
  - Participants are asked to write down 3 new ideas within 5 minutes.
  - After 5 minutes the A3 are rotated around and the participants can add new ideas or elaborate on the previous.
  - The rotation is repeated until no new ideas surface.

The ideas that came up in the brainstorm session are documented per design direction. These ideas were the basis for the concepts presented in the next section.

7.2.2 List of concepts

Concept 1: Attention focus baby 7.1
A monitoring system that is located close to the baby in order to draw the attention towards the baby. The parents can look at the baby and at the same time receive information about the internal state that is normally 'hidden'. For example a hat with icons that indicates the real-time changes in heart rate and blood saturation. It is probably easier for parents to relate events to evoked responses from the baby, when the monitoring system is in the same vision field as the baby. The monitoring system located close to the baby fits into the design direction category (I): a monitoring system as a means to get to know their child.

Concept 2: Abstract real-time monitoring animation Figure 7.2
An abstract visual representation of the baby's vital signs. The idea is that parents can intuitively gain an impression of how their baby is doing. For example a grid of animated feathers, the parameters of which are directly controlled by vital signs: temperature determines color shade, heart rate the speed of motion, saturation the width of the feathers, et cetera. The endless possibilities in combinations potentially lead to a rich visualization in which patterns can be recognized more intuitively than on the medical monitor. Parents can choose from different visualization styles. The abstract representation enables the parents to obtain non-medical information about the baby's state to get to know their baby (I).

7.2.2. List of concepts

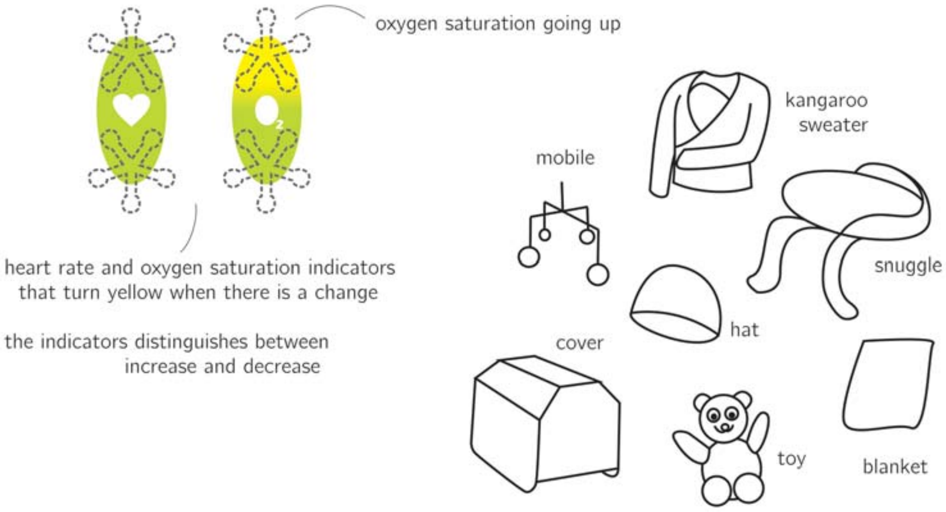


Figure 7.1: Concept 1: Attention focus to baby

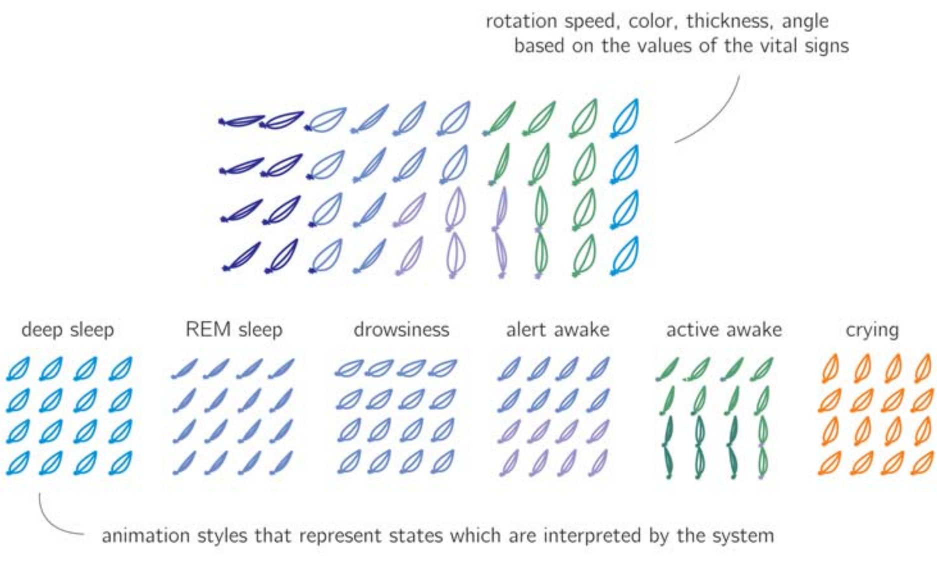


Figure 7.2: Concept 2: Abstract real-time monitoring animation

And alternative is to display predetermined animation styles matching specific states of the baby. For example, the six states of consciousness shown in Figure 7.2. The baby's state would be distilled from monitoring data and additional modalities such as acceleration and CFM monitoring. Parents may need to 'teach' the system in finding the personalized settings for detecting the correct state for their baby, similar as with the Exmobaby described in section 1.2 [Exmobaby, 2010]. Informing the parents about the states could help them to adjust their interaction style (e.g. comforting, guiding the transition from one stage to another).

Concept 3: Multi-modal object 7.3
The multi-modal object is held by the parents and tactically communicates the temperature, heart beat and respiration from the baby to the parent. With the object, parents can feel the vital signs while looking at their baby at the same time. This offers an intimate experience as alternative to touch when the baby needs to rest. While the baby is awake the object potentially enables the parents to sense a effect of talking, singing or (facial) expressions. While the parents are away, the textile object can be placed in the incubator to collect and distribute scent back and fourth between the parent and baby, including the modality of scent as well. The aim of the multi-modal object is to support parents in getting to know their baby (I).

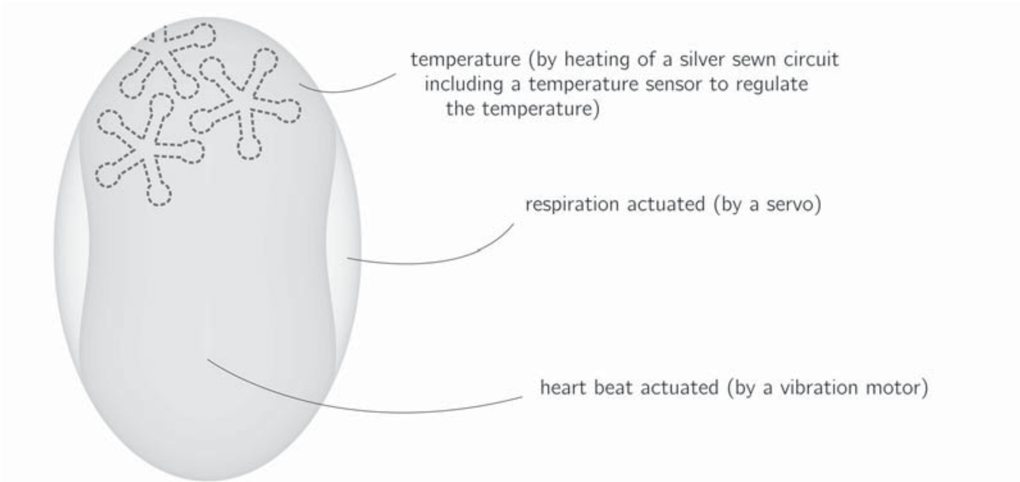


Figure 7.3: Concept 3: Multi-modal object

Concept 4: Baby soundscape 7.4
In the concept of the baby soundscape the parents are listening to what they cannot see or hear through the incubator's wall. Through the headphones they can hear the natural heartbeat and breathing (recorded with a microphone in the babies hat) while all their visual focus is on the baby. Next to natural baby sounds, non-auditive monitor data could be transformed into pleasant music. For example: guitar strokes, melodies, or a change in pace. Proximity of the parent controls the volume of the sound, creating awareness of the nearness to the child. Sound and music could potentially be experienced to be much more

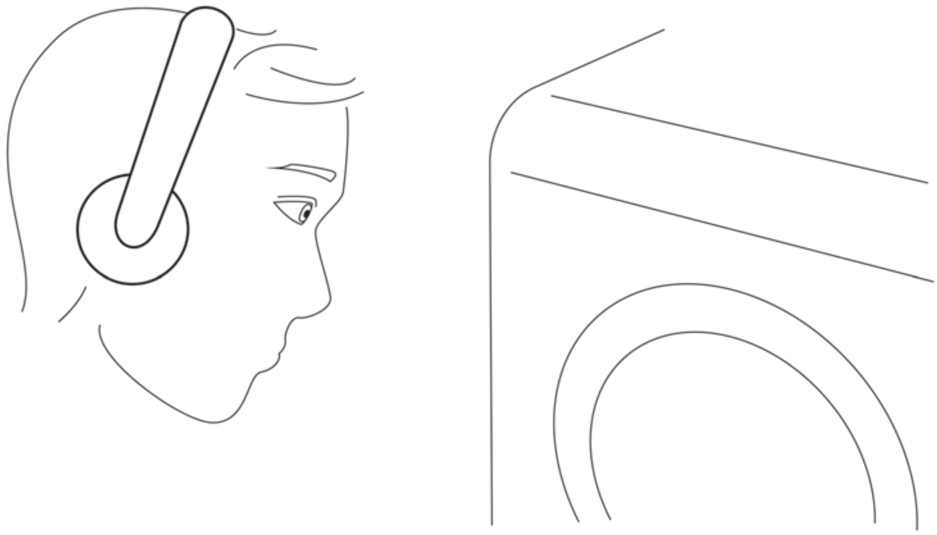


Figure 7.4: Concept 4: Baby soundscape

intimate than visuals. The aim of the real-time soundscape is to support parents in getting to know their baby by amplifying natural sounds of the baby and offering extra information about the baby's internal state that is otherwise hidden (I).

Concept 5: Positive growing visualization 7.5
An application that shows to the parents the milestones the baby reached towards to the day the parents can take their baby home. The application offers information that is relevant for the parents: weight, amount of sleep, feeding, activities, comfort, et cetera. This concept is aimed to support parents in getting to know their baby in a non-medical manner focusing on the positive developments (I).

Concept 6: Diary linked to monitor data Figure 7.6
The concept is to combine a monitoring display with diary function in an application. Parents can create diary entries which are inserted into the time line of monitoring data, such as texts, pictures or videos. Parents can engage using the diary while the baby is sleeping. It is a flexible platform in which according to individual preferences functions can be selected or hidden. They can create entries such a the baby's 'firsts', look for patterns, show something to the nurses, or play back video footage. Possibly the link between the parents' observations and documentation of events and the monitoring data history over time can illustrate patterns, supporting parents in getting to know their baby (I). The diary is mean for the parents to actively contribute (II) as well.

Concept 7: Positive effect visualization 7.7
An application that shows the parents that their presence in particular has a positive effect on their baby. The system detects when the parents are with the baby and compares the vital signs recorded during their presence to the vital signs recorded in a period of absence.

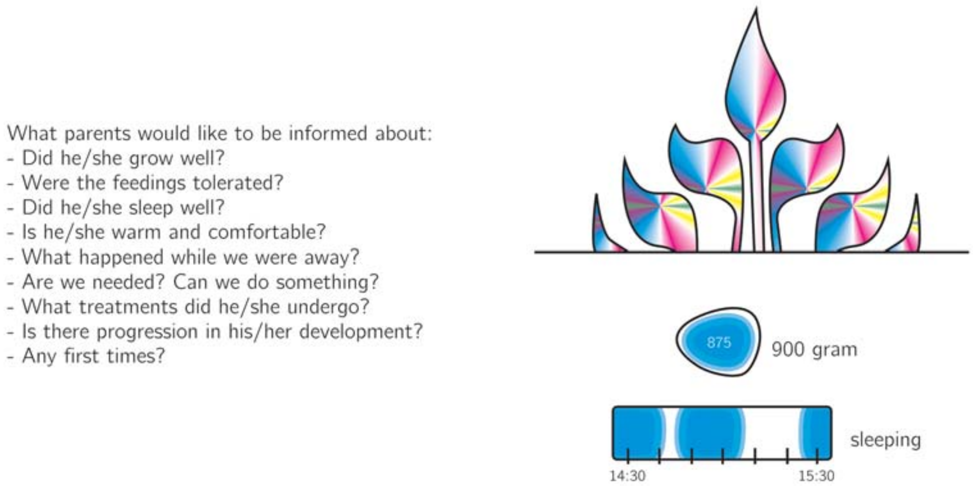


Figure 7.5: Concept 5: Positive growing visualization

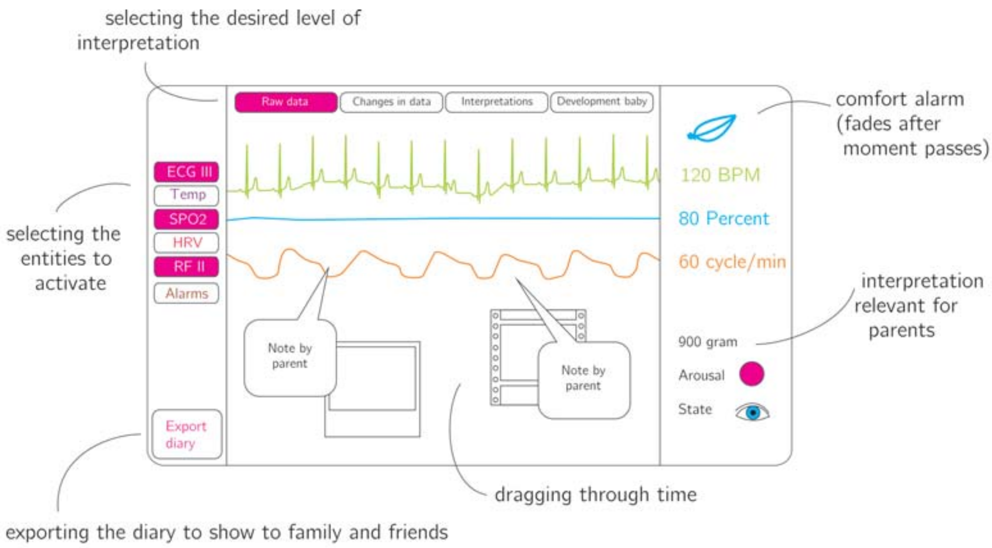


Figure 7.6: Concept 6: Diary linked to monitor data

Positive changes in the baby are visualized. An example of a positive effect could be the fast adjustment to temperature during KC. This concept addresses the design direction of acknowledging of the difference the baby knows between parents and medical professionals (III).

Concept 8: Baby observatory 7.8
This application supports the parents in observing subtle behavior and looking for patterns. The parents can document their observations by choosing events from a list. The application also contains information about the possible behavior of a premature baby, which may differ from a term baby. It provides the parents with pointers of what to look for, such as looking behavior, gestures, facial expressions, posture and skin texture. Parents can share their observations with the medical staff. For the medical staff this information can be helpful to get to know the baby and provide individualized care. This concept potentially helps parents to get to know their baby (I) and provides a means to actively contribute to the care (II).

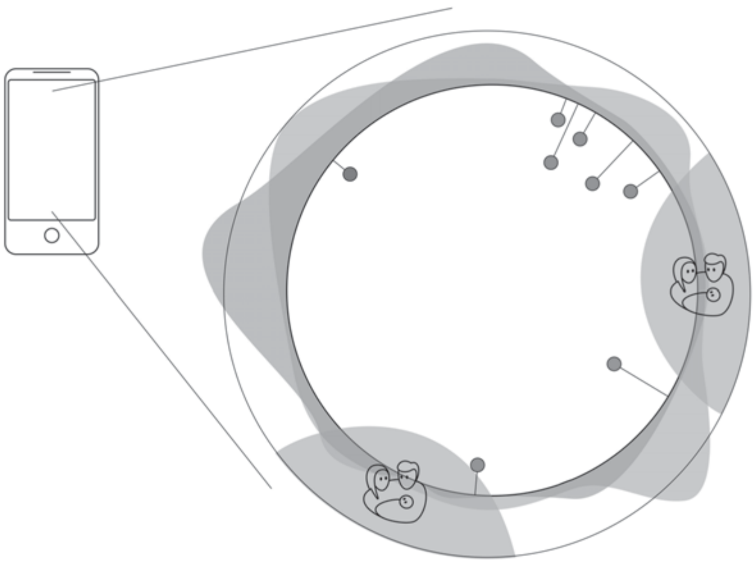


Figure 7.7: Concept 7: Positive effect visualization

Concept 9: Combination real-time and longterm 7.9
The system can be a combination of one of the proposed long term monitoring (tablet) applications with a real-time application close to the the baby. The long term visualization provides the parents with the opportunity to detect patterns and keep track of the overall development, while the real-time display feeds the parents continuously with updates of the current state and thereby potentially enables them to sense the effect of their presence in the moment.

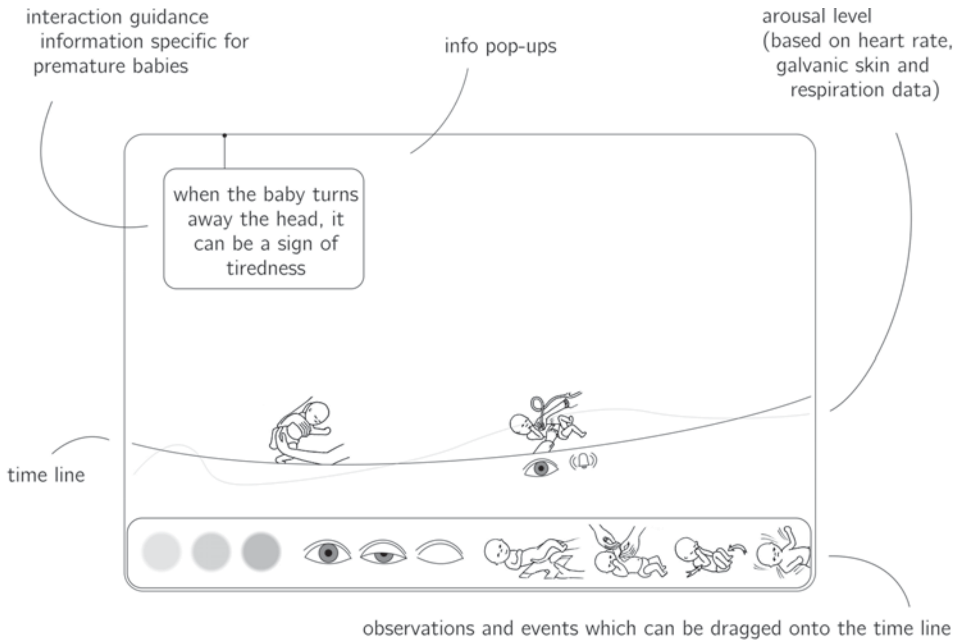


Figure 7.8: Concept 8: Baby observatory

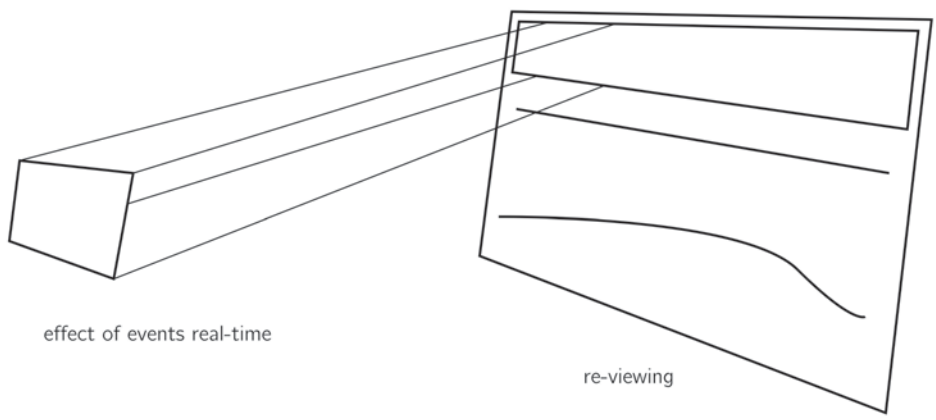


Figure 7.9: Concept 9: Combination real-time and longterm

7.2.3 Design insights and guidelines

During the brainstorm and the process of creating the concepts, two additional design insights and guidelines were identified.

Monitoring data is currently offered to the medical professionals and parents in the form of 'unprocessed' values and plots (unprocessed: except from filtering, calculation of frequency variation and alarm boundaries), leaving most of the interpretation up to a person. Specialized knowledge and experience determines how much a person can conclude from the monitoring data. Not just the vital signs are taken in account, but also what is observed in the baby and medical history. In the brainstorm ideas arose about automatic interpretation of monitoring data by a computer. A calculation of variation in frequency in a continuous measure is quite straightforward. Analysis of whether the baby is positively or negatively aroused becomes more complicated, and assigning an emotion is a complex task for a computerized system. Automatic interpretation by a system requires extensive research and testing, especially when new sensor modalities or types of interpretation are introduced. Parents might have to provide input in order to 'calibrate' the system specifically to their baby, similar to the Exmobaby garment [Exmobaby, 2010]. The level of interpretation performed by the system has to be well considered concerning the risk of misinterpretation. Even though a separate monitor for parents would not replace the current clinical monitor, providing the parents with false or misleading information is unacceptable and potentially harmful to the bonding process. This insight lead to the following new design guideline:

11 The product may not provide the parents any misguiding information about the status of their baby, neither when the interpretation is performed by a computer nor by a person.

A system becomes much more engaging, when true interaction is possible. Interaction requires that the parents are not merely passively receiving updates about their baby, but are able to intervene, resulting in a change. The feedback loop of the baby, sensors, display and parents, can be seen as a complete system, in which reactions the the parents are supported by the display. This insight lead to an addition to the design guidelines:

12 It is preferable that the design offers interaction and thereby empowering the parents.

7.3 Conclusion

The objective was to generate a concept that is likely to positively impact the bonding experience. In the choice for a certain concept there is no guarantee that the chosen concept will be the most effective or that it in practice will indeed impact the experience of bonding (design guideline 1: positively affecting 'repeated (initially physically close) reciprocal pleasurable experiences'). The concepts 1, 2, 3 and 4 are basically four variations of a real-time monitoring system, and the concepts 5, 6, 7 and 8 are four applications that display the monitoring history. Concept 9 is the combination of a real-time monitor and a long-term monitor. We select the concept that is most promising to develop further.

The real-time monitoring concepts are in principle all four about providing the parents with additional 'hidden' information about the baby's state, which can directly be linked to the parents' own observations in the baby. Possibly this enriches the interaction in a very direct manner, because it potentially contributes to: 'feeling connected', 'reassurance', 'sensitivity to the baby's needs', 'seeing the effect parents have', 'getting to know the baby' and 'focusing on the baby'. The real-time monitor could potentially positively support the interaction between the parents and baby, which would lie at the heart of the experience of bonding. The concepts differ in the type of sensor data used as input, the applied signal processing, the actuator type and the mapping of the data. It is expected that the different actuator types offer different experiences of intimacy and connectedness. Furthermore, attention is focused on the baby in two different manners: baby and data visually in one field or visual focus on baby and data with another sense modality.

The long-term concepts basically all offer the entering observations and/or by reflecting upon the monitoring history while the baby is resting. Reflection on the history of monitoring data in combination with their own observations might enable the parent to find patterns and thereby 'getting to know their baby better' and/or 'see a positive effect of interaction'. Entering the observations and sharing them could give the parents a means to contribute. And detecting positive developments over time could provide 'reassurance'. The concepts differ in the type of sensor data used as input, the applied signal processing and the mapping of the data. Additionally, the visualizations must easily reveal patterns.

Before making a choice, we needed to gain more practical insights into the execution details and the resulting experiences. Whether the design guidelines of non-obtrusiveness, autonomy, safety, positive experiences, comfort, attention focus, naturalness, accuracy and actualization are being met, depends much on the exact execution of the concept. We created an iteration on concept 9; the combination of a real-time monitor with a long-term application. Especially the mapping of monitoring data to animation parameters was an aspect which we wanted to explore early on, in order to gain an idea of whether it is possible to present the data in a non-medical manner which is yet informative. Also from the perspective of design and research we wanted to find a gap where the boundaries of innovation and knowledge could be pushed. The process of creation helped us to reveal these challenges.

In Figure 7.10 and Figure 7.11 an iteration is shown of the real-time display positioned nearby the baby, combined with the long term application outside the incubator. The animation with pinks dots was created in the open source software called Processing (started by Ben Fry and Casey Reas in the spring of 2001 at MIT Boston) to explore the effect of mapping the vital signs to animation parameters. In the pink dot animation the interpretation was left to the parents by mapping the vital sign one-on-one to the animation parameters, see Figure 7.10. The idea is that in a similar way parents observe the baby and thereby gain an impression of how the baby is doing, they can additional observe the display to incorporate 'unseen' subtleties. We mapped for example the heartbeat frequency to the speed of the circular motion of the pink dot. The result was a peaceful visualization. The visualization is more restless when the heartbeat frequency is literally mapped to a frequency for example alternation in color shade, because the heart rate of a prematurely

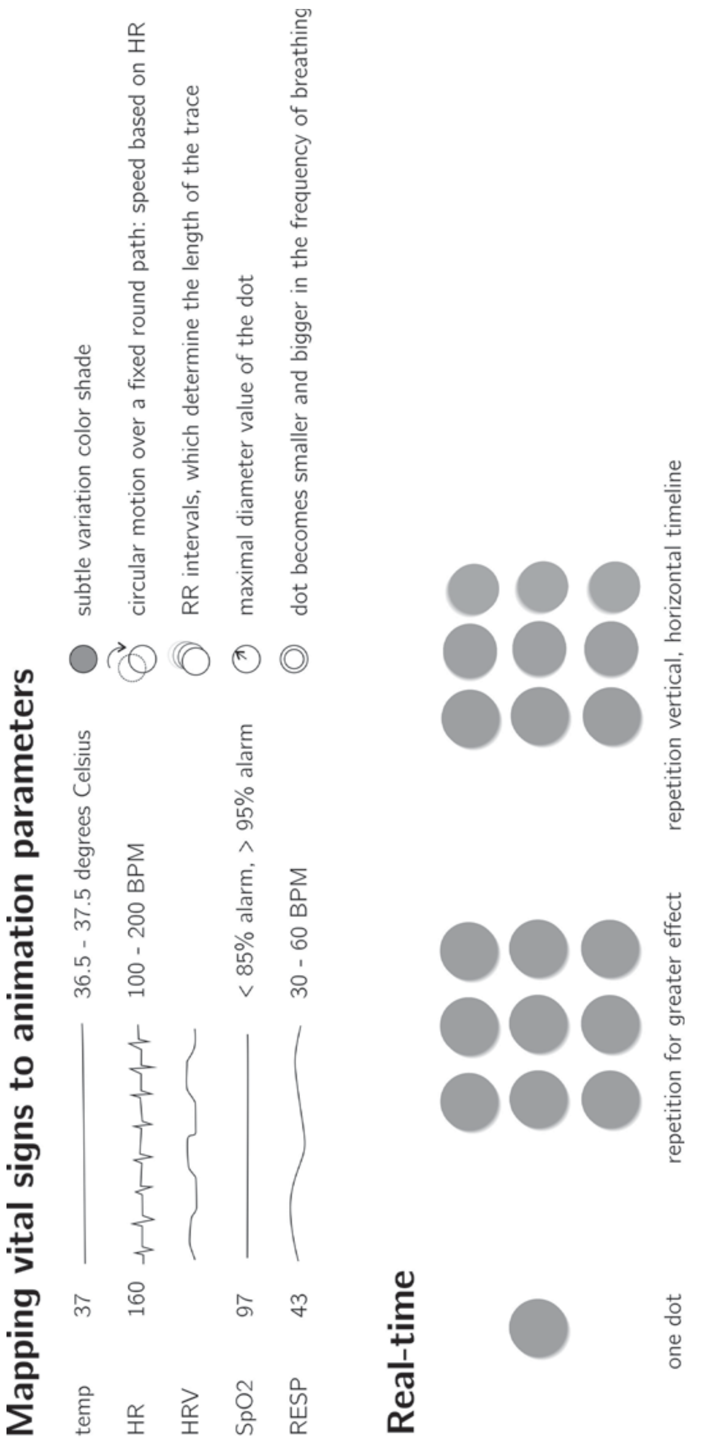


Figure 7.10: Iteration concept 9: Pink dots design

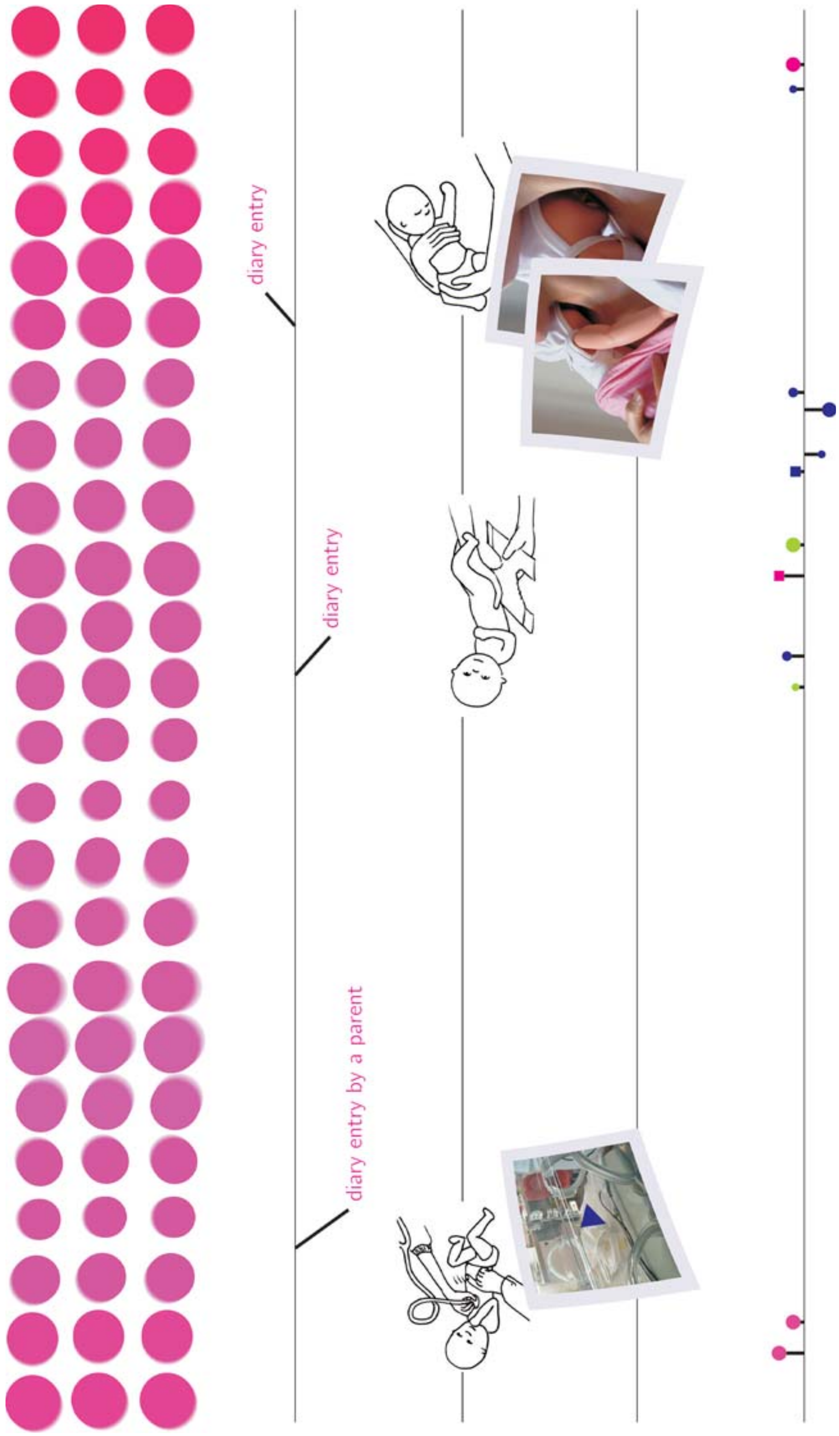


Figure 7.11: Iteration concept 9: Pink dots timeline

born baby is really fast. The downside of mapping the frequency to the speed is that it is unlikely that parents intuitively will recognize this to be the heartbeat frequency. A literal mapping of heartbeat frequency to a frequency is more likely to be interpreted as heartbeat. Additionally, the literal heartbeat is potentially more intimate. The techniques of programming a new application for a phone or a tablet to present the data is fairly traditional. The idea of focusing the visual attention to the baby realized by locating the display nearby the baby, or a multi-modal object held by the parent, requires different types of actuators than a LCD screen. The actuators must be suitable to to be applied nearby the baby and parents. We identify the opportunity to create a non-medical real-time display that can be used comfortably nearby the baby or parents.

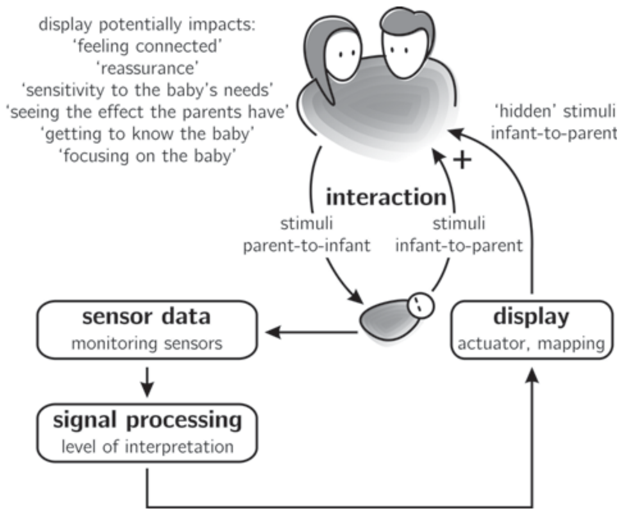


Figure 7.12: Real-time monitor design aspects and its potential role in the action-reaction cycle

We choose for the concept of a real-time monitoring system, because we foresee that it has much potential to positively contribute to the bonding experiences ('repeated (initially physically close) reciprocal pleasurable experiences') in a direct manner. See Figure 7.12. The real-time monitor could become an integral part of the action-reaction cycle between parents and baby. In the figure the design challenges are illustrated in the boxes. A type of 'monitoring sensor' must be chosen, in combination with 'the level of automatic interpretation' in signal processing, the type of 'actuator' for the display and 'mapping' of the processed data to actuation parameters. Research-wise the choices in sensor data and signal processing will impact the long-term effect of using the real-time monitor, because it depends on how the parents will use the additional information in real-life with yet unknown user scenarios. The type of actuator and the modality in which the display is designed is expected to greatly impact the experience in the moment and the mapping of data will influence how well the display can be read. From a design perspective the challenge of building prototypes creating an experience with different actuators is interesting.

Chapter 8

Exploration of actuators for real-time monitoring display designs

8.1 Introduction

The real-time display was selected for further development because it is a design challenge to create a bonding experience by representing monitor data in a non-medical way and to create a display comfortably close to the baby and parents. This chapter is about the designing of several versions of a real-time monitoring display using various actuator types. Firstly, we explored the implementation of actuators by building mock-ups and reflecting upon them. We aimed for a display design that is unobtrusive, informative, attractive, safe and allows for the focus of attention to be on baby. Secondly, we made design decisions for the real-time monitor based on the experiences with the mock-ups. We built four real-time prototype simulation monitor displays. In the next chapter we will present the results of gathering feedback on the designs in a comparison.

8.2 Design exploration of display actuators

8.2.1 State-of-the-art textile and actuator technologies

To create the intended experience we looked into the state-of-the-art textile and actuation technologies which might allow the production of a data display which will be close to the baby and/or parents. Table 8.1 shows an overview of most actuators and other relevant materials and techniques, accompanied by examples. Some of the actuators are under development, others are widely available. In the next section we describe the technologies that we used to create the prototypes.

8.2.2 Experiences with creating real-time mock-up displays

By building the mock-ups, the real life challenges and effects were explored. Prototyping is an essential part of the conceptual phase in order to evaluate the experiences early on. The book 'Programming Interactivity, A designers guide to Processing, Arduino, and openFrameworks' [Noble, 2009] has been a source of inspiration for the practical electronic hardware and software implementation of the actuators. We explored the application of thermo chromic ink, optical fibers, OLED, LCD, magnetic actuation, speakers and solenoids.

Thermo chromic ink
The design (Figure 8.1) created with thermo chromic ink, is a baby hat with two ellipses that indicate when HR and SpO2 increase or decrease. The material is DynaColor thermo chromic textile screen ink [Chromatic, nd] which changes color from dark green to lime green at a 31 degree activation temperature. The thermo chromic ink was stenciled onto the cotton textile. A circuitry from Shieldex silver yarn was stitched through the ink. The four circuitry sections (HR increases, HR decreases, SpO2 increases, SpO2 decreases) changed color when power was applied, because the resistance of the conductive yarn generated heat. We created a controller with an Arduino to test the effect. In the circuit we used a potentiometer to manually set the pulse width modulation (PWM) percentage that controlled the power, to explore when the activation temperature was reached. The color changed functioned well. We noticed that the ink heated up right next to the conductive yarn stitching, therefore to cover an area, the embroidery pattern should be denser. The visualization and communicated information on the hat is rather simplistic. Another issue is that a hat is a rather small product for integration of a chip, circuitry and battery. A mattress, blanket, toy or another object in the incubator would offer more space to include electronics. The positive aspect of the hat design is that the data is displayed close to the baby and the signaling is subtle.

Optical fibers
Using optical fibers we have created several mock-up prototypes to explore the possibilities and limitations for a real-time monitoring display in the form of a blanket. In [Oscarsson et al., 2009] we found that there are three methods for side emitting of light with optical fibers: (1) "Adding a special, light-scattering material to the core of the fiber", (2) "mechanically, by scratching the surface of the fiber" and (3) "bend the fiber continuously, as the light will leak out of the fiber when it is bend at a certain rate".

The blanket with the tree design (Figure 8.2) was designed to realize the same representation as in Figure 7.10, however in a blanket. It contains six groups of fibers that can individually be connected to LEDs. The inner and outer circles represent breathing in and out. They are designed to be controlled with a 'fading' function: the illumination is supposed to move around the circles in the circular path in a speed relative to the frequency of the heart rate. Optical fibers with a diameter of 0.3 mm from a commercial 'UFO lamp' were applied. The light was released where the outer layer was scratched with sandpaper.

Actuator type	Function	Example(s)
(SMD) LED	Light emitting source point	[Kassenaar, 2011]
Fiber optics	Plastic or glass cable that transmits light	[LumiGram, nd]
Electroluminescent (EL) wire or panel	Light emitting surface or wire	[Earlsmann, nd], [Winters, nd]
OLED	Light emitting surface	[Holst, nd], [Philips, nd]
LCD	Light emitting surface with individual pixels	[Sparkfun, nd]
Electroluniscent textiles	Soft, flexible textile display	[Cetemmsa, 2009]
Polymer Opal Lycra	Rubber that changes color when bended	[NanoPhotonics, nd], [Winters, nd]
Hydrochromic paint	Translucent when whet	[Mindsets, nd]
Hydromorph	Grows five times in size when whet	[Mindsets, nd]
Nitinol/shape memory alloy	Contracts when heated or returns to default shape	[Kokabant, nd]
Thermo chromic ink or sheet	Changes color or transparency when heated	[Mindsets, nd], [Chromatic, nd]
Glow in the dark pigments	Emits light for a while after having absorbed it	[Pakhchyan, 2008] [Mindsets, nd]
Black light pigments	Glowing color in UV light	[Mindsets, nd]
Piezoelectric materials	Generates force (sound)	[Pakhchyan, 2008]
Pumping air/fluid	Generates force (pressure)	[Al-Kaylani et al., 2012]
Servo motor, motor	Rotation angle, rotation	[Sparkfun, nd]
Solenoid	Linear motion	[Sparkfun, nd]
Vibration motor	Unbalanced rotation	[Sparkfun, nd]
Speaker/voice coil	Linear motion	[Kokabant, nd]
Flux detector	Turns dark where a magnetic field is perpendicular	[Supermagnete, nd]
E paper or e ink	Non-light emitting discrete display	[E Ink, nd]
Flip dots	Electromechanical rotation of a colored disk	[van Dongen, 2012]

Table 8.1: Textile and actuation technologies

Figure 8.1: Hat with SpO2 and HR indicators of change

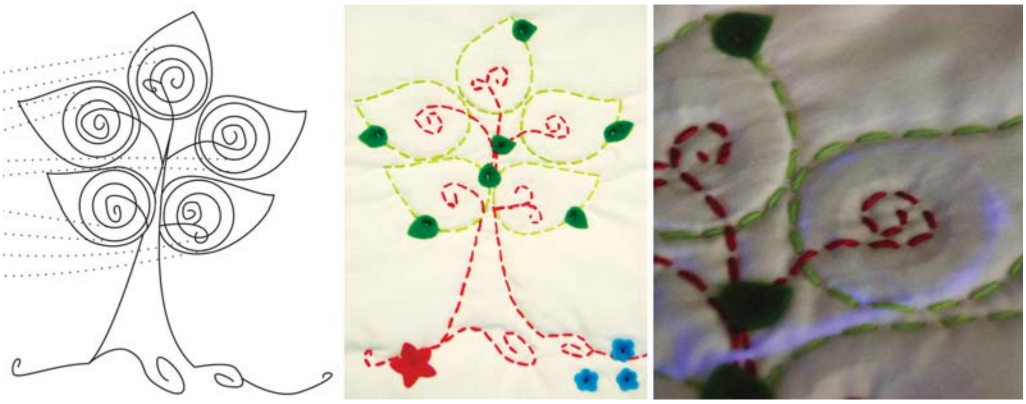


Figure 8.2: Blanket with tree visualization

8.2.2. Experiences with creating real-time mock-up displays

We sanded the ends of six fibers of different lengths and bound them together in a circle. The circles were embedded in a blanket of cotton, padding, embroidery yarn and felt. In the result, the visibility depended much the brightness of the LED and the environmental light. In relative darkness the circles were clear and the light was visible along the fiber until the point where it was sanded. The fibers were quite stiff and reduced the comfort of the blanket.

In Figure 8.3 a mock-up can be found in which partially sanded fibers of 0.3 mm thickness were integrated by hand into the weaving process of the textile. We used thin see-through acrylic yarn for the vertical weft and cotton yarn (3.5 knitting needle) for the horizontal weft. Between each cotton line, a fiber was woven along. In the mock-up, the amount of fibers (+/- 40) was just high enough to define the two circles. If several elements would be placed next to each other in a design, the density of fibers had to increase accordingly, because when sanding one fiber, it only had one light emitting 'spot'. The integration of the fibers in the weaving process resulted in a homogeneous flat structure. The part of the fabric where no fibers were woven along was much more flexible and pleasant to the touch. Using the same weaving technique we also created a few test patches using different types of yarn to evaluate the yarn' light absorbing properties Figure 8.4. We concluded the white cotton/acrylic yarn offered the brightest colors.

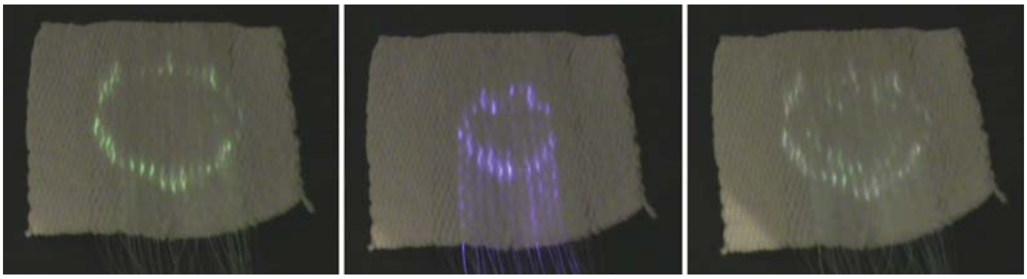


Figure 8.3: Woven fabric with integrated optical fiber sections

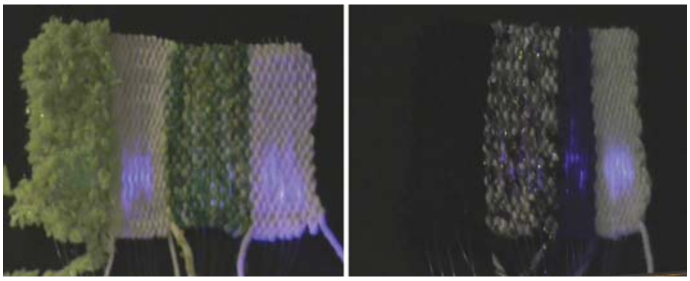


Figure 8.4: Various test yarns

In Figure 8.5 we used elastic fibers which are sold for the stringing jewelry beads. The elastic fiber was less suitable for sanding because it is rubber-alike. However, the property of flexibility allowed for bending with a small radius. In a bend of the fiber, the light 'leaked'. We proposed to string a glass bead with two holes along the fiber. Twenty beads stringed to elastic fibers were distributed evenly in the weave of the fabric. The result was a soft flexible fabric with here and there a bead. Although the bend in the bead made sure all light was released at that point, much intensity was already lost on the way to the bead. The elastic fibers did not maintain the light as well as the fibers from the 'UFO lamp', even though the elastic fiber was much thicker: 0.8 mm. Due to their elasticity, the fibers slightly bended between the vertical wefts. A benefit of the beads was that the fiber was lifted from the fabric, preventing coverage by the cotton yarn. As shown in the figure where a regular LED was held against the end of the fiber, the brightness was not high. A strong light source and efficient connection to the fiber could increase the light intensity. In [Ziemann et al., 2008] we found information about the connection. Fiber optic cutting and polishing kits are commercially available. They are used to to cut the fiber straight and polish the cut surface for efficient light transfer in professional glass fibers for data transfer. The roughness of the cut surface should be smaller than the visible light spectrum. The LED has to be placed close to the fiber end and a lens can be used to focus the beam. For the data visualization we did not directly have anything in mind, because up to this point the focus was on integration of the actuator type.

OLED

One square OLED [Philips, nd] was at hand for exploration. The advantage of an OLED is that it is a bright, homogeneous and flat light source, which can be controlled in the same manner as a regular LED. We held the OLED under a fuzzy cotton fabric and it resulted in a bright enlightened square section. Negative properties for our application in a blanket would be that the OLED is made of a non-breathing and rigid material. The OLED is however clearly visible, even in a well lid room. The OLED can be produced in many shapes organized in any figuration. We created a 'Wizard-of-Oz' version of a OLED real-time monitoring display design using regular LEDs. Figure 8.10b shows that the design consists of one circular section (meant for the pulsating heart rate) surrounded by four ring sections (meant for the breathing increase/decrease). The LEDs were placed in the bottom. A fuzzy cotton fabric was lain on top. The distance between the fabric and LED created a similar diffuse effect as the OLED.

Figure 8.5: Elastic fiber with 20 beads

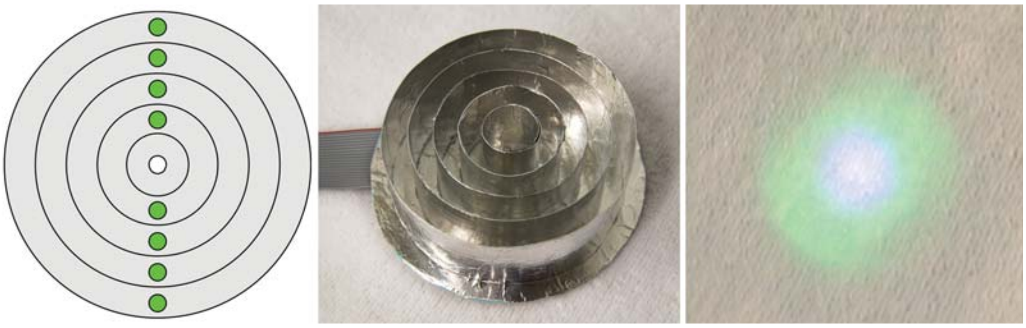


Figure 8.6: OLED 'Wizard of oz'

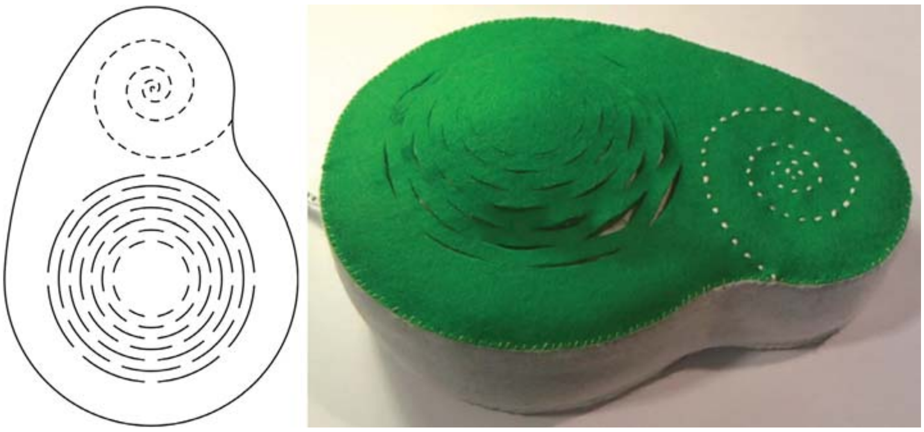


Figure 8.7: Hapic real-time display with a speaker and solenoid

Speaker

We experimented with a speaker as an actuator for the realization of linear motion for the representation of breathing. When the cone of a speaker moves linearly in and out in a fast frequency, sound is generated. Our main questions were whether, when we applied a sinus rhythm in the frequency of breathing, sound would be generated. And, whether the motion would be powerful and large enough to move the hand and thereby providing haptic feedback. In the lab we used a sinus generator to provide frequencies around 0.67 Hz to 1 Hz (40 BPM to 60 BPM) for a speaker with a of diameter +/- 15 cm. The result was a very smooth motion which was strong enough to 'push back'. The next step was to remove the cone that guides the motion of the coil linearly along the magnet, because the cone is large and doesn't fit the hand nicely. After the cone was removed, the speaker scrapes along the sides when the hand guides the speaker sidewards. However without force, the hand was still guided smoothly. After integration into a structure of felt (Figure 8.7), the speaker had no problem of pushing and pulling the felt along with the movement. A larger challenge arose when we tried to control the speaker with the Arduino. Without a filter, the speaker started to generate sound and vibrated, because the PWM signal send by the Arduino contained high frequencies. A filter with large capacitors and coils silenced the speaker and greatly reduced the vibration. A side effect was that the motion range decreased as well. One of the strength is that parents can feel the data, while keeping all visual attention to the baby. We experienced the literal translation of the respiration as intimate in the mock-up.

LCD

The LCD screen of the laptop (Figure 7.11) offered endless possibilities for data visualization. The downside it that a LCD screen is rigid and therefore it is less suitable to locate closely to the baby. On a mobile phone it could be an attractive application to held by parents next to the incubator and only be glanced at when desired. A mobile application would offer many options for extension of functionality.

Magnetic actuation

The idea for magnetic beads originated from e-ink displays. We build mock-ups with mini coils and magnets (Figure 8.8) and by trial and error found a configuration that worked: fixation of two strong disk magnets (diameter 5 mm, thickness 1 mm) around an plastic axis centered within a copper coil Figure 8.9. When we applied a current, the magnetic field induced by the coil ensured the magnet arranged the North and the South either up or down. By alternating the direction of current, the side of the magnet which was up was controlled. By applying a color to each side of the magnet, the disk was alternating between color. We created a set of beads. It was challenging to work on a such small scale and the laser cutting of plastic elements was a welcome solution. In the end result the beads were not always flipping when power was applied, probably partially because there was too much friction in the rotation around the axis and partially because of their sensitiveness to fields in the environment.

The idea for a visualization was to create a grid of beads that actuated patterns of motion and alternating color. The discrete actuation however limited the possibilities of visualization greatly. The visualization could become more detailed, as more beads are applied. We encountered however two issues. One, that the beads were sensitive to the presence of (magnetic) metal in the environment and the influence the magnetic field of the beads had on each other. When we applied a smaller magnet (diameter 3 mm, thickness 1 mm) the distance between beads still had to at very least be 60 mm. And two, when increasing the resolution of a visualization that involves a frequency, more motioning takes place within the same time span. At the high frequencies of the heartbeat and respiration of an infant, the amount of motioning became restless. The beads might be more suitable for signaling gradual changes or low frequency continuous data.

The digital and analog pins were programmed as if they were PWM pins, using the SoftPWM library, which enabled to set a fade in and fade out period. A fading period of 10 milliseconds resulted in a decisive, yet 'softened' flip of the bead. Before we applied a fading time, the flipping of the bead (with stronger magnets) could be felt subtly. Actually, it felt similar to a heart beat. Also even when the bead was covered by a felt layer. We identified that the bead could be applied to provide haptic feedback.

In September 2012 the Flip-dot dress project of Pauline van Dongen was published on her website [van Dongen, 2012]. She had worked in parallel to our development of the beads, on the integration of flip-dot actuators (usually applied in large screen displays) into a dress. The main strength of the flip-dots is that they can be placed right next to each other. The main strength of the beads is that they are small in size.

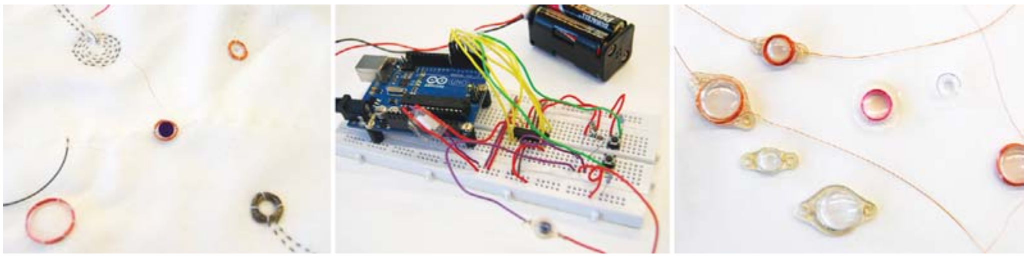


Figure 8.8: First explorations with coils and magnets using a test circuit

Figure 8.9: Beads (yet without the cover)

Solenoid
A solenoid (linear actuation) was connected for the actuation of respiration. The effect was unpleasant to watch and feel because the solenoid moved between the outer positions in one step. A softPWM library to control the fading did not fully slow down the motion to realize the impressing of a smooth motion. We did however come to the conclusion that the solenoid is suitable for heartbeat actuation. A small push against a cover of felt, was similar to a real heartbeat sensed on the skin. The intensity and frequency of the beats was easily adjusted with the Arduino.

8.3 Design choices for real-time monitor

The previous exploration of actuator types for real-time monitoring has let to new design insights. During the design process we concluded that the actuator type greatly impacts the instantaneous experience and also determines the opportunities and limitations in mapping (speed, resolution, intensity). Therefore, the choice in actuator type was leading.

Choices in type of actuator

We decided to further develop four display designs: (1) a bead blanket, (2) an optical blanket, (3) a mobile application and (4) a tactile object. The actuators and modalities that were not further developed are: chromic ink, Smart Metal Alloy (SMA), air/fluid pockets, and the modalities of sound, taste and scent. The thermo chromic ink and SMA response time are too slow for real-time continuous monitoring. The mechanical actuation by filling pockets with air or fluid was not further explored, because of the disadvantages of incorporating it into a blanket: non-breathable materials, motion nearby the baby and noise by the pumps. Sound is a modality that we do not wish to add to the NICU. Although sound can be intimate, it is preferable that the parents can hear each other, themselves (talking, singing), nurses approaching, real sounds from the baby and alarms. The modalities taste and scent also have too long response times to represent real-time data. Some of the other technologies such as glow in the dark ink and Black light pigments simply had not lead to inspiration for viable ideas for our application of real-time monitoring in the NICU.

Choices in type of monitoring sensor

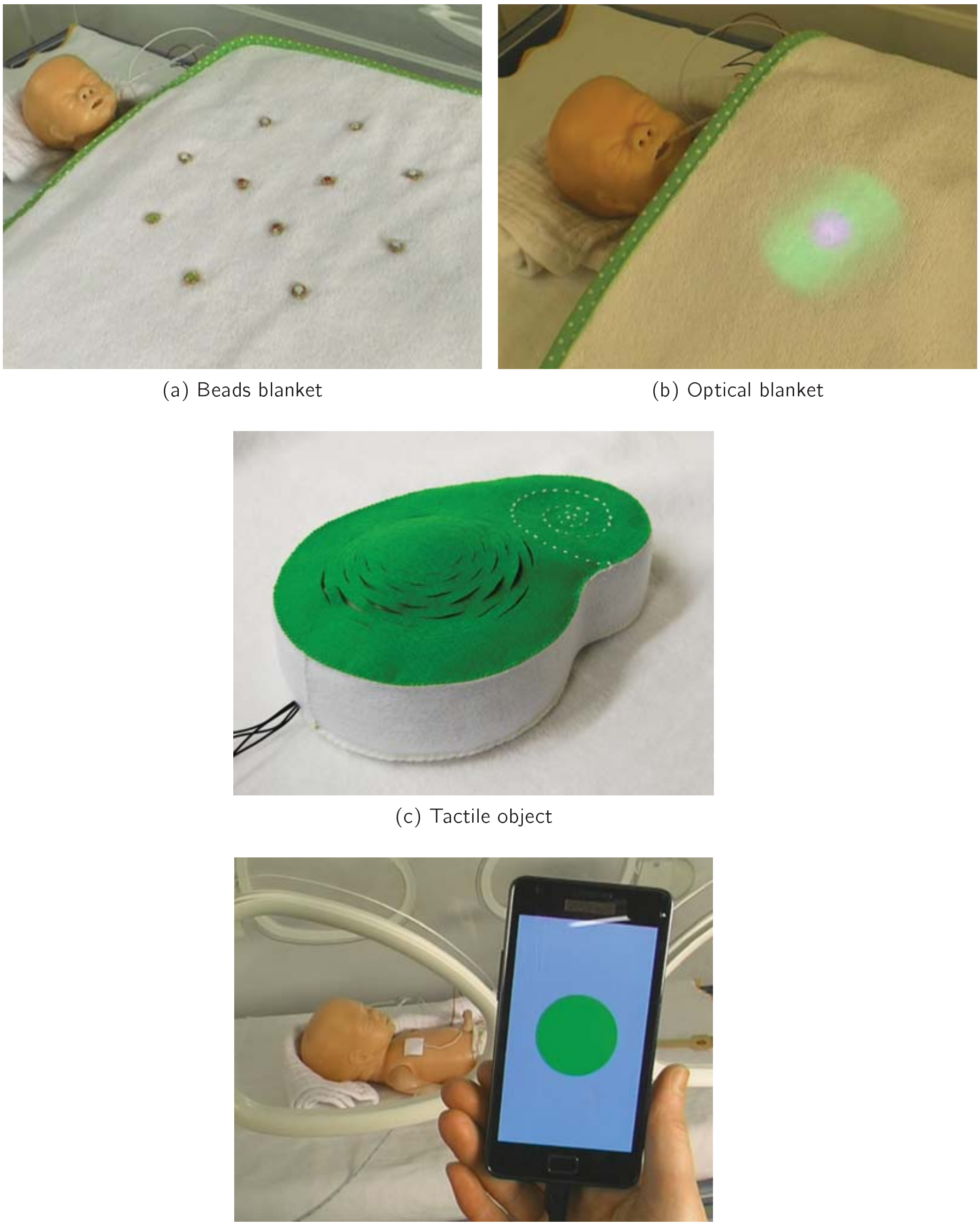
For the type of monitoring sensors we chose to represent the heartbeat and breathing rhythm in a real-time and literal translation (frequency to frequency, gradual change to gradual change, et cetera) in all the designs. We chose these two monitoring modalities because they are natural, intuitive and continuous. Research has shown that the feeling of the heartbeat can support feelings of connectedness [Janssen et al., 2010]. Whereas the SpO2 for example is a percentage that signals an increase or drop, and temperature is a constant that changes gradually over time.

Choices in mapping

We chose for a literal mapping of the data to prevent misinterpretation by the computerized system. Breathing is represented in the growing and shrinking of a green circle in the real-time frequency. This was chosen because when breathing the chest also increases and decreases in size. For the heartbeat was chosen for alternating between two color shades or intensities with intervals based on the HR frequency, because the mapping is literal and is independent from the breathing. Next we describe how this was realized for each of the actuator types.

The prototypes

The bead blanket display (Figure 8.10a) is located closely to the baby inside the incubator. The monitoring data is expressed in the motion of beads that alternate between two colors. The heartbeat is represented by the flipping of the three pink beads in the middle. The respiration is represented by the flipping of four green and four blue beads in a circular pattern. Half of the circle (blue) stands for breathing out, and half of the circle (green) stands for breathing in. This mapping is slightly different from the increase and decrease of size due to the limitation of the actuators, however, does literally represent the breathing frequency.



(a) Beads blanket

(b) Optical blanket

(c) Tactile object

(d) LCD mobile screen

Figure 8.10: The four real-time monitoring designs

The optical blanket (Figure 8.10b) is located closely to the baby inside the incubator. The monitoring data is expressed in a circle that grows and shirks with rings around and varies in light intensity. The breathing is represented by the growing and shrinking, which is built up from five green rings, the light intensity which is smoothly controlled passing from one ring to another. The middle dot's white light intensity pulsing rate represents the heart rate.

The tactile object (Figure 8.10c) is located outside the incubator held by the parent. The monitoring data is expressed in motion. A speaker imitates the breathing by moving up and down gradually, and the heart beat can be felt, through a 'push' actuated by a solenoid that goes out on the R-peak of the ECG.

The LCD screen (Figure 8.10d) is located outside the incubator on a phone held by the parent. The LCD screen has a similar animation as the optical blanket. The breathing rate controls the size of a green circle and the heartbeat controls the color shade of the circle.

8.4 Hardware and software implementation

We developed the prototypes up to the same level of detail in order to make a fair comparison. Here we describe the technical details of the design implementation.

Beads blanket 8.10a
We connected eleven beads to an Arduino UNO via an H-bridge (L293DNE) and a resistor. The H-bridge enables to switch direction of current, which flips the color of the bead. Eight of the beads were individually connected to the H-bridge and three were connected in series. The three beads in the middle formed a group. The circuitry in the blanket was created with thin isolated copper wire sewn on a thin cotton fabric. In Arduino 1.0 we wrote a program for the heartbeat and respiration actuation. Prof.dr.ir. Loe Feijs suggested a Finite State Machine (FSM) for the parallel timing of the heartbeat and respiration in Arduino. See Appendix A. A 6 Volt 1.5 Ampere adapter was used to power the circuit. Using the SoftPWM library a fading period of 10 milliseconds was set.

Optical blanket 8.10b
The visualization consist of one LED in the inner circle, and two LEDs in each ring each pair connected in series 8.10b. We re-used the circuit with H-bridges, only replacing the resistors matching the actuators. The circuit was powered with a 6 Volt 1.5 Ampere adapter. In Appendix A the Finite State Machine can be found for the optical blanket. The SoftPWM library was included and fading periods were calculated by the period of the frequency divided by the number of states. This resulted in a smooth and adaptive fading.

Tactile object 8.10c
The speaker and solenoid were both connected to an H-bridge. The timing of the heart beat and respiration was realized by the Finite State Machine A. Without applied power, the speaker stays in neutral position. When a voltage is applied in one direction the speaker

moves upwards (half a frequency period), and when the direction of current is switched, the speaker moves downwards (half a frequency period). By setting the fading time of respiration on one-fourth of the frequency period, the power is applied in a zigzag wave with a range of twice the voltage. The PWM signal from the Arduino was filtered for the speaker using large capacitors and coils. The solenoid was connected in series with a resistor (22 Ohm). The solenoid was programmed to move outwards once every period, for a length of one-fourth of the period. The rest of the period the solenoid was being pulled in (actively and supported by gravity). The circuit was powered with a 7 Volt 2.14 Ampere adapter.

LCD mobile screen 8.10d
The LCD mobile screen was programmed in Processing and exported to an Android phone.

8.5 Conclusion

From the mock-up prototyping we gained insights into the opportunities and limitations that the explored actuator types offered. We chose for four display designs: (1) a bead blanket, (2) an optical blanket, (3) a mobile application and (4) a tactile object. The designs all have different types of actuators, and offer different experiences. In the next chapter we describe the gathering of feedback from the users in a comparison of the designs based on their readability and the instantaneous experience related to bonding.

Chapter 9

Comparing the performance and bonding experience of five real-time displays

9.1 Introduction

In this chapter we describe the user experiment that was conducted with the goal to select a real-time monitoring design from the four proposals in Section 8.3. We aimed to select the display actuator type and gain design insights for further development, based on user feedback. When in future the impact of a real-time monitor display on the level of bonding is to be tested with parents in the NICU over a long period of time, a highly developed prototype is required. Such extensive testing involving observation methods for the measurement of level of bonding is time consuming for the parents, medical staff and the researchers. Therefore, the 'pre-testing' of more instantaneous experiences with a wider range of participants, can potentially increase the usability of the prototype before extensive testing. Our approach is to make design choices early on in the design process based on user feedback, and thereby contribute to the design insights for a real-time monitor.

Earlier in Section 7.3 we decided to explore the effect the actuator type has on the experience of bonding, resulting in four designs. In the experiment we decided to measure whether the type of display actuators offer different instantaneous bonding experiences, to evaluate which display offers the best experience and how the designs can be improved. Additionally, the choice in actuator type also likely impacts how well the display can be interpreted correctly. These two aspects could be measured on one session with participants, which at this stage did not necessarily have to be parents at the NICU. We formulated research question (Q) 1 and 2 and hypothesis (H) 1 and 2. Research question 1 is subdivided into four questions.

Q1 **Performance**
Can the real-time abstract representations of monitoring data be interpreted by the parents at least as well as the current monitor?

- Q1.1 Can heartbeat be recognized equally well in each display?
- Q2.2 Can the breathing be recognized equally well in each display?
- Q3.3 Can the combination of heartbeat and breathing be recognized equally well in each display?
- Q4.4 Can changes in heart rate and breathing rate frequencies be detected equally well in the displays?

Q2 **Experience**
Do the real-time abstract representations of monitoring data offer variation in instantaneous bonding experiences by the parents, and if so which design offers the most supportive experience?

H1 **Performance**
The correct interpretation percentage of one of the designs is significantly higher. This display is easier to interpret that the other conditions.

H2 **Experience**
The rating of experiences of one of the designs is significantly higher. This design offers the best support of the instantaneous bonding experience.

Research questions 1 and 2 inquire to the preferences people have for a display based on their instantaneous bonding experience and how intuitively it can be read. The follow-up research question, not addressed in this experiment, would be: Does a real-time abstract representation support the parent-to-infant bonding, and in which way? This question goes beyond the instantaneous experience. It is about how the extra 'sense of connectedness' would be used in real-life and its long term effect on the parent-to-infant bond. This question is not addressed in the experiment, however it is mentioned to illustrate the bigger picture.

The experiment in this chapter is two-fold. The first part of the experiment is about measuring the performance of the different prototypes: whether they successfully convey the information to the parents. The performance test is a rating of whether the displays could be interpreted correctly. The second part of the experiment is about measuring the instantaneous bonding experience qualities of the various designs. A questionnaire for the instantaneous bonding experience did not exists yet, which is why we constructed a list of questions inquiring to the instantaneous bonding experience. This is a pilot version, on which it' reliability and suitability we reflected. The objective of the experiment is to select a display design based on actuator type and gain design insight for improvement. Figure 9.1 shows how the chapter is structured.

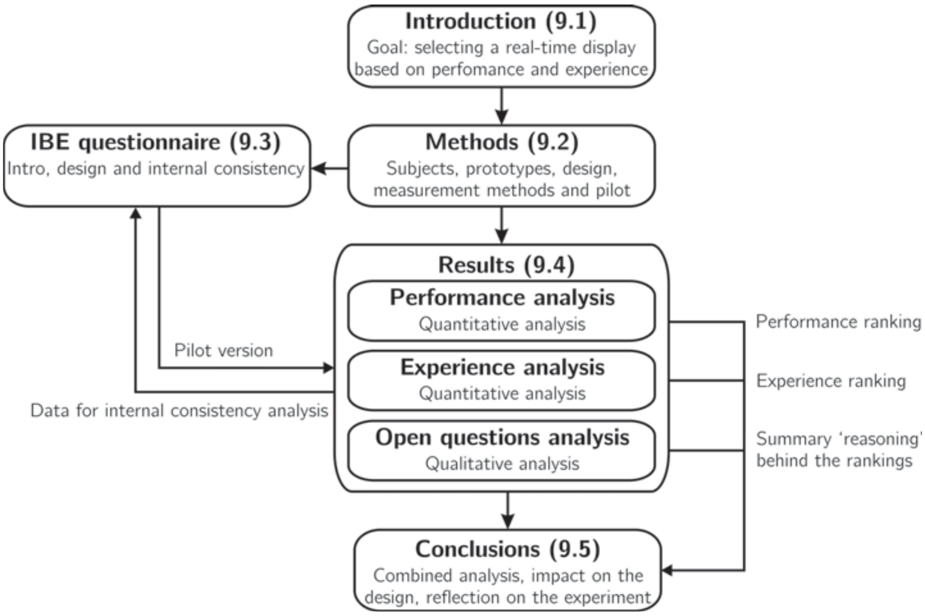


Figure 9.1: Structure of the study

9.2 Methods

Subjects

Participants were gathered through non-random sampling, namely quota sampling up to an aimed sample size of n = 25. We aimed for a balance of male/female and parents/non-parents in the sample. All participants required to be Dutch speaking and adult. The participants were requited by email or in person through the researchers network.

Prototypes

The four display designs and the standard monitor as control condition are the independent variables. The four prototypes are described in Section 8.3. The standard monitor display (Figure 9.2) design is located next to the incubator and offers detailed monitoring data. The monitoring data in this design is expressed in values and plots. The aesthetics are 'medical' and 'functional'. The current monitor includes a trace of the data, which was not altered because it is the control condition. The prototype was programmed in Processing.

Figure 9.3 shows schematically how the monitoring data is mapped in the five displays. The heartbeat, breathing, the combination of both and the change in frequency in both are four dependent variables in the performance experiment. The type of monitoring sensors, level of interpretation and mapping are continuous throughout the displays, as far as could be realized with the types of actuators. Inherently to the actuator type, other design parameters varied such as: materials, colors, resolutions and location. Due to the multiple design qualities that vary per display, it may not be possible to explain the specific source of an effect.

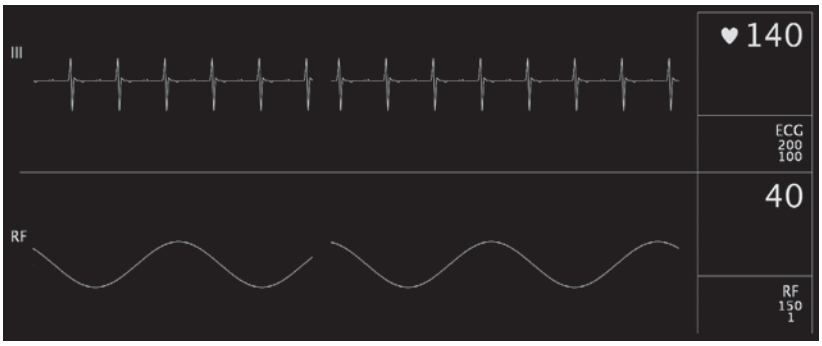


Figure 9.2: Control condition: standard monitor display

The prototypes were programmed for the same sets of 'behavior':

1 Only HR fixed at 140 BPM (30 seconds)

2 Only BR fixed at 40 BMP (30 seconds)

3 Both HR and BR fixed at 140 BPM and 40 BPM respectively (30 seconds)

4 Both HR and BR fixed at 140 BPM and 40 BPM respectively (10 seconds), both increasing to 40 BPM to 60 BPM respectively (10 seconds) and both fixed at 180 BPM and 60 BPM (10 seconds)

Design
The experiment procedure consisted of the following steps:

step 1 Introduction to the experiment
Short introduction to the NICU, consent form (B.0.1) and explanation of the experiment.

step 2 The performance experiment
Showing 20 videos of each 30 seconds. In randomized order (5 groups). Asking the participant what they observed (multiple choice) in the videos . (B.0.2).

step 3 The experience experiment
Showing 5 functional prototypes with the full behavior of the display in randomized order (5 groups). Asking the participants to fill out one 13-item IBQ questionnaire. (B.0.3) per prototype.

step 4 Qualitative feedback
Asking open ended qualitative questions (B.0.4) afterwards, providing insight into the 'why' behind the performance and experience.

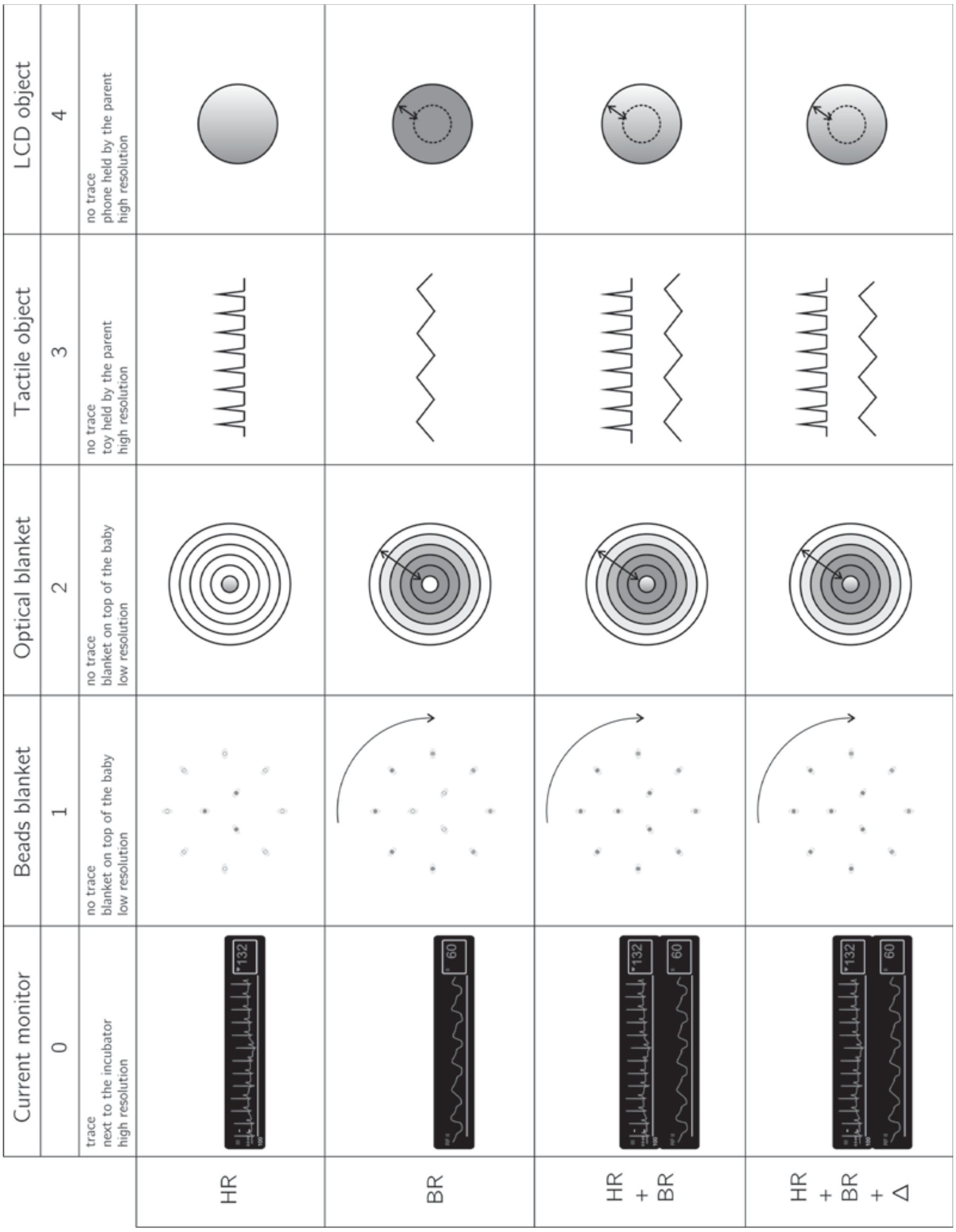


Figure 9.3: Overview of the variables

Method of measurement performance experiment

The hypothesis of difference describes a ranking of the displays according to how well they are interpreted by the parents, compared to the standard monitor. The independent variables are the five real-time displays. The participants are shown 20 movies each of 30 seconds (C, 1, 2, 3, 4) x (HR, BR, HR+BR, HR+BR+ Δ). Per video there are two questions (a) 'what do you recognize in the video?' (heart rhythm, heart rhythm and breathing pattern, breathing pattern, I don't know) and (b) 'what do you observe in the video?' (continuous speed, change in speed, I don't know). The form can be found in Appendix B.0.2. The dependent variables are the comparisons of the answer to what the participants observe to the intended truth providing with the nominal outcome of (true, false). For question 1.1 the dependent variable is the (true, false) rating (a) on the movie containing HR. For question 1.2 the dependent variable is the (true, false) rating (a) on the movie containing BR. For question 1.3 the dependent variables is the (true, false) rating (a) on the movie containing HR+BR. For question 1.4 the dependent variable is the (true, false) rating (b) on the movie containing HR+BR+Δ. For example: the answer of (a) observing 'HR' in the video 'HR + BR' was noted as a 'false'. The binary list contained values of 'true' = 1, 'false' and 'I don't known' = 0.

Method of measurement experience experiment

The hypothesis of difference describes a ranking of the display according to how well they support the instantaneous bonding experience perceived by the participants, compared to the current monitor. The design of the Instantaneous Bonding Experience questionnaire (IBE) is presented in 9.3. The independent variables are five demonstrations of the functional prototypes each of about two minutes (C, 1, 2, 3, 4) x (HR+BR+Δ). The dependent variable is the score on the IBE questionnaire (13 - 65 points per condition) based on 13 items each with an ordinal 5 point Likert scale.

Pilot test

A pilot test allowed to test and optimize the duration of the experiment and clarity to the participants. The setup in the lab was as can be seen in Figure 9.4. We concluded that the experiment duration was around 45 minutes. The setup with a central control laptop for the researcher from which the videos were started up on a second screen on the left and from which the prototypes were started up in sequence on the right, was functional. A major adjustment that needed to be made was the formalization of the performance questions. In the pilot test the participants could only choose from the options that were presented in the independent variables (HR, BR, HR+BR, HR+BR+ Δ) and the option 'none of the above'. This lead to frustration for in the participants for not being able to provide the answer that the participants had in mind. We decided to split the question into two parts: (a) the vital sign modality/modalities and (b) the change in frequency and adding the option of 'I don't know' for both. Another issue was that the fast frequencies of the vitals signs of a baby may be unfamiliar to the participant. Both frequencies are high and unfamiliar to anyone who has no experience with small babies. We decided that in the introductions awareness for this should be created by explaining that a baby has a higher frequency of heart rate and breathing and providing the normal values for heart rate and respiration rate for a prematurely born baby. A procedure was written in order to realize continuation in the experiment.

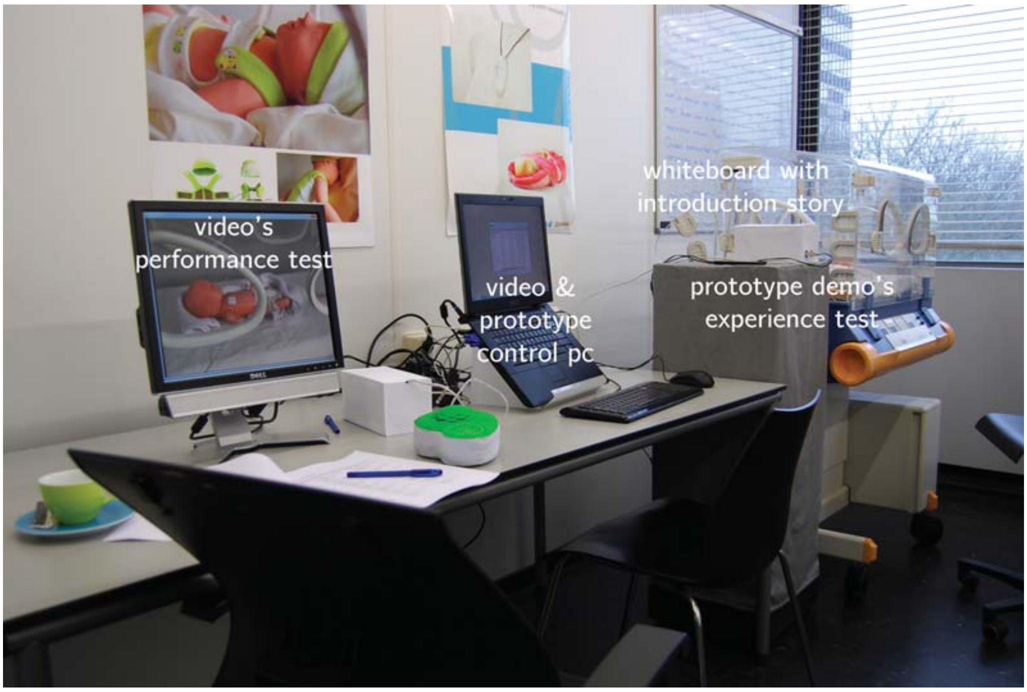


Figure 9.4: Experiment room setup

9.3 Instantaneous Bonding Experience questionnaire design

9.3.1 Introduction

An instrument that measures the effect of an intervention on the bonding experience could be of interest to any designer of products, architecture, or services for the NICU. For such an instrument we propose that:

- it measures instantaneous bonding experiences
- it measures positive nuances (not to scan for clinical bonding abnormalities)
- it is relevant to parent-infant bonding in the NICU
- it is applicable to fathers as well as mothers
- it is low in demand for the participants
- it is not labor intensive
- it is written in native language to the participants

In our literature study we found self-report questionnaires and observational studies from the field of psychology that are designed to measure the level of bonding. Table 9.1 lists the self-report parent-to-infant bonding questionnaires. Most of these questionnaires are designed to screen for bonding disorders in a general population of mothers with new born babies. One of the questionnaires [Nagata et al., 2000] contains items about parent-baby

Questionnaire	Abbreviation	Reference
Mother-to-Infant Bonding scale	MIB	[Taylor et al., 2005]
Maternal Postnatal Attachment scale	MPAS	[Condon and Corkindale, 1998]
Parental-Infant Attachment	PIA	[Condon et al., 2008]
Postpartum Maternal Attachment scale	PMA	[Nagata et al., 2000]
Postpartum Bonding Questionnaire	PBQ	[Brockington et al., 2006]
Bethlem Mother-infant interaction scale	BMIS	[Kumar and Hipwell, 1996]
Maternal Attachment Inventory	MAI	[Muller, 1994]

Table 9.1: List of self-report bonding questionnaires

bonding specifically in the context of the NICU. We conclude that none of these questionnaires are suitable for our purpose, because they are not designed to measure the effect of a design intervention in the instantaneous experience. These questionnaires all include items inquiring to experiences beyond the instantaneous experiences and often contain items that are too negative or confronting to propose to parents in the NICU.

Instruments for the measure intimacy and closeness between adults [Masheck and Aron, 2004, Romero et al., 2007] were also considered. However, the main reason that these instruments are not suitable for our purpose is that they depend on equal responsiveness in interaction between both parties. In case of parent and prematurely born baby interaction, the responsiveness and capacities are skewed to the side of the parents. Another option considered were observation studies, which are conventional in the field of psychology for measuring parent-infant bonding. A few examples of observation instruments are: the strange situation test [Ainsworth et al., 1979], the Brazelton behavioral test [Brazelton, 1973], the Emotional Availability Scale (EAS) [Biringen, 2000], the Care-index [Crittenden, 2005], and the Maternal Behaviour Q-set (MBQS) [Moran et al., 2011]. These observation studies are labor intensive and thereby usually allow for a low sample rate. We suggest that the bonding self-report questionnaires and observation instruments are suitable for measuring the long-term effect of a robust prototype on the level of bonding in practice. However, in a earlier product design stage, we would benefit from measuring the experience of bonding in a faster, less demanding from participant and less labor intensive for the researcher. To our best knowledge a validated instrument meeting our requirements for measuring the effect of an intervention on the bonding experience was not available yet. Therefore, we created a first pilot version of a self-report questionnaire, suitable for measuring instantaneous bonding experiences in the NICU.

9.3.2 Questionnaire design

The instrument must measure how well an intervention (product, architecture, service) supports the instantaneous bonding experiences of parents in the NICU. We note that the aim is to measure the experience in the moment, versus the actual clinical level of bonding, which requires time to develop. In the theoretical design framework in Chapter 5 these bonding experiences are described as: 'repeated (initially close) reciprocal pleasurable experiences'. Our approach is to formalize items that fit into the themes of this definition, because these themes were previously identified as the most directional influential experiences which seem to apply to all parents.

We chose for a Likert scale of 5 points asking how much the parents agree with the proposed statement. Scoring on the range from one to five points, one meaning 'low bonding experience support' and five 'high bonding experience support'. The positive direction of the statement is inverted for some of the items. It is avoided to use ambiguous wording, ask socially desirable answers and double barreled questions.

Criteria for the questionnaire items:

- The item must inquire to one of the four determinants of the definition:
  - repeated, as in frequency, intensity and duration of being involved with the baby
  - (initially physically) close
  - reciprocal, as in interaction between parents and baby
  - pleasurable
- The items must inquire about the instantaneous experience in the environment, rather than the long term development of the bond.
- May not inquire about negative or socially undesirable bonding experiences, such as 'thinking of harming the baby'.
- Must apply to the general experience during the parents time in the NICU.
- Must apply to mothers and fathers.

For inspiration of items we looked into the following sources and selected items that fit the criteria: the MPAS and the PPAS (inspired 12 items) [Condon and Corkindale, 1998, Condon et al., 2008], the PMA (inspired 8 items) [Nagata et al., 2000], PBQ (inspired 13 items) [Brockington et al., 2006], BMIS (inspired 17 items) [Kumar and Hipwell, 1996], a non-published bonding level self-report questionnaire (ESM) constructed to measure the effect of interventions created by Daan van Bel (inspired 19 items), and the experience flows (inspired 33 items) Experience flows as the basis for design inspiration. The experience flows have been consulted to obtain items specifically for the NICU bonding experience, with the expressions that parents in this context use. A total sum of 102 items, adjusted to fit the the scale, language and tense, were included in the list. The list of 102 items includes repetitions. We grouped similar items and selected one formulation, obtaining thereby a list of 29 items. The list of 29 items was forwarded to a panel of four persons who were asked to test the face validity. The panel members were given a short introduction about the NICU, and asked to keep a specific experience in mind, such as Kangaroo care, while filling out the questionnaire. We asked for their feedback about clarity, need to recall experiences from the past, ethics, clarity of the introduction and relevance to fathers as well as mothers. The panel reported that some items stimulated to recall experiences beyond the instantaneous experiences and suggested that this could be prevented if they

no.	item	theme	sources
1	I could just sit there looking at my baby for a long period of time	repeated	PIA
2	I felt that I was able to contribute much to the well-being of my baby	repeated	EF
3	I felt stimulated to take care for my baby	repeated	EF
4	I was afraid to touch my baby	close	PMA, PBQ, EF
5	I was experiencing intense contact with my baby	close	EF, ESM
6	I felt a close connection to my baby	close	EF, ESM
7	I had the feeling that my baby was responding to me	reciprocal	EF, ESM
8	I had the feeling that I was getting to know my baby	reciprocal	EF, ESM
9	I felt comfortable in the environment being with my baby better	pleasurable	EF
10	I was worried about whether my baby was well	pleasurable	PMA, PBQ, EF
11	I enjoyed my baby	pleasurable	MPAS, PMA, PBQ, BMIS, EF, ESM
12	It was very difficult to see my baby like that	pleasurable	EF
13	I was feeling at ease while being with my baby	pleasurable	MPAS, PMA, PBQ

Table 9.2: 13 items Instantaneous Bonding Experience questionnaire

condition	Alpha	Item (alpha if deleted)	Items (alpha if deleted)
Control	.789	Q10 (.801)	Q1 (.794), Q4 (.793), Q12 (.798)
Beads	.793	Q10 (.818)	Q1 (.808), Q12 (.806)
Optical	.874	Q1 (.881)	Q8 (.796), Q12 (.877)
Tactile	.813	Q4 (.826)	Q1 (.818), Q10 (.822)
LCD	.803	Q10 (.831)	Q1 (.821), Q12 (.812)

Table 9.3: IBE questionnaire internal consistency

were reminded in each question about the specific experience. Therefore, we decided to phrase the items in retrospective. The past tense also solved the ethical objections that some items posed. For example, item number 11 'I enjoy my baby': When asking 'I enjoyed my baby', it refers to the instantaneous experience, instead of how the parent generally feels about the baby. Based on the panel suggestions, we re-formalized, reorganized and eliminated items until the questionnaire was reduced to 13 items. In table 9.2 the 13 items translated to English are listed, including the accompanying themes and their original sources of inspiration. In appendix Instantaneous Bonding Experience questionnaire form the questionnaire is documented. The items number 4, 10 and 12 require reversed scoring on the Likert scale.

9.3.3 Internal consistency

Twenty-five participants filled out the questionnaire five times (one IBE questionnaire for each display). The sample size consisted of 14 woman and 11 men, of which 8 of the participants were a parent. The ages were varying from 23 to 59 (M = 33.56). The participants all had a relation with the Eindhoven University of Technology, by either studying or working there currently, or having done this in the past. For each of the 25 participants the 5-point Likert scale scores of 13 questions were added to total scores (from 13-65 points) for each condition. This resulted into 25*5 samples. The control condition was missing one entry (participant 22, control group question 3) which has been replaced with the mean answer given to question 3 in the control group by the other 24 participants (which was 2.8, rounded up to 3).

The IBE questionnaire has not been previously validated, therefore we ran the statistical test Cronbach's alpha to evaluate the internal consistency. In the IBE questionnaire there are 13 items that each address a different aspect of the single construct; the instantaneous bonding experience. Because the items are all meant to measure the same construct, participants should respond to them consistently. The data from the different conditions were processed separately in the analysis of internal consistency. In table 9.3 the outcome is summarized per condition.

Concluding, the Cronbach's alpha values are above 0.7 in all conditions, therefore the internal consistency is acceptable. The alpha values vary between .789 and .813. The internal consistency of the IBE questionnaire could be improved by removing the items Q1, Q4, Q8, Q10 and/or Q12. Three of those are the negatively formulated items (Q4, Q10 and Q12). We prefer to maintain all the items for analysis now that the data is collected using the 13-item list. For future use, we do recommend to remove item Q10 'I was worried about whether my baby was well' because removal of this item results in a higher internal consistency (alpha > .8).

9.4 Results

9.4.1 Performance experiment results

Twenty-five participants filled out the performance questionnaire. The sample size consisted of 14 woman and 11 men, of which 8 of the participants were a parent. The ages were varying from 23 to 59 (M = 33.56). The participants all had a relation with the Eindhoven University of Technology, by either studying or working there currently, or having done this in the past.

In this section we present the result from the statistical analysis of the performance data. The Cochran's Q test was applied because it is designed for binary results and related samples (one individual providing data on multiple occasions). The Cochran's Q test tests whether there were significant differences among the effect of the five displays, therefore a paired comparison of all the display combinations was performed to offer a more detailed raking of the design. The McNemar test was ran with the 10 possible pair combinations. For each independent variable we ran the test separately.

Can heartbeat be recognized equally well in each display?
The number of 'true' answers on the heartbeat sample were compared between the displays. Cochran's Q (with alpha .05) was statistically significant, meaning that there was a significant difference between how well participants could recognize the heartbeat in the different displays, Q (4, N = 25) = 11.407, p = 0.22. In Figure 9.5 the percentages are shown in a histogram. To locate which displays show significant difference, a series of pairwise comparisons were performed using the McNemar test. None of the comparisons achieved however statistical significance at the Bonferroni corrected alpha of .005. The difference between the control and the beads display approached statistical significance (p = .015). Because the significance indicated in the Cochran's Q test is not confirmed by the NcNemar test, it is unclear whether there is significant difference or not.

To the question whether heartbeat could be recognized in each display equally well, no concise answer can be given based on the statistical tests. There is a small indication that heartbeat was more difficult to detect in the beads blanket than in the standard monitor.

Can respiration be recognized equally well in each display?
The number of 'true' answers on the respiration sample were compared between the displays. Cochran's Q (with alpha .05) was statistically significant, meaning that there was a significant difference between how well participants could recognize the respiration in the different displays, Q (4, N = 25) = 33.434, p = 0.001. To locate which displays show significance difference, a series of pairwise comparisons were performed using the McNemar

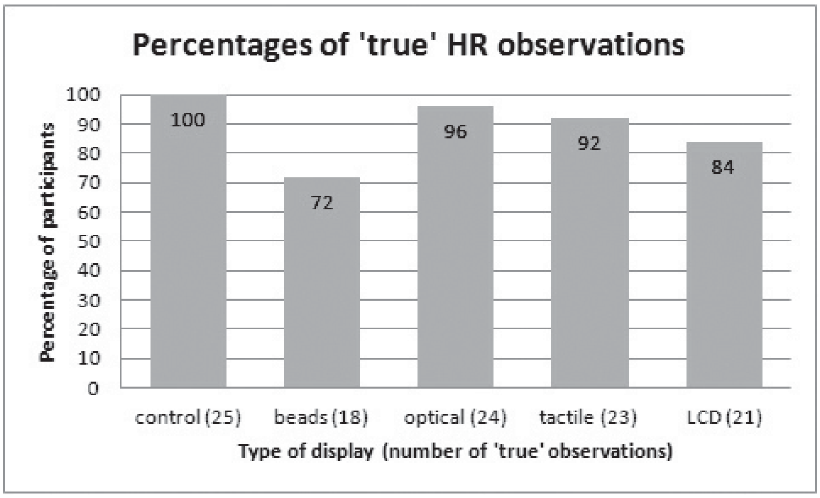


Figure 9.5: Recognition of heartbeat

test. The comparison between the pair control and beads (p = .001) and control and tactile (p = .003), beads and optical (p = .002), beads and LCD (p =.001) and tactile and LCD (p = .002) achieved statistical significance at the Bonferroni corrected alpha of .005.

To the question whether the breathing could be recognized in each display equally well, the answer is no. Both the standard monitor and the mobile phone were interpreted correctly more often than the beads blanket and the tactile object. Additionally, the optical blanket was interpreted more correctly than the beads blanket.

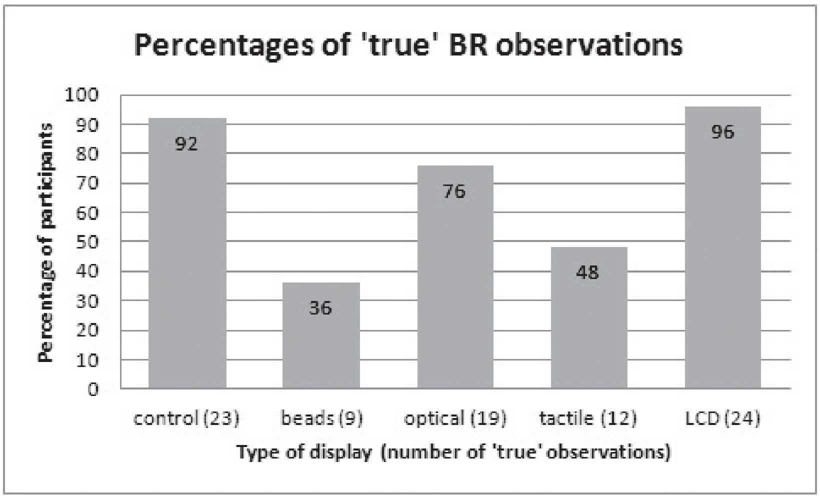


Figure 9.6: Recognition of respiration

Can the combination of heartbeat and breathing be recognized equally well in each display?
The number of 'true' answers on the heartbeat + respiration sample were compared between the displays. Cochran's Q (with alpha .05) was statistically significant, meaning that there was a significant difference between how well participants could recognize the combination of heartbeat and respiration in the different displays, Q (4, N = 25) = 29.440, p = 0.001. To locate which displays show significance difference, a series of pairwise comparisons were performed using the McNemar test. The comparison between the pair control and tactile (p = .002), control and LCD (p = .001) and optical and LCD (p = .001) achieved statistical significance at the Bonferroni corrected alpha of .005. There were also a couple of paired combination that approaches significant difference: control and beads (p =.031), beads and LCD (p = .022), optical and tactile (p = .021). The same tests were performed on the data from the number of 'true' answers on the heartbeat + respiration + change. The same pairs showing significant difference came out, as would be expected.

To the question whether the combination of heartbeat and breathing could be recognized in each display equally well, the answer is no. The combination of heartbeat and respiration was more often correctly read from the standard monitor than the mobile phone and the tactile display. Furthermore, in the optical blanket respiration was interpreted better than in the mobile phone.

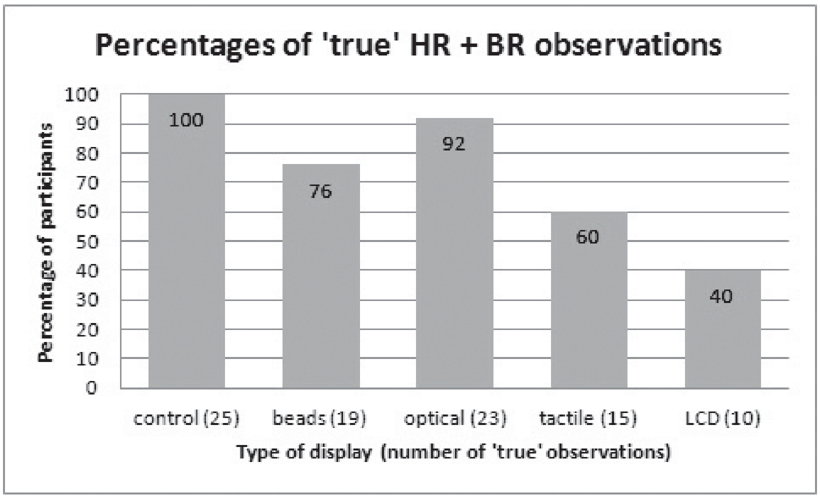


Figure 9.7: Recognition of the combination of heartbeat and breathing

Can the change of heartbeat and breathing be recognized equally well in each display?
The number of 'true' answers on whether the participants observed change in heartbeat + respiration + change sample were compared between the displays. Cochran's Q (with alpha .05) was statistically significant, meaning that there was a significant difference between how well participants could recognize the change of heartbeat and respiration in the different displays, Q (4, N = 25) = 23.879, p = .001. To locate which displays show significance

difference, a series of pairwise comparisons were performed using the McNemar test. The comparison between the pair control and beads (p = .002) and LCD and beads (p =.004) achieved statistical significance at the Bonferroni corrected alpha of .005. The differences in recognition of change in the following pairs were approaching significant difference: control and tactile (p =.016), beads and optical (p = .012) and tactile and LCD (p = .031). The same tests were performed on the data from number of 'true' answers on the whether they observed change in heartbeat + respiration + no change. The same pairs showing significant difference came out, with the additional pair of control and tactile (p = .002) and beads and optical (p = .001). The histograms appeared similar and the ranking of the sample means per condition was the same.

To the question whether can changes in heart rate and breathing rate frequencies could be detected equally well in the displays, the answer is no. The change was detected correctly more often in the standard monitor and mobile phone than in the beads blanket. There were small indications that the optical blanket was interpreted better than the beads blanket as well. A small indication for the standard monitor scoring better than the tactile display as well.

From the hypothesis about performance, the hypothesis 1 was met because the displays were on several fronts (BR, combination, change) not equally correctly interpreted by the participants. There is a small indication that this was also the case for HR.

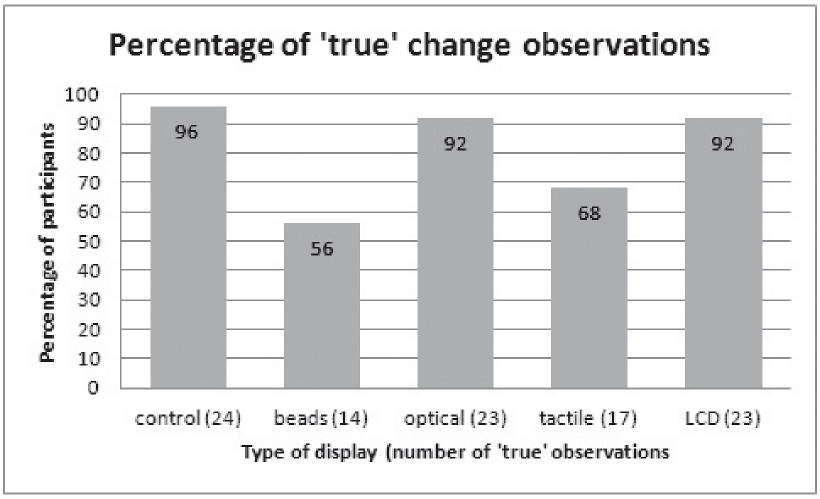


Figure 9.8: Recognition change in heartbeat and breathing frequency

9.4.2 Instantaneous bonding experience experiment results

Twenty-five participants filled out the questionnaire five times (one IBE questionnaire for each display). See Section 9.3.3 for the details about the sample. A One-Way Repeated ANOVA test was applied on the data to calculate the statistically significant differences

condition	was rated sig. higher than	was rated sig. lower than	no sig. difference
Control	none	beads, optical and tactile	LCD
Beads	control	optical and tactile	LCD
Optical	control, beads and LCD	none	tactile
Tactile	control, beads and LCD	none	optical
LCD	none	optical and tactile	control and beads

Table 9.4: Raking of the displays according to the IBE

between the sample means in the five conditions.

First it was checked whether the data was normally distributed using several measures. According to Shapiro-Wilk test and the Skewness and Kurtosis statistics the assumption of normally distribution was not violated. Also the boxplot (Figure 9.9) is roughly symmetrical which supports the assumption of normally distribution as well. We decided not to remove the outliers, because the sample is already small and it is not said that these outliers would not be present in a larger sample. Based on the Fmax, the homogeneity of variance has not been violated and the Mauchlys test of Sphericity was met.

Based on the descriptive statistics it appears that the optical blanket and the tactile object are rated more positively based on the experience they offer. Namely the mean IBE score of the tactile object of 44.76 is the highest, close to the 44.32 of the optical blanket's mean IBE score. The means run from 33.35 (control) and 44.76 (tactile object). The standard deviations indicate a greater variability in the ratings by the participants of the optical (σ 8.24) compared to the rest that range from (σ 6.28 - σ 6.88).

The ANOVA outcome shows that some of the displays are significantly experienced as more supportive of the bonding experience than others, $F(4, 96) = 29.728$, $p < .001$, partial $\mu 2 = .55$.

Pairwise comparisons of all possible display combinations (10 pairs) indicate the significant differences between the individual displays. See also the boxplot for a visual overview of the mean ratings in Figure 9.9 and table 9.4. The hypothesis 2 is met, because the optical (M = 44.32, SD = 8.24) and tactile (M = 44.76, SD = 6.88) displays were both rated significantly higher than the control (M = 33.35, SD = 6.69), beads (M = 37.48, SD = 6.28) and LCD (M = 36.48, SD = 6.73) displays. The optical and tactile displays did not differ significantly between them, therefore it can also be concluded that the tactile and the optical displays offer a similar level of instantaneous bonding experience.

Concluding, concerning the instantaneous bonding experience the prototypes offer, the tactile and the optical displays both are the best choice among the tested displays based on the outcome.

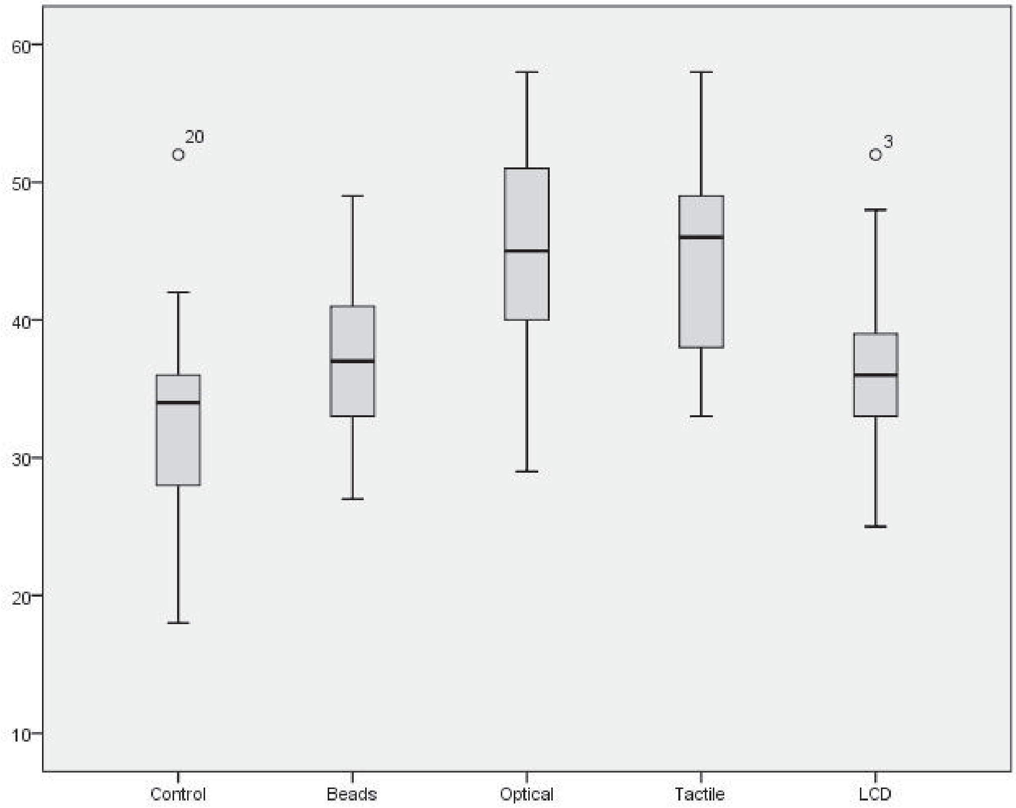


Figure 9.9: Boxplot IBE questionnaire outcome per condition

9.4.3 Qualitative questionnaire results

Twenty-five participants were asked open questions about their experiences and opinions about the prototypes. The sample size consisted of 14 woman and 11 men, of which 8 of the participants were a parent. The ages were varying from 23 to 59 (M = 33.56). The participants all had a relation with the Eindhoven University of Technology, by either studying or working there currently, or having done this in the past.

The open coding analysis was performed to provide insight into the reasoning behind the outcome of the quantitative performance and experience tests. First the answers to the question which display was perceived as most informative and attractive and why were grouped. Statements for these questions were marked in blue and listed. The quotes resulting from the additional remarks question were grouped into the five different monitors (marked in pink) and into more general remarks (marked in green).

Informativeness
It is no surprise that almost all participants answered that the standard display was the most informative. (One participant stated that the tactile display was most informative,

however would like to see it combined with the standard display.) They stated that the information was clear and exact. It was informative because the vital signs were expressed in numbers and the trace was shown. In one glance all the information was there, easily to understand and recognize changes in frequency. One person expressed that the screen was calm to look at, although one other person stated that the standard display was despite informative, also cold and a bit scary.

Attractiveness

In their answer to the question which monitor was most attractive the participants were divided between the optical and the tactile display. (One participant choose the standard display as most attractive because this person just wanted to see the baby, because all the information around was driving crazy.) Twelve participants chose for the optical display, nine for the tactile display and three felt the tactile and optical were equally attractive.

Reasons for preferring the optical display were that it was soothing and informative according to most participants of those who chose for the optical display. There was one participant who expressed that the optical blanket was nervous and hypnotizing. Participants stated that the optical blanket was insightful and that they could relate the data to the baby in one glance. Furthermore it was stated that the optical blanket was drawing attention to the baby and not distracting. Remarkably, a few individual comments were made relating to interaction, such as 'shows interaction', 'motivates to engage in nursing care' and 'evokes the need to touch'. Perhaps this is because of the blanket or the direct link between the data and the baby. The comments relating to the blanket are discussed further on in the analysis.

Reasons for preferring the tactile display are that participants experienced it as if they could physically feel the baby and felt a bond between them. The contact was described as constant and direct. It was stated that the tactile display allowed looking at the baby without visual distraction and noticed that there is no distraction by information once the hand is let go from the object. A few single comments were: 'less distance', 'friendly', 'soothing', 'interaction', 'less alarming' and 'intuitive'. One of them was contradicting with the rest: 'baby very fragile (scary)'.

General remarks about each of the five displays

In the general remarks, all the displays were discussed and reasons were given for why they were not the most informative or attractive. We added these insights to the insights described above. About the standard monitor it was added that its appearance was not attractive. New insights about the optical display were that the visualization could be improved: one person felt that it was restless and one person thought it looked like a radar. One person mentioned that the bond with the baby felt less strong using the optical blanket than the tactile object.

The additional remarks about the tactile display were confirming that it felt as an extension of the baby. There was no consensus about the strength of the actuation touch. Some felt it was intense (even scary) and others felt it was subtle and natural. Specifically, the breathing was experienced as too subtle by some, however others thought it was pleasant this way. About the heartbeat specifically it was stated that it dominates and should not be stronger. One person mentioned that the change in frequency was difficult to observe. We note that comments on the tactile display were about the contact with the baby rather than about obtaining information. Another new insight was that the object did distract a little, and that a participant felt a bond with the object instead of the baby and did not dare to let go. Combined with the experiences of the tactile object as being intense and scary, it can perhaps be concluded that the tactile object triggers both positive and negative responses and is depending much on individual preference.

About the beads blanket the participants all agreed. It was unclear, restless and distracting. Although about the appearance one person expressed that the beads were fun and playful, also one expressed it was unattractive and another that is was abstract and that he or she couldn't identify with it.

The mobile phone did not trigger many responses. Three participants imagined that it would be nice to have such a device while they were not around the baby. Mostly they felt it was distant, distracting, unclear and didn't relate to the baby much. We conclude from this that a portable device requires different content.

Real-time monitoring
The following was stated about general aspects of the real-time monitoring. A couple of participants expressed that it took a while to learn how to interpret the displays, which is not unexpected because the visualization and mapping was new in the four concepts. The performance test informs about how well the participant interpreted within the span of the experiment. One participant expressed the desire to have a combination of the different displays and one participants suggested to add an alarm function in the displays. It was also suggested that the tactile display could be located inside or on the incubator and that several persons can touch it at the same time. One participant mentioned that the location of the visualization on the blanket should be above the baby. The blanket triggered several different responses. By some participants the blanket was regarded as a pleasant addition because it covers the cables around the baby. However, others felt is was an obstruction for interaction, because it has to be moved and then cables could be pulled. The final topic was whether receiving the information is desirable or not. As mentioned earlier, according to many participants it was experienced as soothing to receive continuous information. However, one participant expressed that noticing a change in frequencies can be worrisome. The option to ignore the standard monitor and remove the hand from the tactile object were mentioned.

9.5 Discussion and conclusion

Four display designs with different actuator types in which the vital sign parameters of heart rate and respiration were expressed were compared to each other and to the current monitoring display. A self-report questionnaire inquiring to the ranking of several designs according to instantaneous bonding experience qualities based on our definition was created. We first measured the performance of the designs: whether they succeeded in conveying the information to the parents. Secondly, we measured the instantaneous bonding experience qualities of the design.

Research question 1: Performance
Can the real-time abstract representations of monitoring data be interpreted by the parents at least as well as the current monitor?

We conclude that some of the real-time abstract representations of monitoring data may be interpreted similarly well by the parents as the current monitor. The optical display was interpreted equally well as the standard monitor; based on the finding that in none of the four performance aspects a significant difference was measured in our sample of 25 participants. The mobile phone ranked lower than the standard monitor only in the category of combined vital signs. The tactile object ranked significantly lower than the standard monitor in the tests of respiration and the combination of the vital signs. In the qualitative analysis parents expressed specifically that they felt the standard monitor was clear. Perhaps, it was easier to interpret the standard monitor., which was not necessarily measured in the 'true' or 'false' rating, since no response time was recorded. About the sub-questions we concluded the following (incorporating insights form the qualitative analysis):

Heartbeat was equally well recognized in the displays, except for in the beads display. The qualitative result confirms that the bead display was not as clear as the others. The explanation could be that the beads (flip-dots) were not suitable for displaying the continuous and fast vital signs. There was no possibility to make smooth transitions in color or intensity and the resolution was low. Perhaps the beads would be more suitable for displaying something discrete, such as to indicate an alarm.

There was more variation in how well respiration was recognized. The beads blanket ranked low, probably because of the unsuitability of the flip-actuators for showing vital signs, and because additionally the mapping of the respiration was slightly different to the others, inherent to the limitations of the actuator type. We conclude that this manner of visualizing the data was not understood as well as the others. The tactile display was also ranked lower than the control and LCD, which we can explain with the responses from the qualitative data, saying that the actuation of breathing was subtle. It is likely that some participants couldn't feel the motion.

The combination of heartbeat and respiration showed something surprising. Although in the mobile phone the recognition of heartbeat and respiration did not significantly differ from the standard monitor (with a high ranking), the combination of the two vital signs was not well recognized in the mobile phone. It ranked significantly lower than the standard monitor and the optical blanket. The explanation we can think of, is that the heartbeat fluctuations in color shade of the dot may have been overlooked when the dot was also varying in size.

How well changes in frequency were detected differed significantly between the beads and the standard monitor, and the beads and the mobile phone. Even tough participants expressed that they felt it was difficult to observe the changes in the alternative displays, the scoring on recognition of change for the optical and the LCD did not significantly differ to the control condition.

Research question 2: Experience
Do the real-time abstract representations of monitoring data offer variation in instantaneous bonding experiences by the parents, and if so which design offers the most supportive experience?

The results from the IBE questionnaire and the qualitative analysis confirmed that the tactile and optical displays are ranked equally as the most attractive and most supportive of the bonding experiences. The standard monitor ranked significantly lower on the bonding experience scale. We noticed that the optical display received slightly more votes in the open questions about attractiveness, however in the argumentation the tactile object seemed to trigger strong responses related to experiencing contact and a bond.

The experience IBE questionnaire items most likely did steer the participants in their phrasing and thought processes, influencing the qualitative responses. Due to the introduction and questionnaire they were set on the track of evaluating the display in regards to parent-infant bonding, instead of the medical point of view. It has to be kept in mind that in practice the parents might value the medical information more than feelings of connectedness. Also it has to be kept in mind that two of the participant expressed that it was difficult to fill out the IBE questionnaire, because it was challenging to image the interaction. Real-life situations may be different. And, finally (although not applicable to the performance measure) participants may feel socially pressured to report differences in experience or be positive about the prototypes.

Final conclusion combining the outcomes
Combining the outcomes from different tests, the optical blanket and tactile object both come out as viable options. The optical blanket performed well in experience as well as being informative. On the other hand, the tactile object seemed to enable a sense of contact. We think the final choice depends on the objective. In the next chapter the tactile object, renamed 'close-to-you' is worked out in more detail.

Our suggestion for future research is to develop the optical blanket or the tactile object into safe and robust prototypes for long-term testing in the field for the effect on the level of bonding. The Instantaneous Bonding Experience questionnaire showed potential as a means to quickly evaluate interventions for the NICU based on their instantaneous bonding experience qualities. A factor analysis could be performed to further access the construct.

We feel that the experiment was an effective method to evaluate the series of designs. The experiment in itself was not time consuming, extensive or demanding compared to running a similar experiment in the hospital. By far the most time consuming aspect was the creation of prototypes. They needed to be reliable enough for testing and there were some technical challenges in timing the heartbeat, respiration and increases in frequencies. For comparison of the actuators, the provided signal had to be constant in the five displays. Our goal to gain valuable design input from users, appropriate for this design stage, was achieved.

Chapter 10

The close-to-you concept design

The close-to-you concept is an iteration of the real-time monitor designs, inspired by the feedback from the experiment. Here we present the design as an industrial design pitch format.

Bonding in the NICU
The bond between parents and infants is important for the well-being of both. In case of a premature birth, the baby is admitted to the Neonatal Intensive Care Unit (NICU), where he or she receives the essential care for surviving and for developing. The circumstances for bonding however are not optimal. The parents and baby are physically separated, care tasks are given out of hand to specialized nurses and the baby is in fragile health [Klaus et al., 1996]. The close-to-you concept is designed to bring parents and infants in the NICU closer together while the baby is in the incubator.

Close-to-you concept
Fathers or mothers can hold the close-to-you (Figure 10.1) and feel the real-time heart beat, breathing and temperature of their baby. The close-to-you offers an intimate experience when physical contact is restricted, because in the first days/weeks of life, even touch can be stressful (Figure 10.3). The close-to-you allows parents to experience a sense of closeness without disturbing the rest of the baby required for growing and developing. The heart beat can be felt through a subtitle rhythmic pounding, and the breathing through a smooth inhaling and exhaling motion. The soft fabric toy is warm to the touch. Holding the close-to-you, parents can visually focus on their child, without being distracted by the highly technical monitor screen, and yet receive information about the baby's internal state, reassuring themselves. The medical monitoring concept is approached in a non-medical way. Later when more interaction is desired, the close-to-you could support parents in finding

(a) (b)

Figure 10.1: The close-to-you concept

individual ways of interacting with their baby. When changes in heart rate or breathing rate are sensed, parents can link these changes to events such as talking, singing, or touch, and thereby get to know their baby better.

The close-to-you base station needs to be connected to the existing health monitor in the NICU, which acquires the vital signs and sends them to the toy. The close-to-you can be held in various manners, including being worn as a necklace (Figure 10.2). An advantage of the tactile toy it that it is non-disruptive, because the intimate experience is only there for as long as the object is held.

Technology and prototype

The way the heart beat and breathing are expressed defines the experience. Therefore these modalities are prototyped in a demonstration version. The heart beat is actuated by a solenoid, which responds fast and is silent and subtle. The breathing is actuated by a voice coil which moves your fingers silently up and down along the breathing pattern. People who have experienced the prototype have expressed the following: "more (intensive) contact with the baby. It really feels like as an extension of my baby", "friendly, close bond and intuitive", "you can look at the baby, without being visually distracted". The warmth of the close-to-you is envisioned to be realized by an embroidery pattern of conductive yarn, and controlled with a temperature-sensor based feedback loop (Figure 10.4).

(a) Cover with hand

(b) Holding in hand

(c) Worn as a necklace

Figure 10.2: Ways to hold and wear the close-to-you

Figure 10.3: User scenario of close-to-you

Figure 10.4: Embroidery pattern conductive yarn

Chapter 11

Conclusion

In this chapter we look back on the work described in this thesis. We reflect on the outcomes, but also on the process from the design perspective.

11.1 Reducing negative stimuli: How to design for comfortable monitoring?

Already more than five years ago we began working on design for Neonatology with the assumption that besides medical research, there was a role for designers to contribute on aspects related to quality of life such as comfort and bonding. Since then, our understanding of the field was extended and deepened, as described in chapter 1. Looking back, the assumption is confirmed and we are more convinced than ever that this is an important field.

A monitoring jacket for prematurely born babies was designed offering the measurement of ECG using textile electrodes. We found that in designing a comfortable monitoring system, the collaboration of multiple disciplines at the university and hospital are essential in solving the most critical issues: designing from the perspective of the parents, informing about requirements related to medical care provided, gathering clinical monitoring data for validation of reliability, integrating the gathered knowledge into a design and building the functional prototypes.

We concluded that validation of the new design's reliability in monitoring was more complicated than expected. Comparison of the signal quality obtained with textile electrodes to the golden standard of gel electrodes using a high-end amplifier, was complicated due to the interference between the two conditions of measurements. An absolute standard does not exist. The solution we proposed is to engineer the complete monitoring system, including textile electrodes, amplifier, wireless communication, signal processing and display, and to evaluate the quality of the measurements between subjects and through assessment by clinicians. Although we could not validate the reliability, in our experiments we did explore the technical design parameters of ECG monitoring using textile electrodes. The insights into the amplifier, filters, diversity measurements system and validation methods were described.

In the designing of a new proposition in the medical practice of Neonatal Intensive Care, we concluded that an innovation such as a comfortable monitoring system cannot be single handedly be developed, produced and introduced to the market. The Value Flow method was shown to be beneficial in our case study, in finding business partners to collaborate with in the process of identifying value for each player in the ecosystem. The method applied in a workshop with potential partners has also focused my own goals and it has triggered actions in the outside world, notably MMC and Panton.

What has not been solved yet is a measure of the baby's comfort for evaluation of whether the concept achieves in reducing the amount of negative stimuli that reach the baby. We leave this as an option for future research.

11.2 Supporting positive stimuli: How to design for bonding?

From our literature study into bonding between parents and the baby we found that the 'tie' grows with 'repeated (initially physically close) reciprocal pleasurable experiences'. We summarized our findings in the framework of Figure 5.1 which we took as a starting point for our design.

We organized the design process around the experience flow method. The purpose of this is to look for 'opportunities' for design. We did interviews and clustered the data. In our opinion the traditional time-line oriented experience flows were not very helpful. But fortunately the clustering*was* helpful. The design opportunities (I), (II) and (III) in section 6.4.1 came out of this as well as the design guidelines in section 6.4.2. The design opportunities are:

(i) Specific monitor design for parents as a means to get to know their child.

(ii) Supporting a meaningful and active contribution while sitting next to the incubator.

(iii) Supporting the acknowledgment of the difference the baby knows between parents and medical professionals.

In chapter 7 these opportunities are developed further leading to concepts. Four of these are variations on the idea of a real-time monitor to 'invisible information' visible again. Another four give insight into the long-term development of the baby. The ninth concept is a combination of 'real-time' and 'long-term'. Choosing among these concepts was difficult for two reasons:

- we do not know in advance whether the effect that we aimed at will occur indeed;

- we do not know how the parents will use the information offered in the realized concept.

We decided to continue with the real-time concepts because they are really about interactions in the here-and-now.

In order to move forward from the concepts towards realization we found the question of 'which actuator type to use?' a key question. The actuator types are:

- OLEDs (using an active light source)
- flip-actuators (using light passively though reflection of two different colors)
- tactile (speaker motion and solenoid 'push')
- LCD screen (using an active light source)

We choose to display heartbeat and respiration for a variety of reasons: their continuous nature and their potential for connectedness. We avoided interpretation of the signals (no wrong interpretation, directness).

The four designs are design propositions which are close to the displays that could really be used in the NICU by real parents: a blanket with OLEDs, a blanket with beads that mechanically change color, an haptic object to be held by the parents and a visualization on a phone. At the same time they have been used as stimuli in a systematic experiment where we gathered qualitative and quantitative data about the parents' experience and the correctness of the interpretations.

The findings are significant and the qualitative and quantitative data support each other. There is no one-fits-all outcome but two design propositions are promising:

- the optical blanket,
- and the tactile object.

The tactile object has been taken one step further. It is the close-to-you concept of Figure 10.1. Moreover, the questionnaire itself could be re-used, also by others to test all kinds of interventions.

The next step we envisage is a clinical trial to research whether the bonding experience does lead to improved long-term bonding indeed. We leave this as an option for future research.

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Appendix A

Finite State Machine

To control the parallel timing of heart rate and breathing rate of the actuators described in Chapter 8.1 and applied in Chapter 9, Prof. dr. Loe Feijs suggested the application of a Final State Machine (FSM). In the Figures A.1 to A.4 the Date Flow Diagrams for the optical blanket are presented in Yourdon Notation.. Data Flow Diagrams have been made popular by Yourdon (http://yourdon.com/). The FSM program was adjusted and applied for the bead blanket and the tactile object as well.

Appendix A. Finite State Machine

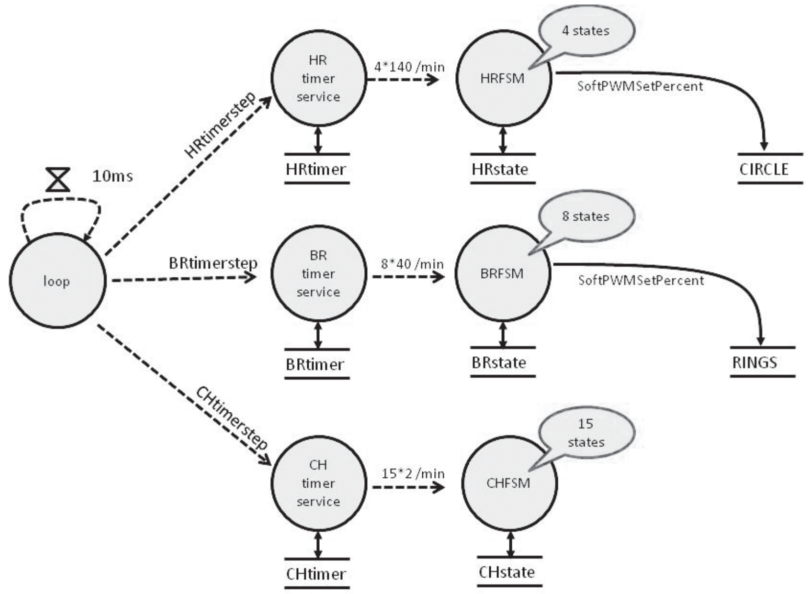

Figure A.1: Timers

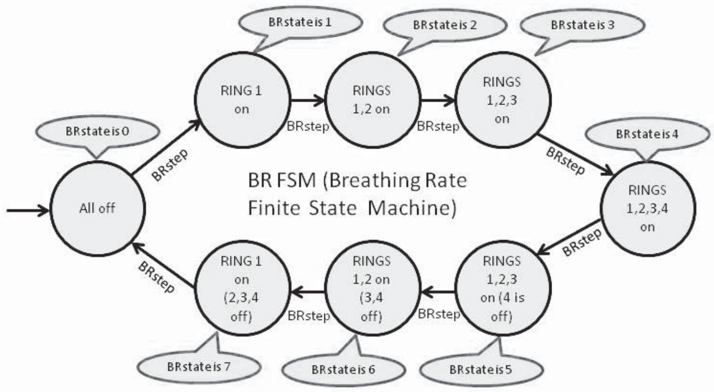

Figure A.2: Breathing states

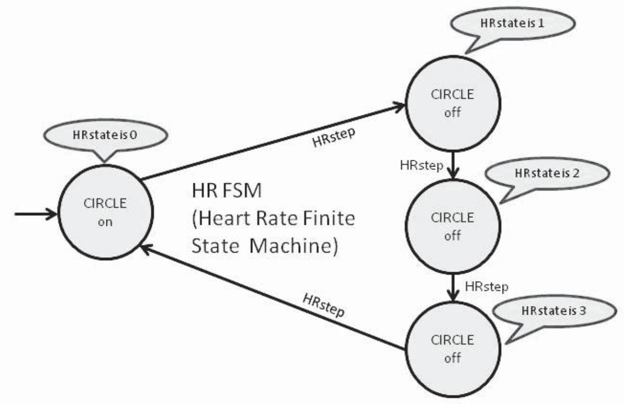

Figure A.3: Heart rate states

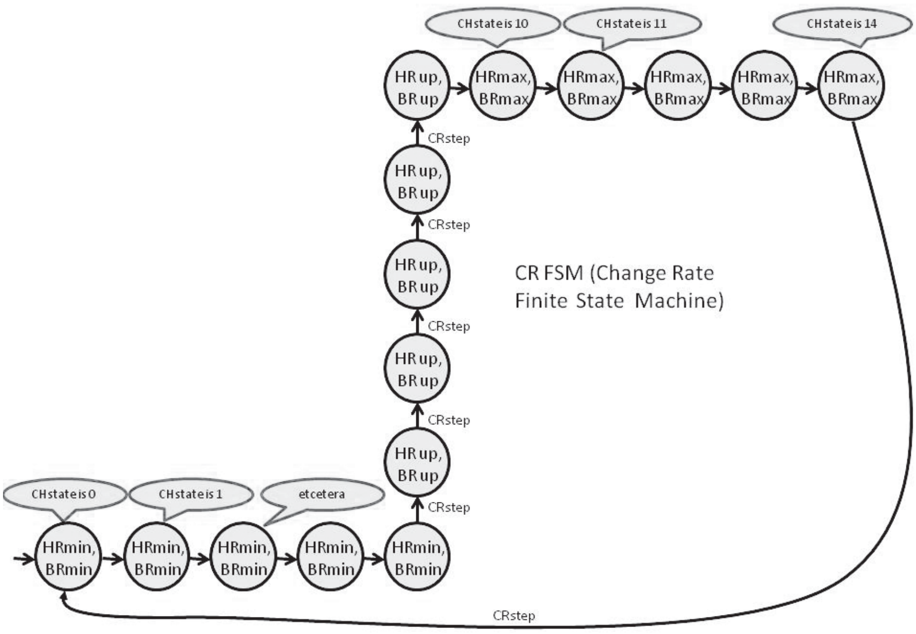

Figure A.4: Change state

Appendix B

Experiment forms

B.0.1 Consent form

Toestemmingsformulier

Toelichting experiment
Dit experiment is onderdeel van het promotieonderzoek Ontwerpen voor ondersteuning van hechting tussen ouders en hun pasgeborene op de intensive care afdeling. Het experiment wordt uitgevoerd door onderstaande onderzoeker aan de faculteit Industrial Design, Eindhoven University of Technology.

In dit onderzoek worden 5 producten met elkaar vergeleken. We starten met een korte introductie over de Neonatologie afdeling in het ziekenhuis. Het experiment begint met het laten zien van 20 videos van elk 30 seconden, met elk 2 bijbehorende meerkeuzevragen. Daarna demonstreren we u de vijf prototypes en vragen u per prototype een vragenlijst met 13 meerkeuzevragen in te vullen. Ter afsluiting vragen we naar uw ervaringen. In totaal kost het experiment maximaal 45 minuten van uw tijd.

Toestemming
Ik ben bij deze geïnformeerd en begrijp mijn rol in de deelname en uitvoering van de hierboven beschreven studie.

Ik begrijp dat de persoonlijke informatie die wordt verzameld tijdens deze studie gebruikt wordt door de onderzoeker verantwoordelijk en anoniem verwerkt wordt.

Ik ben mij bewust dat de verzamelde data niet aan derde partijen vrijgegeven wordt.

Ik heb voldoende tijd gekregen om mijn deelname aan deze studie te overwegen en ik ben mij bewust dat mijn deelname volledig vrijwillig is.

Ik ben me bewust dat ik te allen tijde mijn deelname aan de studie mag stoppen.

Ik begrijp dat ik het recht heb om de persoonlijke informatie die verzameld wordt, in te zien en onjuistheden te laten corrigeren.

Ik stem ermee in om deel te nemen aan deze studie.

Deelnemer

Naam	Handtekening	Datum

Sibrecht Bouwstra, MSc, Phd Candidate
Eindhoven University of Technology
Faculty of Industrial Design, Designed Intelligence Group
HG 2.52
Postbus 513, 5600 MB Eindhoven
T 0645227192
E s.bouwstra@tue.nl

B.0.2 Performance experiment form

Interpretatie van de displays

Deze vragen gaan over wat u denkt dat de display weergeeft. Per video zijn er twee vragen. Vraag (a) gaat over wat u herkent in de video, en vraag (b) over een eventuele verandering in snelheid daarvan. Vink voor vraag (a) één van de vier antwoordcategorien aan, en vink voor vraag (b) één van de drie antwoordcategorien aan.

Video x	1a. Wat herkent u in de volgende video?	1b. Wat observeert u in de volgende video?
	Ademhaling	Constante snelheid
	Ademhaling en hartritme	Veranderende snelheid
	Hartritme	Ik weet het niet
	Ik weet het niet	

B.0.3 Instantaneous Bonding Experience questionnaire form

Beleving van het contact tussen ouders en baby in de NICU

De volgende stellingen gaan over de invloed van producten, ruimtes of diensten op de beleving van het contact tussen u en uw baby. Deze beleving beschouwen we als een momentopname gekoppeld aan het product, de ruimte of de dienst. De stellingen betreffen dus tijdelijke ervaringen en niet de lange termijn band tussen u en uw kind.

Neem wat u zojuist beleefd heeft in gedachten en geef aan in welke mate u het eens bent met iedere stelling aan door één van de vijf antwoordcategorien te omcirkelen.

1	2	3	4	5
Hoge mate mee oneens	Mee oneens	Neutraal	Mee eens	Hoge mate mee eens

1. Ik kon een hele tijd naar mijn baby blijven zitten kijken.
   1 2 3 4 5

2. Ik had het gevoel dat ik veel bij kon dragen aan het welzijn van mijn baby.
   1 2 3 4 5

3. Ik voelde me gestimuleerd om mijn baby te verzorgen.
   1 2 3 4 5

4. Ik was bang om mijn baby aan te raken.
   1 2 3 4 5

5. Ik beleefde intens contact met mijn baby.
   1 2 3 4 5

6. Ik voelde een hechte band met mijn baby.
   1 2 3 4 5

7. Ik had het gevoel dat mijn baby op mij reageerde.
   1 2 3 4 5

8. Ik had het gevoel dat ik mijn baby beter leerde kennen.
   1 2 3 4 5

9. Ik voelde me prettig bij mijn baby in deze omgeving.
   1 2 3 4 5

10. Ik maakte mij er zorgen over of het wel goed ging met mijn baby.
   1 2 3 4 5

11. Ik genoot van mijn baby.
   1 2 3 4 5

12. Ik vond het heel moeilijk mijn baby zo te zien.
   1 2 3 4 5

13. Ik kwam tot rust bij mijn baby.
   1 2 3 4 5

B.0.4 Qualititive feedback form

Persoonlijke informatie
Mijn leeftijd is

Ik ben een man/vrouw

Ik heb wel/geen kinderen

Wat is uw beroep?

Open vragen
Welke display vindt u het meest informatief?
Display omdat

Welke display vindt u het meest aantrekkelijk?
Display omdat

Andere opmerkingen

Hartelijk dank voor uw deelname!

Appendix C

List of publications

1. **Bouwstra, S.**, Chen, W., Feijs, L.M.G. & Bambang Oetomo, S., *A theoretical framework for parent-to-infant bonding design at the NICU*. Proceedings of the 25th annual Gravens Conference on the Physical and Developmental Environment of the High Risk Infant, Clearwater Beach, 25-28 January 2012.

2. Seoane, F., **Bouwstra, S.**, Marquez, J., Lfhede, J. & Lindecrantz, K., *Smart textiles in neonatal monitoring : enabling unobtrusive monitoring at the NICU*. In Chen, W., Bambang Oetomo, S. & Feijs, L.M.G. (Eds.), Neonatal monitoring technologies : design for integrated solutions, (pp. 56-83). IGI Global, 2012.

3. Chen, W. & **Bouwstra, S.**, *Smart jacket design for improving comfort of neonatal monitoring.* In Chen, W., Bambang Oetomo, S. & Feijs, L.M.G. (Eds.), Neonatal monitoring technologies : design for integrated solutions, (pp. 361-385). Hershey: IGI Global, 2012.

4. Langereis, G.R., **Bouwstra, S.**, & Chen, W., *Sensors, actuators and computing architecture systems for smart textiles.* In Chapman, R. (Ed.), Smart textiles for protection, (pp. 190-213). Cambridge: Woodhead Publishing, 2012.

5. **Bouwstra, S.**, Bambang Oetomo, S. & Osagiator, A., *Een smart jacket voor monitoring van vitale lichaamsfuncties van pasgeborenen*. Proceedings of Venticare 2010, The Netherlands, Utrecht, 27-28 May 2010.

6. Chen, W., **Bouwstra, S.**, Bambang Oetomo, S. & Feijs, L.M.G., *Sensor integration for perinatology research.* International Journal of Sensor Networks, 9(1), 38-49, 2011.

7. Chen, W., Nguyen, S.T., **Bouwstra, S.**, Coops, R., Brown, L., Bambang Oetomo, S. & Feijs, L.M.G., *Design of wireless sensor system for neonatal monitoring*. Proceedings of Third International Workshop on Wireless Sensor Networks: Theory and Practice, in conjunction with the 4th IFIP International Conference on New Technologies, Mobility and Security, Paris, France, 7-11 February 2011.

8. **Bouwstra, S.**, Chen, W., Feijs, L.M.G., Bambang Oetomo, S. & Cluitmans, P.J.M., *Designing for reliable textile neonatal ECG monitoring using multi-sensor recordings*. Proceedings of the 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBC, Boston, Massachussetts, (pp. 2488-2491). Piscataway: IEEE Service Center, 30 August - 3 September 2011.

9. Chen, W., **Bouwstra, S.**, Feijs, L.M.G. & Bambang Oetomo, S., *Design new generation of health monitoring systems using sensor technologies*. Abstract presented at the International Conference on Advanced Infocomm Technology 2010 (ICAIT 2010), Haikou, Hainan, China, 20-22 July 2010.

10. Chen, W., Bambang Oetomo, S., Feijs, L.M.G., **Bouwstra, S.**, Ayoola, I. & Dols, S., *Design of an integrated sensor platform for vital sign monitoring of newborn infants at neonatal intensive care unit*. Journal of Healthcare Engineering, 1(4), 535-554, 1010.

11. **Bouwstra, S.**, Chen, W., Feijs, L.M.G. & Bambang Oetomo, S., *Smart jacket design for neonatal monitoring with wearable sensors*. Proceedings of the sixth International Workshop on Wearable and Implantable Body Sensor Networks 2009, (pp. 162-167). IEEE, 2009.

12. Verbeek, J.T.A.A., **Bouwstra, S.**, Wessels, A., Feijs, L.M.G. & Ahn, R.M.C., *Johnny Q. Proceedings of the 3rd European Workshop on Design and Semantics of Form and Movement (DeSForM 2007)*, Newcastle-upon-Tyne, United Kingdom, (pp. 182-183). S.l.: Koninklijke Philips NV., 12-13 December 2007.

Appendix D

Summary

Designing for the Parent-to-Infant Bonding Experience

The development of the bond between parents and new born baby is beneficial for the wellbeing of both. In case of a premature birth the baby is admitted to the Neonatal Intensive Care Unit (NICU) where specialized care is provided around-the-clock, necessarily for the baby's survival and development. In the case of a premature birth, the bonding process between parent and infant is hampered due to physical separation, the baby's fragile health and the care being performed by the medical staff. In design for bonding we are designing for the ill-defined goal of parent-to-infant bonding. It is unpredictable how a design will impact the complex bonding process and there is not yet an instrument that straightforwardly measures a products impact. Additionally, the NICU environment is a context in which ethics have to be considered carefully when gathering design input or testing. We gathered knowledge about how to design for bonding through designing. We describe the actual designs and encountered design challenges, as well as design process meta-insights. The thesis consists of two case studies.

The first case study describes the design process of a comfortable and attractive wearable monitoring system. In the iterative process the multi-disciplinary nature was dealt with by developing the 'technology, user focus and design' aspects simultaneously through quick literature studies and explorative tests. The result is a jacket containing textile sensors for ECG monitoring, as a platform to which the wireless communication, power supply and other sensor modalities can be added. It looks like regular baby clothing and bonding is

addressed by making the baby more approachable for the parents. For reliability of the ECG monitoring with textile sensors diversity measurement was proposed.

Clinical multi-modal sensor data was collected using a state-of-the-art amplifier in combination with the Smart Jacket in order to test the concept of improving reliability through diversity measurement. We compared textile electrodes to gel electrodes and explored whether additional sensor data such as redundant electrodes, acceleration and video could be used to improve reliability. We found that reliability testing of just the sensors was complicated due to the absence of the golden standard for this type of measurement. It led to the insight that the complete system should be tested independently, complicating the design process of making design decisions creating the complete system. We learned how choices in amplifier, type of sensors, location of the sensors and wearable design impact each other in the actual clinical context.

The next iteration of the Smart Jacket focused on the business processes: how to develop such a multi-disciplinary concept involving several necessary partners into a marketable product. A Value Flow Model workshop was organized which resulted in bringing user groups, companies, designers, researchers and medical professionals together and distilling the main values. The workshop resulted in a business approach in which the product would be complete with amplifier and power, but starting only with ECG. This first step was completed successfully and triggered the creation of a new Smart Jacket prototype with wireless ECG monitoring, realized in a separate project launched from the collaboration and the contacts established at the workshop.

The second case study was about building theory around parent-to-infant bonding and designing specifically with the goal of supporting it in mind. Based on a literature study we have defined that the bond between parent and child is a feeling of 'love' that grows with 'repeated (initially close) reciprocal pleasurable experiences'. These experiences are positively and negative influenced by a large set of conditions over the span of a life-time. Bonding is a complex, individualized and flexible process. We decided to design for the conditions during the time of hospital admission, creating positive 'bonding experiences'.

The 'Experience Design' method guided our search for design opportunities, gaining a personal insight into how parents experience bonding, by exploring the complete picture incorporating stakeholders, places, institutions and development through time. Based on in-depth interviews with parents, experience flows were created. In a creative clustering session, a set of design opportunities was derived and design guidelines we identified as well. From brainstorming the following concept resulted: a real-time abstract monitoring display positioned nearby the baby, combined with a long term monitoring system next to the incubator. The real-time display was proposed to offer the parents an extra sense of connectedness to their child and possibly offering extra cues about the state of the baby while interacting. The long-term monitor potentially offers insight into the patterns that develop over time.

The real-time display was selected for further development because of its potential to directly impact the interactions in the here-and-now and because of the design challenges it offers. In a design cycle we aimed to design displays that are unobtrusive, informative, attractive, safe and allowed for the focus of attention to be on baby. Four display designs with different types of actuators offering various experiences were the outcome.

Four display designs with different actuator types in which the vital sign parameters heart rate and respiration were represented were compared to each other and to the current monitoring display. We first measured the performance of the designs: Whether they succeeded in conveying the information to the parents. Secondly, we measured the instantaneous bonding experience qualities of the design. We constructed a self-report questionnaire inquiring to the ranking of several designs according to instantaneous 'bonding experience' qualities based on our definition. The designs of the optical blanket display and the tactile object to be held by the parents both came forward as viable options for further development.

Appendix E

Curriculum Vitae

Sibrecht Bouwstra obtained her B.Eng in Industrial Product Design at the Saxion Hogeschool Enschede and graduated in 2008 cum laude from the Eindhoven University of Technology with a M.Sc in Industrial Design. During the masters she specialized in designing products that are dynamic and offer a rich and lively experience. She is fascinated by the combination of technology and perception and therefore enjoys designing products that are close to body. From 2009 she started a PhD project at the Eindhoven University of Technology within the Designed Intelligence group of which the results are presented in this dissertation.