BSc Thesis Creative Technology

How high is the stress Level?

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Abstract

Toxic stress is a problem influencing babies worldwide, having a potentially significant negative influence on the baby's development. The problem is not easily solved due to the difference in sensitivity to stress and the stressors differing from baby to baby. Also, the babies' inability to communicate with their environment is a major stumbling block in finding out and solving the common stress the babies experience. The present methods and techniques to tackle the problem fail to look objective to the situation or are not fully proven to be effective. Therefore, this research aims to make an unobtrusive device that can monitor the stress level of babies and thereby notifies the stress indicators of the babies to the caretaker(s). By looking into the literature and the present state-of-the-art, it was found that measuring the heart rate combined with the movement and cortisol level of the baby had the most chance of finding and validating the stress response of the baby. Evaluating different feedback concepts with specialists concluded that the caretakers getting feedback via an application is the best method of receiving feedback on the baby's stress response(s). A concept is developed and realised, consisting of two parts. The first part consists of one sensor module containing a pulse sensor and two sensor modules containing movement sensors. All of the modules are put on plasters for easy placement. The second part is a concept application giving the caretakers feedback about the status regarding the baby's stress. Evaluating the two prototypes based on user usability testing, it is still not found if the used sensor modules are able to measure a stress response by having inconclusive data. The second prototype, the application, is also being concluded by usability testing. It is seen to be a great first step in realising a great feedback method for the caretakers but not as an end product to be used in the real world. All in all, as both realisations did not come with satisfactory results, this research's realisations and concept can still be seen as a good foundation to use when the concept is further developed.

Preface

First, I want to thank my supervisors of this project Randy Klaassen and Juliet Haarman, for enabling me to execute the project and helping me throughout the entire project when needed with their endless patience. If I had a problem or questions, they were always there for me. I am very grateful for having such excellent supervisors. Further, I would like to thank my clients, Ellen van der Kroft and Zillah Holtkamp, for their support, feedback sessions, and enthusiasm in every meeting. Also, a big thanks to Anouk van Vossen, who was willing to help me during the period Zillah was on vacation.

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1. Introduction

1.1 Background & Challenges

The first years of a child's life come with fundamental developments shaping the child with effects stretching over the rest of his/her life. As described by Unicef [1], "*The first years are the foundation that shapes children's future health, happiness, growth, development and learning achievement at school, in the family and community, and in life in general"*. When being in this important stage of their life, some babies may have to deal with a potentially big problem on their health and further development named toxic stress.

Having a stress reaction occasionally should not be a problem for babies. However, when stressors, something that causes a state of strain or tension, occur more often and the increment of the stress level stays up frequently over a significant period, it is named toxic stress [2] [3] [4]. The negative consequences of this type of stress may be noticeable in the child's development to an adult. Examples of the consequences are physical and psychological dysregulations causing life-long effects stretching over to the rest of their lives like permanent brain damage [5] [6], and the reduction of physical and mental health [7]. Babies are labelled to be vulnerable to toxic stress because they cannot always communicate through verbal and nonverbal communication to their environment. This lack of communication skills makes monitoring their symptoms and reaction to stress more complicated than, for example, adults. When the stress reaction of the baby is not picked up and continues to occur frequently, as described above, toxic stress occurs.

Which causes the stress reaction may be different between babies. Some babies are more sensitive to stress than others, and the environment around the baby, which could cause a stress reaction, is also different between the babies. Some stressors are obvious and pretty logical for most people to recognize, other stressors are not. As an example of a pretty obvious stressor: in the first years of a child, the relation between the parent (particularly with the mother) and the baby is one of the biggest influences on the child's development [2]. Not being in an environment that includes good family relationships and concludes contexts such as divorce and frequently fighting parents give the baby a good chance of a regular increased stress level [8].
On the other hand, another not broadly known stressors that may also influence the baby's stress level is the stressor found by White-Traut et al. [4] about communicating with your baby when holding him/her. In this study, an increase in cortisol level, a key substance released in a stress reaction, of the baby was measured when the caretakers did not make a lot of eye contact, did not talk, or did not use multisensory intervention the baby when holding the baby. This increased cortisol lever indicated a stress reaction of the baby.

Right now, there are some methods designed to measure and find stress reactions and stressors among young children. These methods have the intention to help the child (and the rest of the family) with the help of professionals or in the form of a device that can measure some stress indicators. However, these methods come with their own problem, making them for now unsuitable for accurately noticing a stress reaction of the baby and finding stressors in the babies' environment.

To start with, the common method used by psychologists is to interview the parents and talk about the baby acting in different ways, such as elevated autonomic arousal [9]. This approach's problem is the amount of time it requires to execute combined with the parent's sometimes biased answers, making it very hard for the professional to examine the situation. Other methods used by researchers are measuring the biological responses of the baby in a stress reaction. An example is measuring biomarkers such as the cortisol level babies' [10]. As this seems to be the more objective approach to determine the stress level, these methods still need to be further studied, verified, and right now are only used in a research environment. A verified method or device that can objectively verify the baby's stress response is right now not available on the market.

This project's core challenge is to objectively measure and verify a stress reaction on children between the age of 0-12 months. This research investigates the psychological and physical side of (toxic) stress among these children. Within this research, the indicators of stress, the most common influences of the childrens' environment on stress, the influence of stress on the children are researched. When having reached the project's core challenge, the caretaker should also be notified about the baby's having a stress reaction(s) and therefore be able to take action when needed.

1.2 Research Questions

The main scope of this research will rely on solving the main research question underneath:

Research Question: *"Which unobtrusive device can monitor the stress level of children between 0-12 months and thereby notify the stress indicators of the children to the caretaker(s)."*

Multiple sub-questions are formed to help answer the bigger main research question. By splitting the main research question into parts, four sub-questions are formed:

Sub research Question 1: *"What are the known stressors of children between 0-12 months."*

Sub research Question 2: *"What is the influence of the environment on the stress of children between 0-12 months."*

Sub research Question 3: *"What are the best possibilities of using state-of-the-art technology to measure the stress indicators of children between 0-12 months."*

Sub research Question 4: *"How can current technology help notifying caretakers about the baby having a stress reaction(s)."*

1.3 Report Outline

This report's outline is made in the same chronological order as to how this research is executed. The report starts in Chapter 2 by providing in-depth information about (toxic) stress on babies to better understand stress and stressors in the environment of the baby. Also, In this Chapter, the current technology and methods linked to this research topic are provided. In Chapter 3, the methodology used within this research is explained. In Chapter 4, the research's ideation phase is described using the founding's of Chapter 2. Chapter 5 describes the specifications of the product. Chapter 6 describes the realization of the product developed in Chapters 4 and 5. A user test regarding testing the concept was evaluated in Chapter 7. In Chapter 8, this research is discussed, and suggestions are given for future work. The 9th and last Chapter concludes and discusses the research's findings and gives recommendations for further study. At the end of this report, the appendices with the additional material regarding this project can be found as well as the references used within this research.

2. Theoretical background

This chapter explains and defines stress by combining multiple already executed researches. The chapter goes into the biological responses of stress and their influences on the person. Also, the environmental factors which could influence the stress level of the babies are discussed. The second part of this chapter discusses the already existing technologies and methods that claim to measure (indicators of) the stress level. The end of this chapter concludes the information described in the first part and the technology in the second part of the chapter to this project's relevance.

2.1 Defining stress and stressors

Stress, to a certain extent, is something experienced by the majority of the population. These people mostly describe stress as formally stated by the oxfords' dictionary as “a physical or mental strain” [11]. This, however, does not include all of the aspects regarding stress, as described by the national scientific council of the developing child [7]. They state that the word “stress” is not just describing a biological reaction, but the term also includes many aspects of a person's behaviour and lifestyle combined with the person’s mental and physical circumstances. McEwen and Seeman [12] share this thought and strengthen this statement by defining the word stress as something that includes personal biological factors combined with daily experiences. They link personal behaviour with environmental influences to the extent of stress. These environmental influences can be biological mediators such as the various cycles of nature (for example, the light-dark cycle).

Most researchers who are investigating the negative influences of stress tend to label stress as something negative when this is, most of the time, not the case. As described by the national scientific council on the developing child [7], stress is a reaction of neural and chemical responses in the body to cope and adapt to a new situation. When a person experiences stress, the body notices a potentially dangerous situation. The person reacts to this by preparing himself for the familiar "fight or escape or tend-and-befriend" reaction, as said by Bates *et all.* [10]. This stress reaction can help, maybe even save, a person in a life-threatening situation. Stress, to a certain extent, should not be labelled as something bad but as something life-saving.

The negative side of stress occurs when stressors frequently appear over a more extended period, where the environment fails to help the baby cope with the stress. Now the stress is labelled as toxic stress, as stated by McEwen and Shonkoff *et al.* [3] [4] [13]. Toxic stress may significantly impact the baby's health and sometimes even influence the rest of the baby's life. This will be more elaborated on later in this chapter.

A factor or thing which causes a stress reaction is called a stressor. In Palmers' research [14], a few current-day stressors of babies are defined such as; not allowing your child to cry without any prenatal attention and affection. Also, when the child asks for food, not giving him/her and not calming the child when experiencing stress.

However, stressors are different from person to person and can come in multiple forms. Linking the word stressor by a particular object or event is simply impossible due to diversity and subjectivity from person to person. However, the development of stressors on persons in general over time is known. For example, it is known that stressors of the current day strongly differ from the stressor of the past. Multiple researchers have stated that the everyday stressors to people have changed and increased in number over the years because of the ever-changing world**.** State [16] describes in his research that the number of stressors between 1990 and 2010 had been increased by about 2 per cent on average. Especially the group living in their mid-life reported having 19 per cent more stress in 2010 than in 1990. If this is compared to the 365 days in a year, this translates to be 64 days of having stress in a year more than before. If the research participants were asked how they think how this increase happened, they would mostly answer that current-day life is becoming more hectic and fewer certain days. As this is not the particular group of babies, this still shows that the number of stressors increases, resulting in more babies having to deal with stress than the babies of the years before. Also, McEwen explains that it may occur that nowadays, more non-life-threatening situations trigger stress reactions due to the more chaotic, ever-changing world [13].

2.2 Understanding the biological side of stress

To better view what stress is and what stress does to a person, the biological fundamentals of the body's adaption to a stressful situation need to be understood. The adaptation starts with neural and chemical responses, as explained by the national scientific council on the developing child [15]**.** Some biological reactions are within the persons' awareness, and others are not. The most important biological reactions to be considered are the sympathetic-adrenal-medullary (SAM) axe response and the hypothalamus-pituitary gland- adrenal cortex (HPA) axe response. By understanding these responses, the researcher (and others) can look if specific biomarkers can be used to measure when needed.

To begin with, the Sam Axe Response, as described by McEwen [16], uses the sympathetic-adrenal-medullary axis/sympathomedullary pathway (SAM). When a stressful event occurs, the response of the SAM axis starts rapidly. This system directs the body's preparation for the familiar "fight or escape or tend-and-befriend" reaction. This reaction uses the autonomic

nervous system, which means that the person cannot actively control this response. This SAM axis reaction focuses on short-term response to a stressful situation. This response answers what the body needs to adapt to a stressful situation as quickly as possible. Ely and Henry [19] confirmed this SAM axe response by experimenting with mice in a controlled environment. The mice were set in a stable social environment, where they did not have complete control. The lack of a specific threat may cause a socially unstable condition to create a stressful situation. Also, a lack of food was used to trigger a stress reaction. The mice's physiological responses were measured. Koolhaas *et al*. [17] further extend this SAM axe description by diving into and comparing different adrenaline and noradrenaline researches. Koolhaas *et al*. [17] and Jack*et al*. [3] conclude that these substances of the body have a role in the SAM axe reactions, linking it with uncontrollability during stress because adrenaline increases the CRF and ACTH production, as later described in the HPA axe response. But both do not go further in-depth into the substances' workings during stress.

The other response, consisting of the hypothalamus, pituitary gland, and adrenal cortex (HPA axis), needs more time than the SAM axis to influence a person. The primary function of the HPA axis is to regulate the stress response. Bruce [16] and Markus *et al*. [18] explain this reaction as follows. At the start, the hypothalamus stimulates the anterior pituitary by using the corticotrophin-releasing hormone (CRH) to produce adrenocorticotropic hormone (ACTH). This hormone will follow the bloodstream to the adrenal cortex, which will release cortisol into the bloodstream.

The working of cortisol is to tear down protein from the muscles to amino acids, which stimulates the transportation of energy around the body and results in increased blood sugar. This helps the body to body recover and thereby counter the SAM response. Cortisol also leads to other physical effects such as higher blood pressure, increased heart rate and a stop in the kidney and digestive functions as defined by Palmer [14]. Eventually, the hypothalamus will notice Cortisol levels within the blood, resulting in negative feedback on the release of CRH and thereby negatively influence the release of ACTH and Cortisol until the bloodstream is back in homeostasis.

Markus *et al*. [18] clarify possible confusement about cortisol resulting from the report of Bruce by stating that variation of the level of cortisol is normal and healthy. The story of cortisol changes over the day, with the highest peak at the beginning of the day and the lowest point. The problems regarding cortisol come when a notable difference in cortisol is measured in a short period, indicating the stress response. De Weerth *et al.* extend the knowledge of the HPA axe response by proving with an experiment using children of different ages that people's cortisol regulations is already established within the first half-year [19]. A schematic is made to get a better view of the HPA axe response, which can be found underneath.

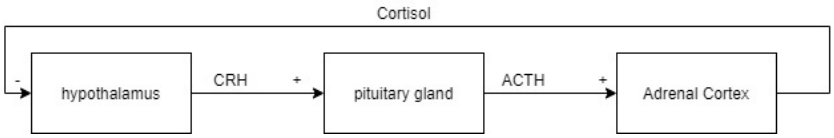


Figure 1: Schematic of the HPA axe response

2.3 The effects of stress

To which extend the stress responses will affect someone depends on multiple factors. For example, as described by Bruce [13] and the national scientific council on the developing child [20], the effect of stress strongly depends on past experiences and the availability of a supportive environment. The extent to which the responses influence a person also has to do with sex. As both responses apply to both sexes (male/female), both sexes' systems' reaction to the fight or escape or tend-and-befriend" situation is not the same. As a male earlier tends to fight in a stress reaction, females earlier prefer to flee out of the situation caused by the higher estrogen level coupled with the oxytocin hormone within a female [21]. One of the workings of Oxytocin is to increase the trust in humans [22], making a smaller chance to fight within a situation. Furthermore, males' conditioning performance tends to improve, where females' performance worsens when looking to physical exercise [23]. The threshold to start the stress reactions and the intensity of the stress reaction diverse from person to person. Underneath, the general short-term and long-term effects of both responses are explained.

2.3.1 Short-term Effects

Jacobs [24] McEwen [16] state that the HPA and SAM reaction to stress in the short term leads to increased heart rate increasing blood pressure, more prominent pupils and more aggression, increasing the chance of spontaneous fighting and increased lung activity and therefore increased oxygen saturation. Palmer extends this list by saying that the stress reactions lead to interrupted digestive and kidney functions [14]. As described earlier, the person will transform to the "fight or flight" mode, making the person ready for impending danger.
Also, the baby will act more restless, like having more frantic disorganised activity, locking more away from others, arms and legs pushing away and frowning, as stated by Children's Minnesota [25].
These symptoms will make the person more alert for sudden action but cost a lot of energy, which could be a problem when dealing with stress over a more extended period.
The activation of an allergic reaction is also linked with a stress reaction. Having stress can make an allergic reaction worse, leading to a more intense allergic response by the increasing histamine

in the blood, as described by Fulghum [26]. She states that some experts have also described that the stress response may lead to allergy symptoms, but this is not completely verified.

2.3.2 Long-term effects

When the child's stress response stays up frequently over a significant period in an environment where the caretakers fail to be supportive, it is stated as toxic stress. Toxic stress includes the more prolonged exposure to chronic elevation of the cortisol hormone and other hormonal dysfunctions. Gilles *et al*. emphasize the problem of toxic stress by stating that even when the period of toxic stress ends, the complications of toxic stress as a child can still be noticed later in life [27].

These complications are as follows. Firstly, the stress reaction threshold will lower, making the person more sensitive to stress in future situations than others [15]. The adverse effects of being more sensitive to stress may lead to a higher chance of having chronic disorders later in life. Following the research of Jacob [24] and McEwen [6], An increase in having disorders such as Insomnia, hostility, anxiety, and depression may be considered later in life [28]. Also, experiencing more stress leads to reduced learning ability.

Further, the mental and motor ability may be negatively influenced by more prolonged exposure to toxic stress, as shown in research by Krugers *et al.* [29]**,** where this was the cause by children with the highest cortisol level compared to other children.

For most people, the considered worst case is described by McEwen, who describes permanent brain damage that occurred in people who had experienced toxic stress as a child [13] [30]. These researches show the great variety of long-term complications caused by toxic stress.

2.4 Environmental influences on the stress level of babies

Following Umberson and Thomeer [31], Shonkof et al. [3] and almost every research on this topic, the caretaker(s) may be considered the most important persons and the most present environmental factors in the babies' lives. This makes them the biggest influence on the baby's stress level. Shonkof et al. [3] made a framework to put the effects coming from the caretakers combined with the resulting baby's stress into a new perspective to help future research. In this research, Shonkof et al. distinguish the response to children's stress in three different categories by intensity and duration with different environments' influence. The first one being the positive stress response. This response describes a relatively mild psychological stress on the child for a short period, where the caretakers help the child cope with the stress. This response promotes positive stress responses in the future and positively influences the psychological development of the child. The second response, named the tolerable stress response, categories the situations where the child experiences a more significant amount of stress by a more substantial amount of

threat towards the child or big negative events such as a family member's death or the divorce of a family member the parents. As in the positive stress response, the child's environment will include responsible caretakers who actively try to help them cope with stress. It assumes that the child will return to baseline status after a longer period of time, which results in no further long-term consequences for the child. The last response, which leads to toxic stress, results from the same situation as the tolerable stress response, with the difference of being surrounded by a bad environment. In this bad environment, the caretakers cannot help the child cope with stress, resulting in a frequent state of (toxic) stress. The National Scientific Council on the Developing Child [15] also defines this last situation as when the caretakers fail to give the baby a feeling of safety and control. The baby will not feel comfortable enough to explore the world, leading to a higher stress level because of more fear towards the world.

Another cause that results in the start of the stress response on babies is physical pain. The cause of physical pain may come from many sources. The most obvious one is the physical pain coming from other people hitting or strangling (the baby). Hannibal and Bishop [32] describe this kind of physical pain linked to chronic stress. When physical intimidation is used on babies, the stress response is likely to start. When this type of stressor is applied over a longer period, this could lead to toxic stress. Other physical pain related stressors described by Palmer [14] could come from neglecting behaviour as not giving breastmilk when needed or decreased skin stimulation towards the child. As pain may be the cause of stress, it also can be a result of stress. Keeping this in mind, not every physical pain should be labelled as a stressor.

As the caretakers may be the most important persons and the most present environmental factors in the babies' lives, these may be considered the most important influences on the baby's stress level as described by Umberson and Thomeer [31]. As defined above, these will influence the most critical stressors in the infants' life. When the caretakers fail to give the baby a feeling of safety and control, the baby will not feel comfortable enough to explore the world, leading to a higher level of stress [15].

A good example that emphasizes the role of the caretaker Is the research of Mark *et al.* [33]**.** They tested the effect of separation of the caretaker and infant over a short period among apes. They found an increased cortisol level in the infants when the parents were not around their baby for around two weeks. Also, the babies showed distress behaviour, such as making more noise and a change in posture towards others. All of this indicates a stress reaction among the infants.

The last thing to consider when talking about the influence of the environment on the stress level on babies is the capability of babies to sense the stress level of others. Gwen [34], with the help of Veronika *et al.* [35]*,* state that babies not only sense the stress of others but also

are affected by it. Gwen compares multiple researches regarding the transfer of stress from mother to baby to prove his point. Keeping this in mind means that when the caretakers are in a stressful personal situation, such as a divorce or financial problems, they could negatively influence their baby's stress level. An extended period of the stress of caretakers may also be carried to a long period of (toxic) stress on the baby.

In conclusion, the biggest environmental influence on the stress reaction of the baby is the parents. The parents' biggest influence on the baby is by may or may not giving the baby a feeling of safety and control. A framework based on these aspects is made to categorize relatable situations. However, there are also other influences from the parents which could result in a stress reaction as the amount of contact with the parents, physical and mental abuse and the baby copying the stress from the parents resulting in (toxic) stress.

2.6 State of the Art

A device or method that is capable of objectively measuring the stress level of a baby is not developed and verified yet. This, however, does not mean that there are not many other techniques already developed to measure the stress indicators (among babies). It is essential to research these products and methods for this project's potential relevance. Looking to past techniques, using parts of the methods and techniques, and learning from the pros and cons may help develop a tool to measure babies' stress. In this chapter, the techniques marked as “measuring stress” are introduced combined with other methods that are not labelled this way but may be relevant to this research. For example, methods or devices not developed to measure stress but still capable of measuring stress indicators. Underneath every technique a table summarizes the described pros and cons. A conclusion comparison is drawn by linking the stated methods and devices with this project's relevance at the end of the chapter.

2.6.1 Measuring Cortisol levels with the use of professionals

As stated above, exposure to stress may lead to multiple biological changes within the body. An example of a hormone released during the stress reaction is the cortisol hormone, as explained by McEwen [16]. The cortisol hormone can be found in multiple places in the body. This leads to a great variety of methods where cortisol can be measured. In short, it is claimed that cortisol can be found in the blood [16], urine and saliva [36] [37], sweat [38] [39] and even hair [40].

Measuring the cortisol level can be done in different ways. The most common way is a method in the form of a blood test by a professional, as executed by MedlinePlus [41]. Here, the professional will insert a needle into the body to collect a small amount of blood into a test tube or vial. This blood will be researched in a lab to measure the cortisol level. Typically, the Cortisol

level decreases over a day, making the timing of collecting the blood very important. This is why primarily two samples are collected, one at the beginning of the day when the cortisol level is at its highest and one at the end of the day when the cortisol level is at its lowest. Both samples will be tested and processed by a professional. This measurement is quite accurate.
Medline [41] also states that within the urine, cortisol hormone levels can be found. For 24 hours, the test person has to collect the urine into a container. These 24 hours are the cause of the earlier explained chance of cortisol level over a day. After 24 hours, the urine will be tested on cortisol by laboratory professionals or healthcare providers.

Another option is to perform the Cortisol Saliva test performed by Heath Testing Centers and Medline [41] [42]. The test persons can execute the Cortisol saliva test at home. Here, the test person needs to a swab into his mouth at 11 p.m. or midnight, when the cortisol levels are at its lowest. After two minutes of swapping, the test person puts the swab into a container and returns it to the health caretaker. The health care provider or laboratory professionals will test this swab and measure the sample's cortisol hormone.

Recently In 2017, Bates *et al.* [40] found a new method to measure the cortisol level. The researchers have measured the cortisol level by using a sample of a childrens' hair. The researchers stated that measuring the hair cortisol concentration (HCC) is reliable to indicate young children's stress levels. After the researchers compared different studies conducted on children with an age mean between 1 and 5 years, it is found that the HCC increased when the children stress response was activated. HCC may be a very reliable biomarker for measuring stress because HCC generalizes the amount of cortisol level over a day. This means that when HCC rises, the general level of cortisol over a day has increased, indicating a stress reaction(s). A small summary can be found in the table 1 underneath.

Pros	Cons
• Various methods of measuring the cortisol level with the use of a professional • Some methods already used on babies • Accurate measurement	• Timing required for measurement • Involvement of professional needed

Table 1: Summary pro's and cons cortisol measurement with professionals

2.6.2 Measuring Cortisol levels with the use of wearables

At this time, already some wearables are developed to measure the cortisol level. A great example is described by the University of Stanford [43] and Healtheurope [44]. Here an on the skin attached stretchy patch measures the cortisol level the body is producing. The sensor located on a flexible patch gives real-time feedback on the cortisol level. Therefore, it has the potential to

measure and give feedback on the stress level of the person. The sensor is still in development and not yet used in real applications outside a research environment.

Another further developed device is produced by the research of Paul *et al.* [45]. Their research created a wrist-worn biosensor that can measure the cortisol level out of a person's sweat. No exercise or physical load is needed to deliver a good amount of sweat to get the sensor the right amount to work with. This device was initially designed to measure the cortisol level to determine if the adrenal gland still functions correctly. On the other hand, the capability of measuring cortisol levels results in the ability of this device to measure the stress response. The research does not define the age of the persons. A small summary can be found in the table 2 underneath.

Pros	Cons
• Accurate • Can be placed on different places on the body	• Only used in research environment • Not tested on babies

Table 2: Summary pro's and cons cortisol measurement without professionals

2.6.3 Measuring the Heart-rate

The heart rate and blood pressure of a person increase when reacting to a stressful reaction. These factors can be seen as stress indicators, making measuring these indicators useful for further development within this research. Multiple already developed devices can measure the heart rate.

Heart rate devices are well developed over the years. With the use in sports, hospitals and other places, it is no surprise that a great variety of heart rate devices are on the market. The first example is that of an optical armband heart rate monitor. Companies as polar and Garmin have developed an armband that is designed to measure the heart rate accurately. Other companies combined this feature with other options as in current day smartwatches. The techniques applied in these bracelets and smartwatches are described later in this chapter with the smartwatches, which uses the same methods.

Another commonly used device developed by many companies as Garmin [46], Powr Labs [47], Polar [48] and many more to measure the heart rate is the chest strap heart rate monitor. These chest straps primarily use the method of ECG to measure the heart rate. As Horton et al. [52] and Polar [53] described, when using the ECG chest strap heart rate monitor, a sensor is measuring your heart's electrical signals. It measures the signal produced when the muscle heart constricts and pumps blood through the body. Horton *et al.* [49] compared the ECG method against the Optical measurement by an experiment on two well-used ECG and optical measurement devices among individuals between 15 and 55 years. They concluded that the optical measurement has a

better accuracy overall but that the ECR measurements were also good when conducting the physical exercise. The optical measurement became less accurate when higher physical activity was conducted.

A completely different approach to measuring the heart rate is described by Liu *et al*. [50]. In an experiment that uses a 640x480 30 fps resolution webcam in an indoor environment with ambient sunlight, a face was recorded for 20 seconds. After using a particular algorithm, they were able to record the person's heart rate in the video. They describe the drawbacks of using this method as; blinking with the eyes causing noise and the need for good lighting. Also, because of certain inherent instability and statistical methods, they found the accuracy of this method is questionable.

Another kind of device targeted at babies is a smart sock developed by Owlet [51]. This device can track the babies' heart rate and oxygen level by letting them wear socks. The sock is connected to an app that provides the information of the sock to the caretakers. When a sudden change of heart or oxygen level occurs, it sends an alarm to the caretakersOwlet says that babies between the age of 0 and 18 months can wear the sock. Most of the reviews on this product are fairly positive. However, Owlet and others do not mention the exact accuracy and how precise the sensors can measure. A small summary can be found in the table 3 underneath.

Pros	Cons
• Already done by multiple parties • Claims accurate measurement of heart rate and blood pressure	• Not tested on babies • Specific accuracy is not mentioned

Table 3: Summary pro's and cons measuring heart-rate

In conclusion, measuring the heart rate is done by already multiple parties. A lot of companies claim to accurately measure the heart rate and blood pressure with their product. However, most of these products are targeted at groups older than babies. The product dedicated to the group of babies claims that their product can measure the heart rate and blood pressure accurately. However, the specific accuracy is not mentioned.

2.6.4 Measuring the breathing pattern

There are already devices developed that can measure the breathing pattern of babies. Most of these devices are developed for the sudden infant death syndrome (SIDS), which is the leading cause of death for infants aged between one month and one year in developed counties, as Rachel et al. [56] stated. Despite the different targeting, this device still can be used to measure the stress level of babies. The first form of this kind of device is a clip onto the model.

Snuza [47] created a clip-on baby sensor. This device, located mostly on the child's diaper, notifies the caretakers when this unregulated breathing happens.

Another way to measure the breathing pattern of a baby is with the use of video recording and video processing. Tveit *et al.* [52] describe how they could measure the breath pattern of a baby using a particular algorithm. They state that this phase-based method works quite accurate and may have some great potential. The only downside of this method is the lack of real-time performance. All of the test subjects were earlier recorded and then put into the algorithm. A small summary can be found in the table 4 underneath.

Pros	Cons
• Options for both clip-on and camera • Real-time performance (clip-on)	• Fairly accurate (camera) • No real-time performance (camera)

Table 4: Summary pro's and cons breathing pattern measurement

2.6.5 Measuring the movement of a baby

Children's Minnesota [28] described children having stress sometimes indicate this by restless behaviour and an increase of their average movement. Monitoring this increased movement of the baby could give hints if the baby has stress.

Tracking the movement of babies has already been done by Manu *et al.* [53], who developed a jumpsuit with multiple sensors as accelerometers and gyroscopes integrated, which can track the baby's movement. Based on comparing the sensor data with a video recording, the researchers were able to make a machine learning algorithm that can detect the seven-month-old test persons' movement and posture. Regarding the researchers, the setup can accurately define the movement and posture of the one wearing the suit. Further, they emphasize the importance of the four-limb recording of the suit because this gave the best results after testing different configurations. The wearability of the test design is being concluded as comfortable to wear for the children. The children did not find any problems or harm in wearing the suit. However, the researchers did not mention testing the suit in different environments with various temperatures.

Another example of an already developed product is the smart baby monitor from Nanit [54]. This camera, which is placed on top of the baby's bed, monitors the baby's movement when sleeping in bed. When the baby starts to move frequently over time, it senses this and notices this as awake. It creates sleep metrics that tell how long the baby slept, how long it was awake, how many times you took the baby out, and uses this information to state the sleep efficiency. Thereby, the caretakers can see if the baby is sleeping enough and correct the environment when needed for better sleep. A small summary can be found in the table 5 underneath.

Pros	Cons
• Measuring technique already implemented on multiple devices • Accurate measurement (jumpsuit) • Both methods already tested on babies	• Accuracy not mentioned (camera)

Table 5: Summary pro's and cons movement measurement

2.6.6 Using Smart Watches

The development and rise of smartwatches in the past few years have made it to a point where multiple measuring indicators of the blood are possible. For example, measuring the heart rate and blood pressure are almost standard on every smartwatch. Some applications that can measure the stress level are already discussed earlier. However, because of the size of the market and the far development of implementing the techniques used in smartwatches, it has its own subtopic.

These smartwatches from major brands as Apple [55], Fitbit [56] and Samsung [57] also include heart and blood measurements with a few additions. The watches use Optical Heart rate Monitoring by using photoplethysmography (RPG) methods explained by well respected biometric technology company Valencell [58], measures multiple blood indicators. It uses numerous optical emitters to pulse a green light (excellent absorption by the red colour of our blood) or a light bundle with multiple wavelengths (the skin level may influence the measurement) into the skin. Some light is reflected by the blood captured by a Digital signal Processor (DSP), which digitalizes the measurement data. With the use of an accelerometer and smart algorithm (also send to the DSP), the devices measure if the person is moving or not. The latest smartwatches can measure the heart rate, movement and blood pressure, and blood oxygen saturation, blood metabolite concentrations, and how many calories are burned. The RPG process is displayed underneath in figure 2.

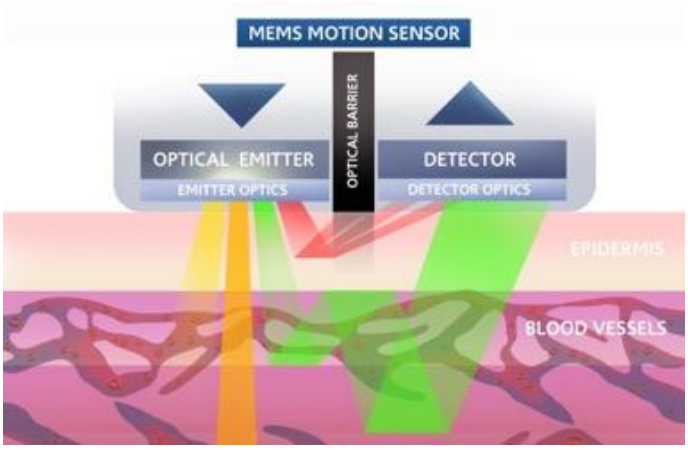


Figure 2: Using Photoplethysmography [63]

As this seems to be an ideal method to measure multiple indicators, this method also has some drawbacks.

To begin with, it has to deal with optical noise. The amount of light around the person influences the measurement because it may indicate heart-pumped blood flow. Also, the skin's health condition, amount of muscle, and other personal factors may affect the measurement's result. Secondly, as every different skin tone, in different weights, differently absorb the light, the skin tone may influence the measurement. For example, green light is being more absorbed on darker skins, limiting heart rate accuracy. Also, tattoos affect the absorb the emitted light more than untattooed skin. Thirdly, crossover problems may occur. Crossover problems are problems caused by the algorithm, interpreting the incoming data as a false measurement by labelling step rate as heart rate.

The placement also may influence the measurement. Some body parts have to deal with much higher optical noise than other parts, such as more muscle, more tendon, bone, higher density of blood vessels nearby the skin, blood perfusion and vascular structure. Ethel et al. [62] discussed the best location on the body for and OHRN, the ears and forehead. The worst place to conduct an OHRM is the calf and ankles, and the not ideal but possible positions considered are the wrist and arms.

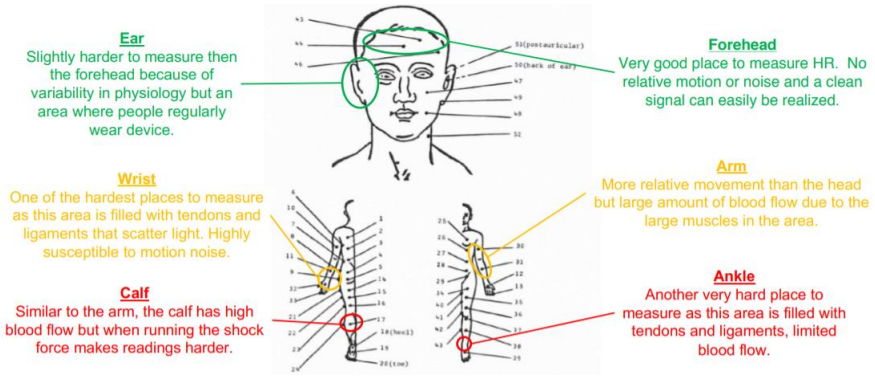


Figure 3: Best placement for OHRM [64]

The last drawback, described by Valencell, is the challenge of conducting an OHRM without low perfusion. Low perfusion is when the blood flow to the capillary beds, the smaller blood vessels, is low. This low perfusion varies significantly among people with obesity, diabetes, heart conditions and arterial diseases. Low perfusion causes an increase of noise in the signal-to-noise ratio

Another type of smartwatch specifically designed to use on babies is the smartwatch coming from Liip [59]. The smartwatch from Liip is able to measure heart pulse, blood oxygen level and distal temperature from the baby in real-time. This information is sent to the app, which is connected to the device. The information of the past week is also stored in the device. The app

gives the user feedback when it concludes that something is wrong with the values coming from the baby but does not give a prognosis of a possible problem for the baby. A small summary can be found in the table 6 underneath.

Pros	Cons
• Measuring technique already implemented on multiple devices • Already used on babies • Real-time feedback	• Accuracy can be a problem • Not designed to measure stress

Table 6: Summary pro's and cons smart watches

2.6.7 Using Questionnaires

Questionnaires are used to determine the stress level and general health of a baby. Various questionnaires have their emphasis on different aspects regarding the health of a baby. These questionnaires are filled in by the caretakers of the baby or by the specialist interviewing the caretakers. Some questionnaires can be made online with the result also being available online, and some questionnaires need some professional intervention to get the result. However, these questionnaires have a major drawback. The questionnaires are not filled in by the one who is being researched, the baby, making it vulnerable to the subjective perspective of others' estimating their behaviour. They have to observe and evaluate the babys' behaviour, personality, health and other personal aspects of the baby and draw a conclusion. This results, in some cases, in strongly biased answers by the one filling in the questionnaire. Babies cannot correct this fault because of the lack of communicating skills. This makes finding the cause and situation of the baby's problem more complex and more time consuming for the parents and the professional. However, the questionnaire, in particular cases, can be pretty valuable. Underneath, the questionnaires of a few different parties are discussed.

Firstly, Vanderbilt University has created a questionnaire that measures coping and involuntary stress responses [60]. They claim that the questionnaire can be used on children until nine years old, adults and adults filling in the child's questionnaire. The questionnaire starts with checking the stressors involved and categorizing this to a specific domain of stress. Then it checks the frequency of the stress response and the intensity of the stress response. The questionnaire also asks how the person thinks about how he/she is coping with the stress on a scale from 1 (not at all) to 4 (A lot). The person needs to underpin the answer by describing which methods the person uses to cope with the stress response. The health is concluded by the number of points scored in the questionnaire. Vanderbilt University also provides different questionnaires for different particular scenarios; one on stress regarding Covid-19, one on stress regarding family problems, one on stress regarding parental issues, etc.

Secondly, The Nederlands jeugdinstituut has made multiple questionnaires for children between the age of 0-3 yea,r which investigates the childs' well-being [61]. For the relevance of this project, a few questionnaires are highlighted. The first questionnaire of Nederlands Jeugsinstituut [62] measures the quality of life by asking how they feel physically and mentally. Has the child some anxiety towards something, and how are the relations with the caretakers, other family members and other children. At the end of the 97 questions (47 questions if you choose the short version) it calculates the score, which represents the quality of life of the children, on a scale between zero (worst health) and hundred (best health). In addition, the different categories within the questionnaire described above all have their own rating. The target group of this questionnaire are children between 2 months and five years.

The second relevant questionnaire of the Nederlands Jeugdinstituut focuses more on the twelve different domains of the child [63] within 43 questions. Stomach problems, skin issues, lung problems, sleep problems, eating behaviour, problem behaviour, positive emotions, fear, liveliness, social functioning, motor functioning and communication skills are the twelve domains. The questionnaire applies to children between six months and five years.

A lot more questionnaires are available, but these are not very different from the ones described above. They all consist of almost the same kind of questions described in other words. A small summary can be found in the table 7 underneath.

Pros	Cons
• Variety of different questionnaires • Tested on babies	• Strongly influenced by subjectivity of parents and researcher

Table 7: Summary pro's and cons using questionnaires

2.6.8 Using camera's to sense emotions or physical conditions

As Fernando et al. [70] describes, it is possible to measure emotions and stress from facial expressions. Their research researched twenty adults who are playing a game where the stressful situations linear increase. Using a video camera recording for 6 hours, a heart rate sensor, questionnaires, and manual analysing, they claimed to measure the adults' stress level. However, they admit the multiple limitations regarding their research by stating the lack of confirmation of other researchers' research methods and the not very substantiated results of their study.

Further, Rice and Dunbridge developed a camera that can sense the emotional and physical condition of the test persons [64]. In this research, a two-dimensional camerate is used in combination with image processing and database analysis. First, a speckle (interference) detection and tracking sensor is pointed to the test person. After this image processing, the face will be compared to multiple images of faces whose emotions are already defined. By using this comparison, it suggests the emotion of the tested face. This method claims not to be accurate in

all of the measurements and is not tested on babies. A small summary can be found in the table 8 underneath.

Pros	Cons
• possible	• Still in development • Not tested on babies

Table 8: Summary pro's and cons using camera's to sense emotions and physical conditions

2.6.9 Measuring brain activity

During stress, brain activity increases. Multiple applications and methods can measure this increment of brain activity. When comparing these applications to each other, primarily the temporal resolution is compared to the spatial resolution. The spatial resolution defines how precise the electrode can measure the location of activation within the brain. Temporal resolution is the resolution response in the time domain. In other words, how precisely can the method tell you when the activation happened. The comparison between multiple brain activity measurement tools is made by He et al. [65], as seen in figure 4.

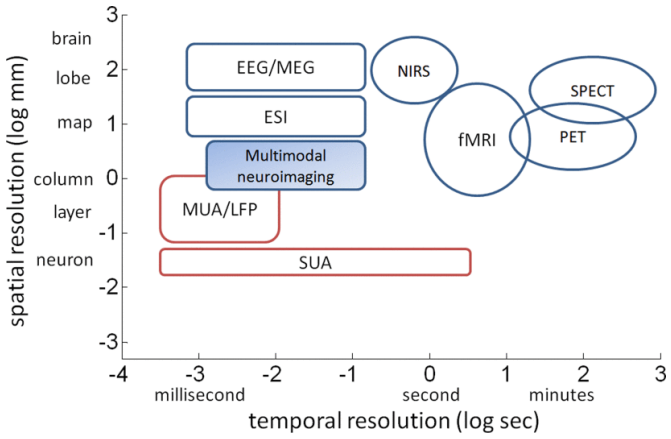


Figure 4: Comparison between different brain activity measurements [72]

The most common methods used in research to measure the stress level among a person are EEG and fNIRS. As used by Haak *et al.* [66], who combined measuring the brain activity with eye blinks in a stressful situation by using EEG measurement. EEG measurement consists of a cap with multiple electrodes on it, measuring the electrical activity of the brain. The signals are transported to a device that reads, amplitudes, and translates the signal coming from the electrodes to more understandable data, as explained by He *et al.* [65]. When the brain activity increases, the voltage fluctuations within the brain increase, picked up by the electrodes. With the placement of the electrodes all around the head, the areas within the brain which are activated during a stressful event can be measured.

The research of Haak *et al.* claim to find a relation between stress, causing an increased brain activity and an increased number of blinking. However, the study does not state to which group the experiment was executed. Further, they conclude that their method is not accurate enough to be used in commercial applications. Moreover, using EEG measurement comes with an unavoidable delay by using many electrodes, making EEG not ideal for fast measuring (also seen in figure 4).

The other common measurement method to measure stress is named functional near-infrared spectroscopy (fNIRS). Adrian and Hasan [74] explained that by using fNIRS, the concentration of haemoglobin (a substance within the bloodstream) is measured within a specific area of the brain using sensors placed in a cap. The method enables us to see increased brain activity in a certain place in the brain because more brain activity leads to a higher concentration of haemoglobin in the specific area.

This method uses two sensors; one sensor emitting infrared light into the brain and the other sensor sensing the infrared light coming from the brain. The higher the level of haemoglobin, the higher the absorption of the infrared light in the brain, the lower the amount of infrared light going back into the second (sense) sensor. A researcher who uses this method to measure stress is Fares [67]. In research with twelve adult participants, Fares measured an increased haemoglobin level in some regions of the brain when participants were in a stressful situation. Based on his successful experiment, he supports the claim of others that using nFIRS leads to an unbiased measurement of the stress level. A small summary can be found in the table 9 underneath.

Pros	Cons
• Many different options • EEG and fNIRS can be accurate and suitable	• Need of wearing a cap

Table 9: Summary pro's and cons measuring brain acitvity

2.6.10 Concluding the state of the art

A lot of measurement techniques are discussed, which can be helpful for this project. Most of them are not labelled as capable of measuring stress but can still measure stress indicators. All of the different measurement tools have their own benefits and drawbacks. To get a better overview of the different techniques and devices and their strong and weak points, a table is made as displayed in the table underneath in table 10 . In the table, the various methods are compared based on multiple aspects. The table is filled in with Yes, Neutral and No.

With the help of the table, it is concluded that there are many relevant techniques and products, except the physical measurement by a camera, already available on the market. However, most techniques still need a professional, which can be a problem when developing a

product that should be used at home. Further, there are also a lot of techniques already implemented in well-developed products for babies, such as heart rate, breathing pattern and movement. However, these products lack giving direct feedback regarding stress.

Based on the comparison, the products that are more likely to be emphasized in the ideation part measure the heart rate, brain activity, and movement. Solving the third sub research question.

Measurement	Can Measure accurately	Already sold as product	Need of professionals	Wearable	Needs more investigation	Designed for measuring stress	Already used on children	Relevant to this research
Cortisol: Blood	Yes	Neutral	Yes	No	No	Yes	Yes	Yes
Cortisol: Urine	x	Neutral	Yes	No	Neutral	Yes	No	Yes
Cortisol: Saliva	x	Yes	Yes	No	Neutral	Yes	No	Yes
Cortisol: Sweat	x	Yes	No	Yes	Yes	Yes	No	Yes
Cortisol: Hair	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Heart rate: ECG	Yes	Yes	No	Yes	No	No	Yes	Yes
Heart rate: Camera	No	No	Yes	No	Yes	No	No	No
Heart rate: RPG	Yes	Yes	No	Yes	Neutral	No	Yes	Yes
Heart rate: Smart Watch	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Heart rate: Sock	Neutral	Yes	No	Yes	Neutral	Yes	Yes	Yes
Breathing pattern: Clip-on	Yes	Yes	No	Yes	Neutral	No	Yes	Yes
Breathing pattern: Camera	Neutral	Yes	No	No	Yes	No	Yes	Yes
Movement: Jumpsuit	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Movement: Camera	Neutral	Yes	No	No	Yes	Neutral	Yes	Yes
Questionnaires	Neutral	Yes	No	No	Neutral	Yes	Yes	No
Physical Conditions: Camera	No	No	Yes	No	Yes	No	No	No
Measuring brain activity: EEG	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Measuring brain activity: fNIRS	Yes	Yes	Yes	Yes	Yes	No	No	Yes

Table 10: Comparing the different measurement techniques

3. Methods & Techniques

This project uses the design method described by Mader and Eggink [68]. This method consists of 4 different phases: Ideation, Specification, Realisation and Evaluation, to help to get to the answer to the research question. A schematic overview of this method that includes the different phases and the links between the phases and processes can be seen in the appendix A: A design process for creative technology. Underneath, the different phases of this designing process are described with the additional methods used in this research within the particular stages.

3.1 Ideation Phase

This phase is the starting point within the method. In this phase, the stakeholders are defined combined with the client's inspiration and desires. Further, the first ideas are made and assessed based on their relevance to the project. In addition, the requirements for the product are made by finding based on the desires of the stakeholders and earlier find literature. At the end of this phase, the initial concept design is chosen and further developed.

3.1.1. Defining the stakeholders

Firstly, the stakeholders are defined to get a better view of the situation of the problem. It is chosen only to describe the primary stakeholders. In other words, the stakeholders who are in any way affected by the result, plan or action of this research. This primary stakeholders group does not include the researchers or other people who are only influential in being included within the research.

Within this research, it is chosen to make personas within the program uxPressia [69] to describe the primary stakeholders. The personas are based on the descriptions giving to the stakeholders' group in researches of the previous chapters and on additional descriptions found on respectable sites. These personas have the purpose of giving more humanised expressions, resulting in a better understanding of the stakeholders. The personas do not fully represent the stakeholders' group but give a good general impression of the general person in that group. The personas will be used in this research to better evaluate the ideas in the brainstorming part of this research.

3.1.2 Brainstorming

The reason behind the brainstorm session is to get to a concept that is most suitable to solve the research question. Within the brainstorming, the researcher considers the described strong points and weaknesses of the persona's described above and the earlier products and methods described in the state-of-the-art section to get to the concept. At first, a mind-map was created with draw.io [70] to better view the different subjects and the different links between the

different subjects involved in the problem. The mind map contains everything the researcher considers to be related to the project. The related subjects were written down and linked to a certain category. Secondly, to get a better result out of the brainstorming, the researcher first had to come up with a minimum of 50 rough concepts. Using this method will bring a lot of ideas and many different kinds of ideas. To evaluative the best idea, the ideas were graded on the, by the researcher made, different criteria. The researchers had made these criteria based on the considered important aspects found in earlier research and personal preferences. After the best rough concepts were chosen, the best concepts were further developed by extending the description and visualising the concepts by making drawings in illustrator [71].

3.1.3. Interviewing specialists

The best ideas were discussed, combined with the different methods to measure a stress response and the ideal placement of a possible sensor on a baby with different specialists. These specialists have a better view of the situation of the problem, making them capable of helping to choose the final concept to be realised. It is chosen to use a semi-structured interview with the specialists. By executing a semi-structured interview, the researcher prepares a set of questions to ask the specialists. Using this method of interviewing, the researcher still has some room to ask additional questions. This enables the researcher to go more into depth into certain subjects, resulting in better results. However, the researcher's important thing to keep in mind is to keep the question related to the already asked questions. The interview is executed with both participants at the same time by using Zoom [72].

3.2 Specification Phase

Within this phase, the final concept to be made is further specified by adding requirements and making a theoretical prototype. This specification phase is thereby used to specify the functionalities and how these can be used in the final concept.

3.2.1 Stating requirements

Using the interview with the specialist and knowledge as defined earlier in the report, the requirements are made for the final concept. The requirements will be defined and ranked using the MoSCow-method as described by René [73]. This MoSCow-method categorises the made requirements into four groups. The four groups are: must-have, should-have, could-have and won't-have.

The first one being the "Must have" group. This group contain requirements that have to be satisfied by the product. Otherwise, the product will not work. When the product would be released without having these requirements, the product becomes useless. The second group is

the "should have" group. The requirements of this group are considered important to implement within the product but are not necessary. Without having a requirement of this group, the prototype still can be used, but it does not work at its best performance. The third group is the "could have" group. These requirements are not necessary for the core values of the product. The requirements have less priority than the should have group; however, the requirements of this group could still improve the product. The last group is the "won't have" group. This group consist of requirements that are very hard to accomplish and implement. These requirements are mostly being considered in further recommendations after the project because of the difficulty level of implementation.

The requirements were further categorised into functional and non-functional requirements. As described by QRA [74], a functional requirement defines the systems' behaviour on what the system should do. A non-functional requirement defines how the system should do something.

3.2.2 Further designing the concepts

The concept is further designed by looking at the made requirements and adding suggestions for solving these requirements. Additionally, the concept is further developed by adding a brief additional description of how the concept would look, how the design would act, and which methods should be used. Further, an additional drawing is made with Illustrator [71]to understand the concept better.

3.3 Realisation Phase

The final theoretical concepts, as stated in the specification phase, are being made as a prototype within the realisation phase. In addition, the processes, components, and choices made to realise the final concept will be further elaborated. The prototype made in this phase should be able to be used later in the evaluation phase.

Within the sensor part of the evaluation, schematics of connecting the sensors to the microcontroller are made with Fritzing [75]. The schematic containing the general overview of the connected hardware and the data flow is made with draw.io [70]. After the concept was realised, the concept was tested by and on the researcher. The data of the sensors were being stored to be put in charts. The charts used within this chapter are made with google sheets [76].

For the application part of the realisation, Photoshop [77] was used to create the colour pallet. The application itself is being made with the programme AdobeXD [78]. Using AdobeXD gives the researcher the possibility to user test the application. This programme lets the user design the front-end of the application and enables the researcher to build interactions into the application so the user could use the application in real-time.

3.4 Evaluation Phase

In this phase, the prototype(s) are evaluated. The evaluation consists of looking at which earlier made requirements are met and assessing how the project is being executed in general. At the end of this phase, the strong points and flaws of the product and this research are stated, which could be used to ensure future improvement.

3.4.1 Evaluation of the sensor part

Due to the current Corona epidemic, the evaluation of the sensor part was held with seven housemates from the researcher. These participants were all well informed by the information brochure and additional explanation about the research and participation by the researcher beforehand. All participants have also agreed by signing the consent form to participate in the research and standard laboratory experiment (/evaluation). The information brochure can be found in Appendix B: Consent form interview specialists about the different ideas and consent form can be found in the appendix C: Information Brochure interview specialists about the different ideas.

At first, one participant had to place the sensor on the other participant using the explanation shown beforehand on the computer. When the sensors were properly connected, the participant who had placed the sensors could leave the room.

The other participant now has multiple sensors on a band-aid connected to the body. These sensors are connected to an Arduino, which is connected to a laptop. This setup will measure and capture the various biomarkers of the participant. The participant first had to execute the task of singing a song for the researcher. The participant executes this task by sitting on a chair and, if needed, looking at the lyrics displayed on the screen in front of him. After the task was executed, the researcher conducts a semi-structured interview with the participant.

During the evaluation, the researcher records the audio during the evaluation, containing the participant's voice and the researcher, and makes additional notes when needed. After the evaluation, the researcher processes all of the gained data by writing out the comments of the participant and researcher and putting the measured data in charts for assessment. The full explanation and outcome of this evaluation can be found in the appendix L: The results and notes per participant in the evaluation of the sensor evaluation.

3.4.2 Evaluation of the application

The evaluation of the application was conducted with 3 participants. These participants were selected on their involvement with the primary stakeholder and recruited by mail. These participants were all well informed by the information brochure and additional explanation about the research and participation within this research by the researcher beforehand. All participants

have also agreed by signing the consent form to participate in the research and standard laboratory experiment (/evaluation). The information brochure can be found in the appendix L: Information Brochure Application Evaluation and the consent form can be found in the appendix M: Consent form Application Evaluation.
Due to corona regulations, the evaluation was being executed in an online environment using Zoom [79] and a web browser.

Within this evaluation, the researcher states a scenario and links a particular task to the scenario the participant has to solve. The participants are asked to use the think-aloud method, as described by Nielson [80]. Using this method gives the researcher a better view of how the participants think about the application when using the application. After all of the tasks are completed, a semi-structured interview with the participant is executed.

During the evaluation, the researcher records the evaluation's audio, containing the participant's voice and the researcher, and makes additional notes when needed. In addition, a screen capture is made from the participant using the application.

By conducting this interview, the researcher gains more information about the application's user experience and gains feedback on the functionalities it contains or does not contain. After the evaluation, the researcher processes all of the gained data by writing out the comments, listening back to the audio recording and looking back at the screen recording of the participant for assessment. The full explanation and results of this evaluation can be found in the appendix O: The results and notes per participant in the evaluation of the application.

4. Ideation

Within this ideation phase, the stakeholders are defined, and ideas are generated based on the defined stakeholders and the knowledge from chapter two. More than 50 ideas are generated related to the topic of measuring the stress level among babies. First, the best ideas are chosen, and with the help of an interview with specialists, the best idea is picked, which will be realised in the next chapter.

4.1. Defining the stakeholders

Underneath the primary stakeholders of this research are described. These parties can be categorized as a particular group of people but also as individuals. These personas have the purpose of giving more humanized expressions, resulting in a better understanding of the stakeholders. The personas do not fully represent the stakeholders' group but give a good general impression of the general person in that group. Within this project, the primary stakeholders are; babies dealing with (toxic) stress, the parents of these children, and the experts on (toxic) stress on babies. The personas are created with the help of uxPressia [69]. Within this research, the personas' are used to link with the made ideas later in this chapter. The ideas should be designed to be used by the persona's described underneath. When afterwards follows that the idea is not suitable to use/does not solve the problem of the persona's underneath, the ideas should not be considered as a good idea for this project to realize.

4.1.1 The baby

The first stakeholder is the baby dealing with toxic stress. The baby is entirely dependent on the care given by the environment around him/her. The baby is in the stage of life where everything is new. In multiple phases, the baby learns more about his/her own body and the world around him/her, as described by Mazel [81]. The only communication he/she can use is limited. By screaming (not in any language) and particular movement, he/she tries to make clear what he/she wants. This method of communication is not always clear to the environment due to the lack of using a specific language. Now, the environment around him/her does not always understand what is meant by the screaming and movement. Due to this communication limitation, he/she cannot indicate the problem he/she experiences. This way, the caretakers cannot solve these problems, which may lead to chronic complications to the baby as toxic stress. The persona which represents this group named Noah can be found underneath in figure 5.

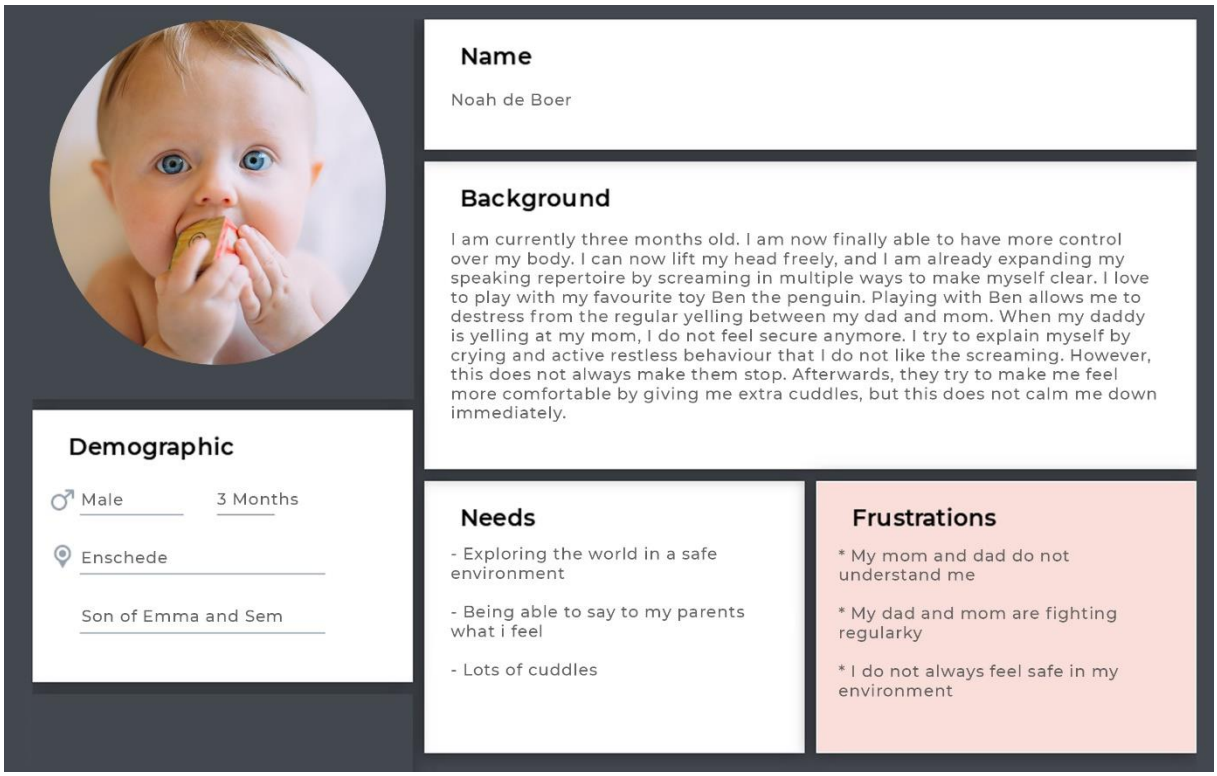


Figure 5: Persona of the baby | Noah de Boer

4.1.2. The parents

The second stakeholder group, the parent(s), is considered the closest to the baby and is therefore regarded as the most important influence on the baby. This group takes care of the baby and, by having a strong bond with the baby, gives this group the baby the confidence to explore the world. The big downfall of this group is the possible biased view on the baby, which leads this group sometimes to misjudge situations. This group does not always fully understand the baby's behaviour and needs. This leads that in some scenarios, they even are the stressors of the baby without knowing about it. Being the solution and sometimes the issue of stress among babies makes this a challenging group to categorize. Nevertheless, this group, in general, always wants the best for the baby.

The personas created for this group are the mother named Marjan and The father named Sem. These personas can be found underneath in figure 6 and figure 7.

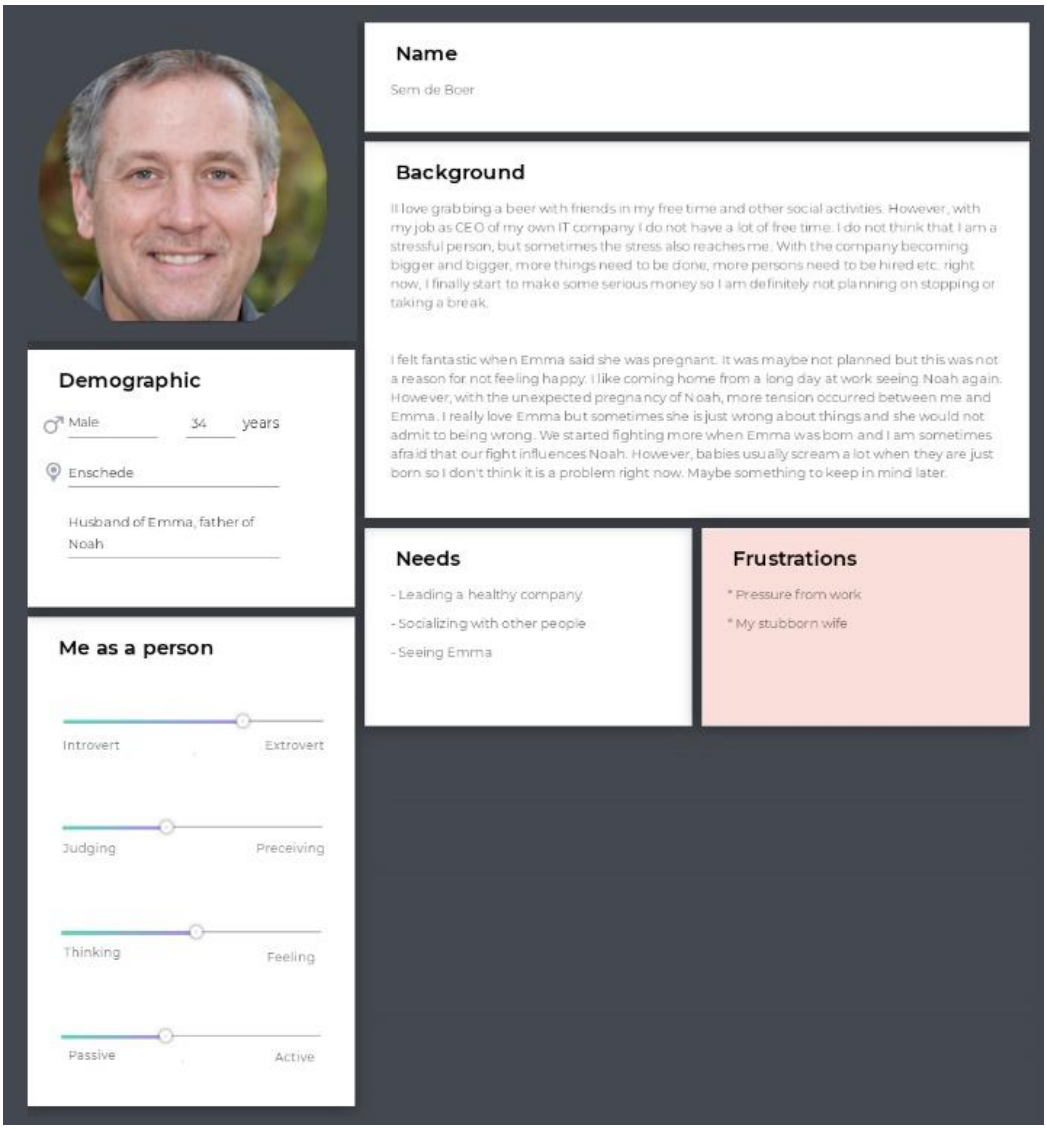


Figure 6: Persona of the parent | Sem de Boer

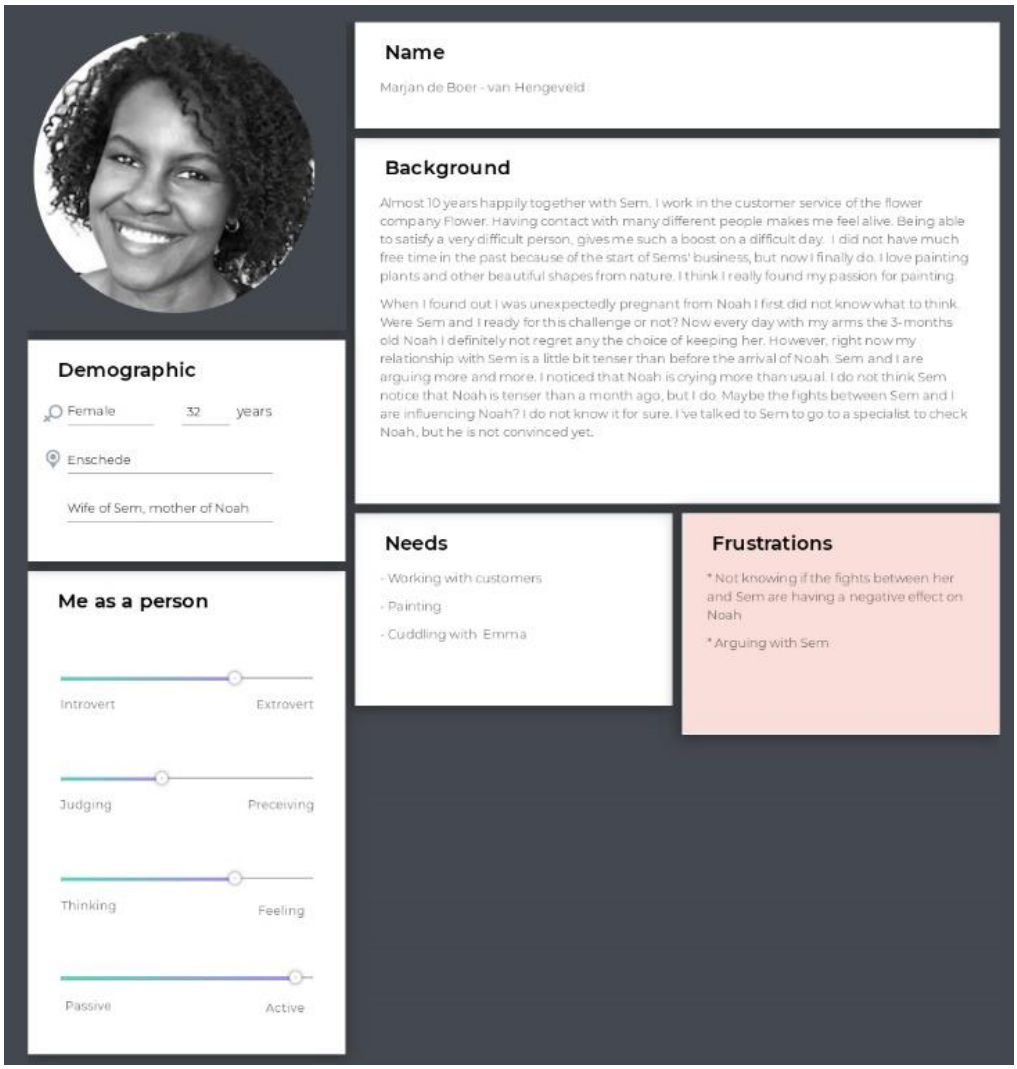


Figure 7: Persona of parent | Marjan de Boer – van Hengeveld

4.1.3. the specialist

The last stakeholder, the specialist, aims to help the baby and parents with problems regarding the stress of the baby. This specialist tries to view the baby's situation in an unbiased manner, being capable of helping and correcting the parents when needed. However, the specialist is limited in the amount of time it can help the child because of the planned sessions with the parents.

He/she tries to find the stressors with the parents by asking questions to the parents regarding the baby's situation. Letting the parents answer the questions to make hypotheses and advises parents about how to solve the problem. The biggest challenge this group faces is getting biased answers from the parents. These (sometimes unintended) answers from the parents strongly influence the hypotheses of the specialist, making solving the problem more difficult. Also, the treatment he/she offers to the parents is not always appreciated. The Hypothesis he/she makes is not completely substantiated by using an objective tool, making it harder to convince the

parents of him/her giving made the right hypothesis on the situation. The persona made for this group, named Benjamin, can be found underneath in figure 8.

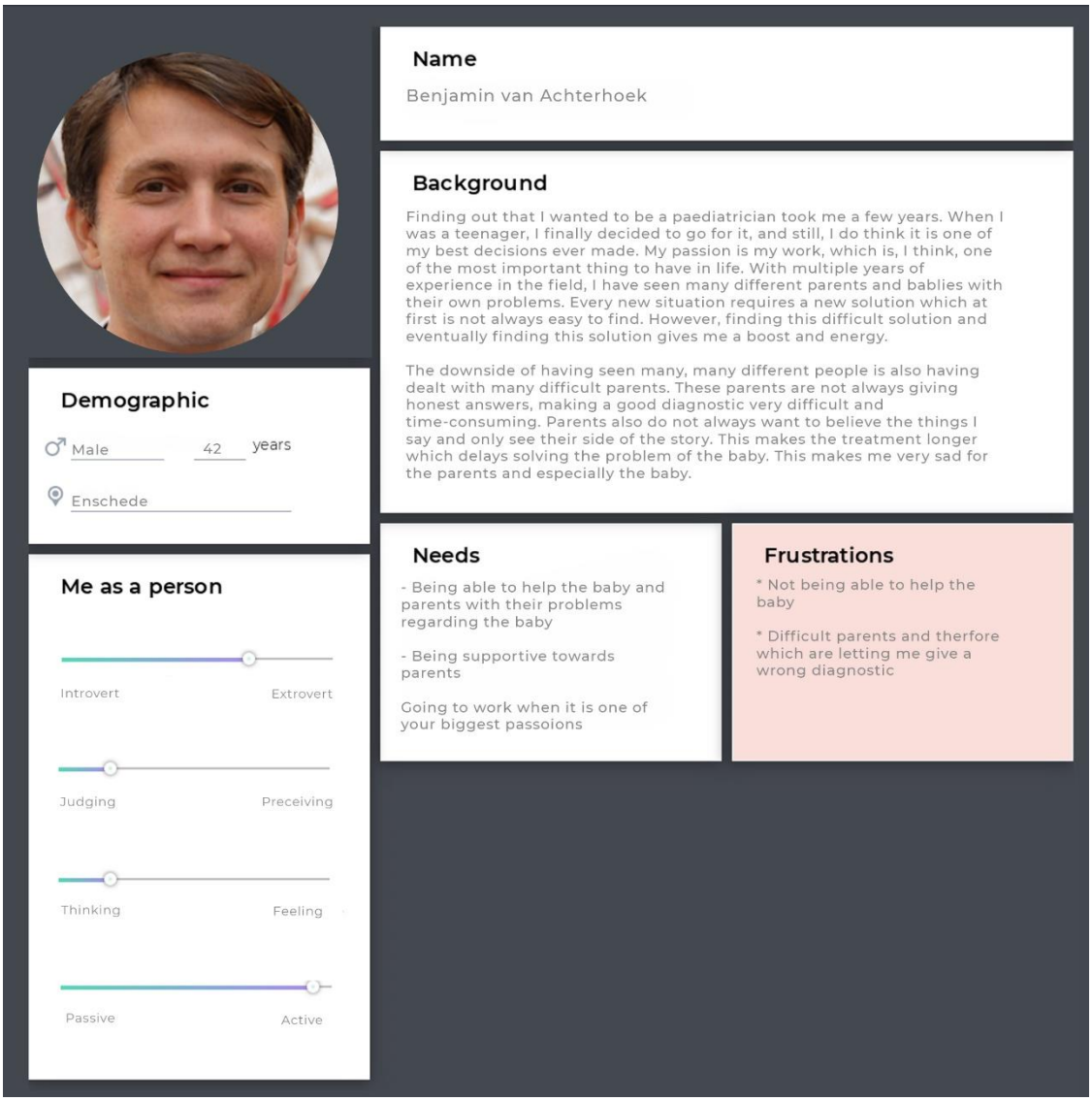


Figure 8: Persona of a stakeholder | Benjamin Achterhoek

4.2. Brainstorming

4.2.1. Mind map

A mind map is created to better view all of the different subjects and the different links between the different subjects. Within this mind map, everything the researcher considers to be related to the project was written down and linked to a certain category. The starting categories were baby, caretakers, stress, awareness/feedback, goals and implementation environment because these were considered to be the most important subjects by the researcher.

Making this mind map should help the researchers with the next step of the ideation phase of making different ideas. The first benefit of the mind map is forcing the researcher to think more intensively about the different subjects involved within the project. The second benefit of this mind map is having a large number of the to be considered subjects involved in the project displayed on one page. This helps the researcher making an idea by more easily linking the different subjects into one idea. The mind map can be found underneath in figure 9 and a bigger version in the appendix D: Mind map with the different subjects of the project.

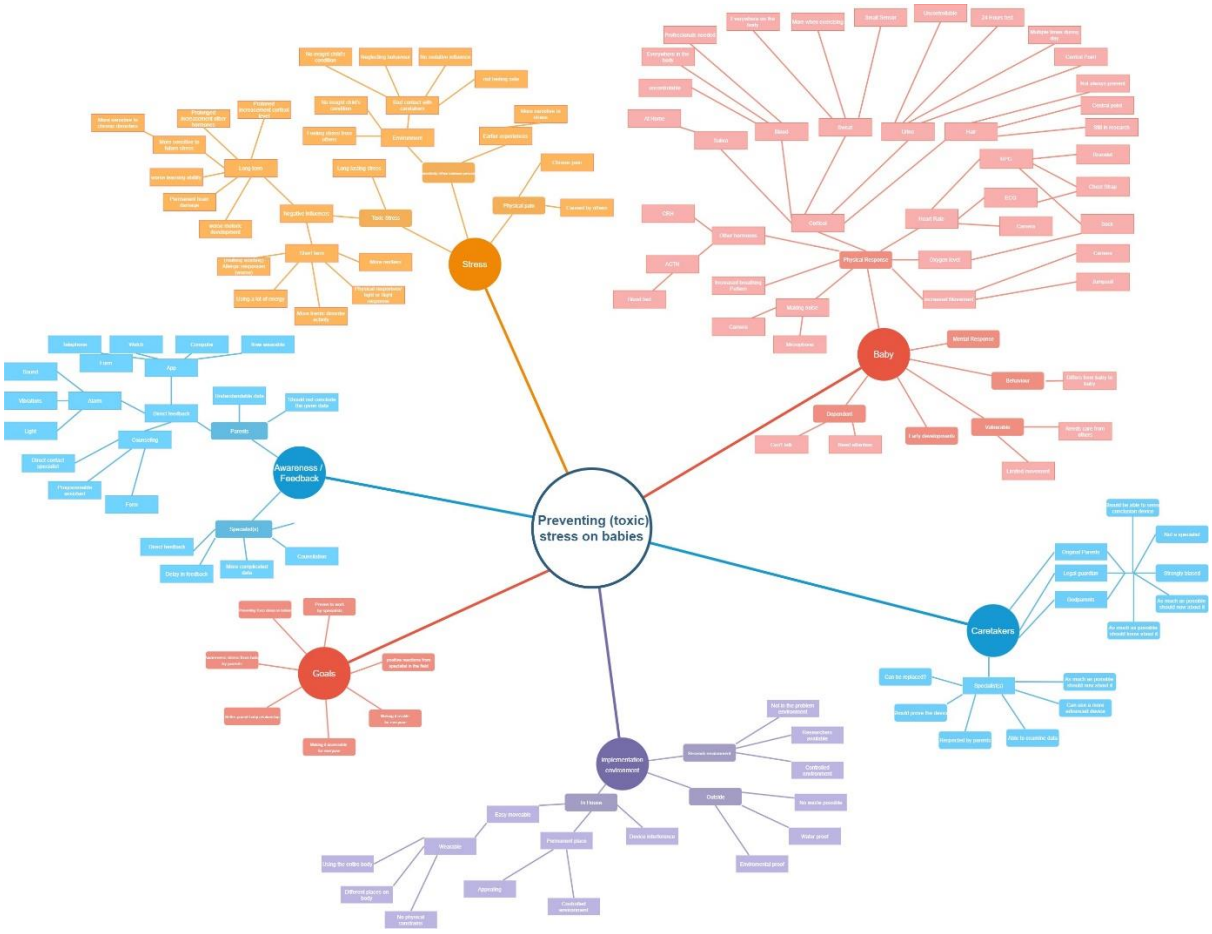


Figure 9: Mind Map used in the ideation phase

4.2.3. Making the ideas

With the help of the mind map above, a minimum of 50 ideas were made by linking the different subjects into ideas. These ideas are categorized into two different categories. The first category focuses on the measurement of the stress indicators. The second category focuses on giving feedback to the user(s). After multiple ideas were made, the best ideas were selected based on a point system that grades the different criteria of the ideas. The criteria made by the researcher to which the ideas are evaluated are; how comfortable it is expected to be for the baby, how comfortable it is expected to be for the parent, how reliable it is expected to measure,

is it doable within this project, does the idea already exists in any form and the general preference of the researcher.

Within the criteria, the ideas are graded on a scale from one to five. One being the worse, and five being the best. There is one category to which this system has an exception. The category “previously tested” has a scale going from one to three. One stands for never previously tested, two stands for for previously tested but only in a test environment and three stands for previously tested and already on the market. The table where points are given to the different ideas can be found in de appendix.

After the points were given to all of the ideas, 11 ideas were evaluated as being the best because they had the most points. However, when looking into these ideas, the researcher found out that some aspects of different ideas were quite similar. Therefore, some ideas could be merged into a single idea. So, after combining some of the eleven ideas, six ideas remained. These six ideas are now being considered to be the best ideas coming from the researcher. These ideas will later be discussed with a professional, and eventually, out of these six ideas, one idea will be picked to be realised within this project. The six different ideas can be found in the table 11 underneath.

Number	Description
1.	A camera that measures the movements of the baby
2.	A sock or bracelet that provides real-time measurements of blood indicators, movement and heart rate
3.	A clip-on movement / sweat / breath meter
4.	Being able to perform cortisol measurements at home by using a certain device
5.	Plaster measuring the cortisol level through sweat
6.	A camera with GPS showing the situation of the environment around the baby

Table 11: List of ideas with the highest points

4.2.4. Explanation of the six best ideas

In this subsection, the six best ideas, as stated in table 11, are briefly explained. A drawing of the idea is added to the description to make the idea more visual to understand the idea better. At the bottom of every idea, a small summary is given from the biggest pro’s (green) and cons (red), according to the researcher.

1) A camera that measures the movements of the baby

A camera is placed on a particular area where the baby spends a considerable amount of time. This camera focuses on how much the baby moves daily and if this is more or less than usual. This means that the device also keeps track of the baby's motion in a certain period and compares this with the new data. Tracking the movement in a certain period gives the device the possibility to notice an unusual increase or decrease of a particular movement by the baby.

The camera captures the movement by first searching for certain recognizable spots on the baby's body, such as knees and ankles. When these spots move to a new position, they are followed by the camera to the new location, which then recognises a movement.

The drawback of using this camera technique is the need to have the camera placed in a correct place to measure the movement (if the camera, for example, is placed sideways, it will have a hard time measuring body places on the other side the baby. This also means that measurements will not always be reliable and that the parents always need to bring the camera to the baby. Also, the parents may consider privacy issues because the camera is filming all day in an intimate environment (such as at home). Underneath in table 12, a small summary containing the biggest positive and negative sides can be found. In figure 10 visualisations of the concept can be found.

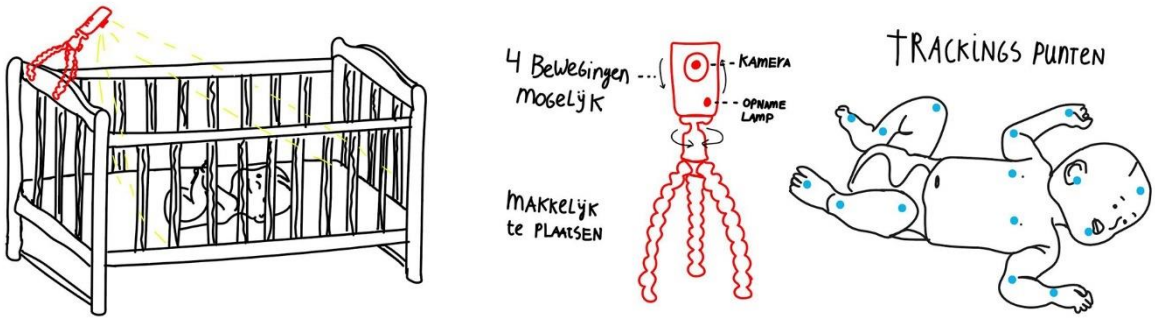


Figure 10: Sketch of a camera that measures the movements of the baby

Positive sides	Negative sides
Able to measure a change in the movement of the baby, which could lead to the determination of stress	The need of placing the camera on a specific spot could lead to problems
Hands-free device	Privacy concerns of the parents due to the camera filming all-day
	The accuracy of the measurement is guaranteed

Table 12: Summary idea 1

2) A sock or bracelet that provides real-time measurements of blood indicators, movement and heart rate

A sock or bracelet equipped with a pulse sensor and accelerometer can measure the baby's heart rate, blood saturation, and movement. By measuring these biomarkers, the activation of the stress level is measured. By giving real-time feedback on the measurements, stressors can be found in the environment by others being with the baby at that moment. Also, the data is stored within a certain period of time. With the storage of the data, the activation of the stress reaction can be considered to be increased within a certain period compared to older data, hinting at the beginning of toxic stress.

The measurement of heart rate and blood saturation within a sock is already done in another product not stress-related, already confirming the reliability of the measurement

techniques. However, the device to make adds an extra accelerometer to track down the baby's movement and processes the data to conclude stress.

Considering that the device will be applied to a particular and vulnerable group combined with the importance of the good placement of the sensors, it is important to note that in every case, the babies' health and comfort go above measurement results. Underneath in table 13, a small summary containing the biggest positive and negative sides can be found. In figure 11 visualisations of the concept can be found.

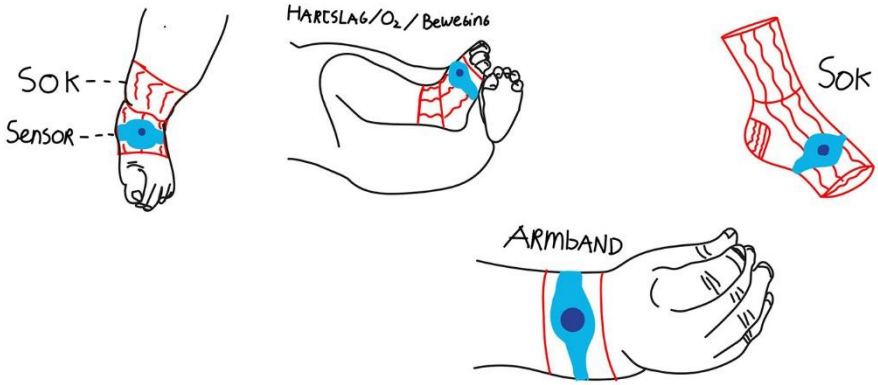


Figure 11: Sketches of a Sock and bracelet that provides real-time measurements of blood measurements/heart rate

Positive sides	Negative sides
Measuring multiple stress indicators	The product can easily be lost
Parts of the idea is already done and proven in another product	Specific placement is needed for a correct measurement
Not harmful towards the baby	
Can measure accurately when being placed correctly	

Table 13: Summary idea 2

3) A Clip on movement / sweat / breath meter

A small clip-on device that can be clicked on the diaper on the baby. This device is equipped with multiple sensors to measure multiple factors of the stress reaction of the baby. The clip-on method allows the parents to put the device on the baby at home easily. Because of the smaller size of the device, the baby will not be limited in his/her movement.

The first sensor is in the device is the accelerator. By using this sensor, this device can track the baby's movement during the day. It stores the data over a certain period to compare if the movement of the baby has increased over the past few days/weeks. When the device notices this increased baby movement, the parent will be alerted on this potential result of stress on the baby.

The second sensor is the sweat sensor. This sweat sensor is able to measure the cortisol level within the sweat of the baby. When an increased level of cortisol is measured, the device will also notice the parents of a potential stress reaction of the baby. When the cortisol level is higher

over a longer period, the device will also measure this and alert the parents to the baby's potential for toxic/chronic stress.

The last sensor is the breath sensor. This sensor sense if there is a change in the baby breathing pattern. This increased breathing pattern will be interparent as the baby's body potentially being in a state of stress

With the combination of these various sensors, multiple stress factors can be measured on the baby, and the method used is simple to use for both the baby as the parents. With various sensors, the chance of having an accurate measurement of an activated stress reaction is more considerable than using just one sensor. Because of the storage of data, the parents will be able to see at which moments the stress reaction was activated and thereby be able to find the stressor of the baby. Underneath in table 14, a small summary containing the biggest positive and negative sides can be found. In figure 12 visualisations of the concept can be found.

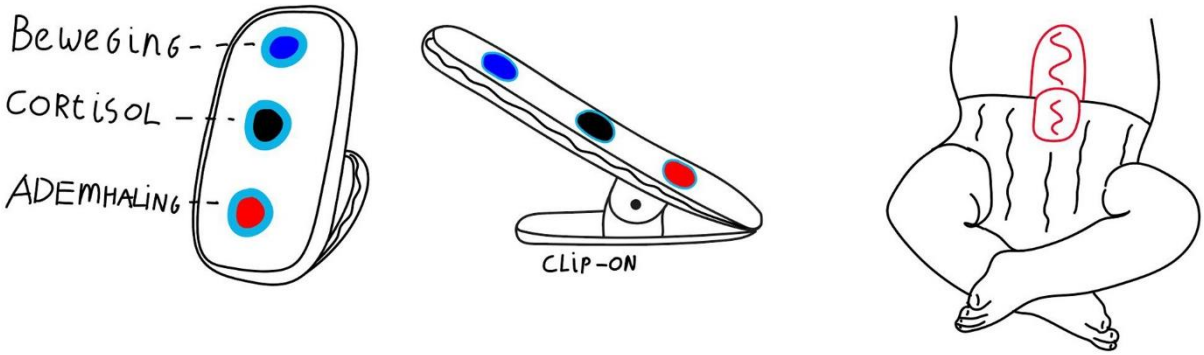


Figure 12: Sketch of a clip-on movement / sweat / breath meter

Positive sides	Negative sides
Easy to use for parents	Sweat sensor is still in development
Multiple measurement techniques used to measure stress indicators	There is a change of the baby being able to remove the clip
Is able to measure accurately	
Parts of the idea already used in other products	

Table 14: Summary idea 3

4) Being able to perform cortisol measurements at home

A cortisol measurement can be done in multiple ways. As stated above, cortisol can be measured in blood, urine, saliva, sweat, and hair. With cortisol, a (chronic) stress reaction(s) can be measured. However, the problem with most of these types of measurements is that it requires the participant to send the test sample to the lab. This has a big disadvantage regarding the speed and accessibility of these tests.

With this new device at home that can process the homemade samples at a reliable rate, these tests can be done more frequently and with more ease. No specialist is involved, and with a

simple guide that tells the user what the measurement means, an increased level of cortisol resulting from having stress can be concluded.

As this device seems to have a big potential to develop for a bigger audience, it also comes with multiple challenges. The expected biggest problems of designing this product are cost, reliability, and ease of use. At first, to perform a reliable cortisol test on stress, it is asked to do more than one measurement a day. This means that within a day, multiple measurements should be conducted and processed, which is time-consuming. Also, the actions required to process the sample could be challenging for some people, resulting in erroneous measurements and motivational problems to use the device.

Secondly, the processing of the samples is now done in a lab with specially made equipment. When first developing this device, the expected costs to develop and make this product could result in a higher price than most people are able/willing to spend on such a device. With the ability to measure cortisol in different areas, the device is expected to work only on one sort of measurement (for example, blood) and not on others, making the target group smaller, resulting in the cost to increase.

Lastly, as described earlier, measuring and process the cortisol level of a baby every day multiple times can be very time-consuming. The parents need to have a great motivation to do this every day indeed. Underneath in table 15, a small summary containing the biggest positive and negative sides can be found. In figure 13 visualisations of the concept can be found.

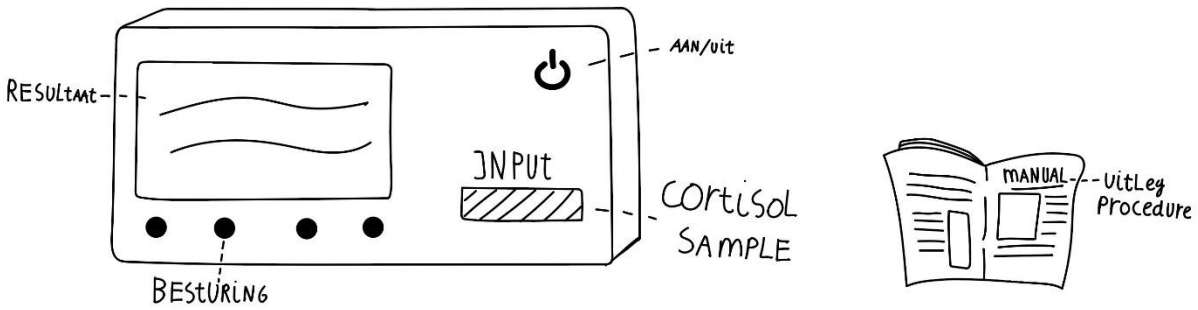


Figure 13: Sketch of being able to perform cortisol measurements at home

Positive sides	Negative sides
Measurement of cortisol can now be executed at home	Potentially expensive
No professional is needed for the measurement	Possibly time-consuming for the parent
	Hard to use for some people

Table 15: Summary idea 4

5) Plaster that you stick on and that is able to measure the cortisol level through sweat

A plaster that is equipped with a cortisol sensor is able to measure the cortisol within the sweat of the baby. This plaster is due to its form also easily attachable to almost every place of the body. The option to place the sensor just like an ordinary plaster makes this idea easy to use for nearly every parent. When the sensor is placed in a great location on the baby's body, the baby can wear the sensor for almost the entire day. By doing multiple measurements throughout the day, it brings a more reliable measurement of a stress reaction. Also, the amount of sweat needed for this sensor does not require the baby to increase movement (and therefore produce more sweat), making it suitable to use all day.

The problem with this idea is that the sensor to use is still being researched and developed by the University of Stanford [82]. They used this sensor for the first time in 2018, which is quite recent. Also, the researchers used the sensor on a wearable wristband, not on plaster. To built this idea, a lot of research still needs to be done. Also, the availability of this sensor is questionable. Underneath in table 16, a small summary containing the biggest positive and negative sides can be found. In figure 14 visualisations of the concept can be found.

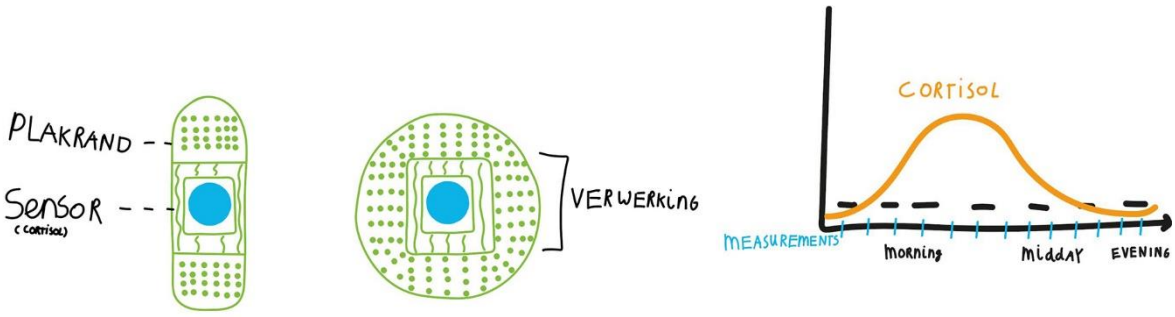


Figure 14: Sketch of a plaster that you stick on and that is able to measure the cortisol level through sweat

Positive sides	Negative sides
Easy to place on multiple spots on the body of the baby	The sensor is still in development
Multiple measurements a day possible	

Table 16: Summary idea 5

6) A camera on the baby showing the situation with GPS

When a baby is having a stress reaction, the determination of the stressor can be challenging. Parents are not always around or aware of the environment making the stressor hard to find. Now a camera is set on the baby and the environment around. When another device concludes a stressful situation, the camera records the environment (by recording sound and vision) and stores this in a place to assess later on. With this recording, the parents and/or are now able to track down the stressor and therefore remove the stressor from the babies' environment. This camera is easily placeable in every environment and only stores the data locally to prevent any privacy issues. Using a detection algorithm, this camera can also constantly point

to the direction where the baby is located. This results in that the parents do not have to move the camera every time when the babys' location chances in the same room.

This camera is, as said before, also equipped with a microphone. This microphone can be used to measure the volume level of the sound in the environment. When the baby is in a boisterous place, the microphone picks this up and labels the noise as a potential stressor in the environment. By not recording exactly the sound of the environment but just the sound level, it does not limit the users' privacy. When the user wants to record the sound level of the environment and the exact sound of the environment, the option will be provided.

As stated before, this camera is triggered to record when a stress reaction occurs in the baby. This means that the camera needs to be combined with another idea to work. Without this trigger, the camera is not able to distinguish a stress reaction and therefore does not know when to record the situation.

By adding an additional GPS to the device, the environment can be seen and the exact location of the potential stressors. This gives the ability to know, for example, in which room the baby's stress level is the highest. It also provides the possibility of detecting places that negatively affect the baby's stress level. Underneath in table 17, a small summary containing the biggest positive and negative sides can be found. In figure 15 visualisations of the concept can be found.

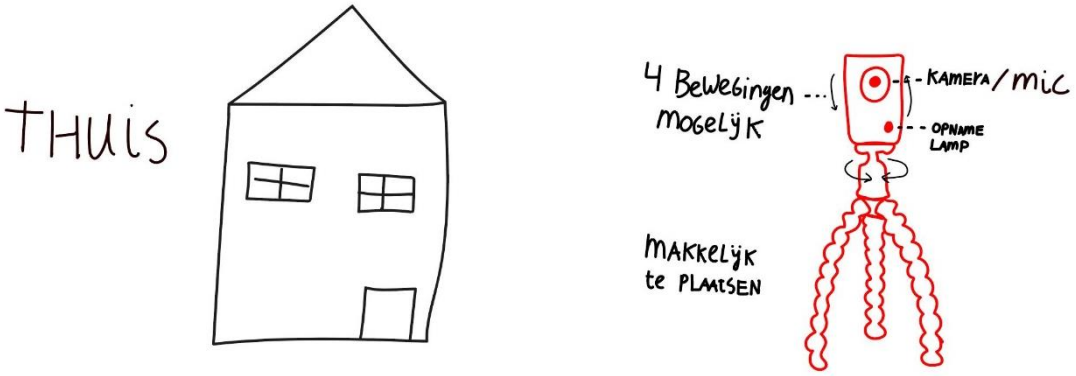


Figure 15: Sketch of a camera on the baby showing the situation with GPS

Positive sides	Negative sides
Being able to detect stressors in the environment	Privacy concerns of the parents due to the camera filming all-day
	It needs always to be present at the same place as the baby
	It needs to be combined with a device that measures the stress level of the baby

Table 17: Summary idea 6

4.2.4. Involving the specialist

For the last evaluation and input on the ideas, an semi-structured interview is planned with two professionals in the field of infant mental health. The main scope of the interview is to

discuss the ideas above, and if suggested, create new ideas. At the end of the interview, the specialist will suggest and explain which ideas have the most potential above others in their eyes. Within the interview, not only the ideas are discussed but also different types of measurement techniques, different placements of sensors, and different feedback methods. By discussing methods of sensing stress and the other aspects of the device, the researcher get a better view of the situation and the preferences of the people being in the environment of the problem group.

The semi-structured interview is conducted online via teams, with both specialists being interviewed at the same time. By discussing the ideas with more than two specialists, the chance of getting a better result is being considered to be higher. Both specialists may have a different view on the ideas caused by their diverse experiences in their field. Interviewing both specialists at the same time also could therefore bring more discussions to the table. Keeping the questions as a general guideline but asking additional questions to go deeper into the material is considered to be essential to get the best result out of the interview. Also, the questions were primarily open-ended questions to get an answer and the reason for the answer from the specialists.

The specialists

The first professional, professional 1, is a specialist who helps parents raise their child(ren) by coaching them and giving supervision, Intervision, advice, and training to the child's parents. The second professional, professional 2, is working at a local hospital in the department of Paediatrics and Neonatology.

Procedure

Before conducting the interview, the researchers ask for uncertainties about the information brochure, consent form, research, or other research-related subjects. At the beginning of the interview, the researcher brings a schematic representation, which can be seen in the appendix, of a baby's body. With the help of the schematic, the professionals are asked to point out and discuss which places on the body they consider to be a good spot to put on a sensor in general and which places are not. The sensor to discuss will approximately be the size of a standard button with no wires attached to the sensor (wireless). This because the specific sensor (and thus the specific size of the sensor) to use has not been picked yet in this stage of the research. The specialist may point out good and bad spots in their opinion. With both specialists doing this task after each other, a discussion may be formed after both specialists have answered a different answer.

Secondly, the ideas above are explained one after the other. First, specialist one is asked to talk about what the specialist thinks about the measurement technique, the implementation of

the device, the specialist eyes' strong aspects of the idea, and the specialist eyes, weak spots/flaws of the idea. After specialist 1, the second specialist is asked to answer the same questions. After both specialists have answered the questions, there is some room for discussion when needed. When the discussion ends, the specialist goes to the next idea, following the same procedure. The whole summary of the interview can be found in the appendix.

Outcome

Firstly, the best placement for the sensor is being discussed. The specialist emphasizes that the sensor's placement should not influence the contact with the parents, movement of the baby, and feeding behaviour. Also, the baby should not be able to access the sensor due to the eating habit of this group (not letting them eat a sensor) and their potential influence on the measurement.

Both the specialists concluded that a distinction should be made between two groups of babies. The first group being the group of babies between zero and three months. This group does not move as much because of the still limited developed physique and will lay very much on their back. After a small discussion between both specialists, they came to the conclusion that the right place for attaching the sensor will be on the feet or forehead. The second group, the babies between the age of 3- and 12 months, is more active. This group have a more developed physique, and this group is more curious to explore their body and the world. They are able and tend to touch everything within their ability. Both specialists concluded that something like a sock would not work with this group because the baby would remove this (sensor) on their own. The specialists came to the conclusion that the upper arm would be the best spot for this group. The chest would also be an option, but the specialist had some concerns about touching the sensor (and causing a displaced sensor) when putting on and taking off clothes.

The second part of the interview was about the ideas, as described above. The specialists came to the conclusion that ideas one(clip-on) and three(Bracelet/sock) could bring some problems regarding the sensor displacement problem as described above. Idea three, the bracelet idea, is considered a better idea than the sock idea but not very innovative. However, the specialists were enthusiasts about the idea of the measurement in idea one. Idea four, processing cortisol samples at home, had some great potential for clinical use but was not considered one of the better ideas because of the expected long development trajectory. The biggest concerns about ideas five and six had to do with privacy. Both specialists do not think that the baby's parents want a camera at home due to privacy issues. Specialist one added to these ideas that parents likely are going to behave differently when being recorded. Further, idea six was

considered to have some potential because some stressors at home could be found. The use scenario for this idea was drawn as the specialist giving this idea to a family where the stressor is being considered to be at home. However, the chance that this idea can identify the majority of stressors was not considered to be high. A lot of potential stressors cannot be noticed with this idea making it more like an addition to another idea, not a standalone idea.

The last part of the interview was about the different types of applications, all with their own method to process the data and give feedback to the parents. Here the specialist also came with two different groups to consider. The first one being the parents who want to know everything (mostly the higher-educated people) and want to see everything registered from the device. The other group is the group that only wants to receive feedback and see data when necessary (mostly the lower-educated group of people). Also, the specialist suggested that frequently giving feedback is not a problem but that the amount should be well balanced. When the device provides too much feedback, the parents could be influenced by the device by having more stress and constantly worrying about a bad “conclusion” of the device, even when it is not the case. This problem harms the family of the baby and should be prevented. As an addition to the data handling, the researchers liked to see to be able to easily see the data of the device when they have to work with the parents. Thus, they have a better (objective) view of the data, and this easy access to the data could improve the baby's treatment. The method to bring the feedback is mostly being considered in the form of an application.

More elaborated information on the interview can be found in the appendix

4.3 Choosing the final concept

With the help of the earlier points system and the additional feedback coming from the specialists, the final concept is chosen. As seen in the subsection above, six ideas came out as being the best. These six ideas were discussed with the specialists. The specialists liked the idea of being able to put the sensor in multiple places by the use of plaster. By being able to put the sensor in multiple places, the caretaker will now be able to take into account the development o the child and thereby the changing best places to put on the sensor. Also, the personal preference of the baby can now be taken into account. For example, when the baby spends a fair amount of time on his back, the caretaker now can easily respond to this situation by putting the sensor in a different location. The specialist also responded to the other measurement techniques. These all had their downfalls making these measurement methods less suitable for this project. A more elaborate explanation can be found in the appendix.

To conclude, the overall winner for the placement was idea 5, the plaster idea. This means that for the final concept, the sensors should be attached to the baby on a plaster kind of method.

As seen in the previous chapters, there are many different kinds of stress indicators, and therefore, there are many methods to sense the stress reactions. However, these indicators do not always indicate stress, but can also be caused by something else, making sensing stress difficult. Measuring multiple stress indicators seems to be a must to verify the stress reaction.

The specialists agreed with this statement. They found the type of measurements in idea 3, the clip-on idea, to be the best option because this idea measured multiple biomarkers to measure the stress responses. In this idea, the heart rate, the movement and the cortisol level can be sensed and therefore, more has more considerable reliability than the other ideas. However, with multiple sensors attached to one kind of plaster, various problems could occur. When the plaster becomes too big, the plaster could negatively influence the movement of the baby. As said by both professionals, influencing the movement of the baby should be prevented at any cause.

Together with the specialists, the researcher concluded that using multiple sensors all having their own plaster (and spot) is needed. The different sensors have their own optimal spot to execute the measurement. This means that having the sensors placed on the same plaster, and therefore on the same spot, would negatively influence the measurement results and flexibility of the placement. Further, having multiple sensors on one plaster could also make the plaster too big to use on babies.

Further, an application should be made to bring the data visual and understandable to the parents. This application should give the right amount of feedback to the parents to prevent any additional stress to the parents.

In short, the final concept should have multiple sensors, such as in idea three, to get a more reliable measurement of the possible stress reaction. Multiple plasters with each having their own sensor will be placed in different places on the body to get a correct measurement result. Further, an application should be made which should give enough but not too much feedback to the parent about the data coming from the sensors.

4.4 Concluding the ideation

In this chapter, the primary stakeholders are described. A lot of different ideas are made and evaluated. With the help of an interview with specialists, the final idea is chosen to be realised. It is found that the final concept should have multiple sensors to measure various stress indicators and therefore get a more reliable measurement of the possible stress reaction. After the measurement, the data should be brought to the parents. These parents should get enough but not too much feedback to prevent any additional stress. It is now chosen to realize a concept

where the heartbeat, movement, and cortisol level are monitored and sent to an application that provides feedback. This concept will be realised in the next chapter.

5. Specification

In this chapter, specifications are drawn to the final concept. The possible solutions to these requirements are stated, and at last, the general design of the final concept containing both the sensor part as the application part is made.

5.1 Requirements

To get the requirements for the final concept, the interview with the specialist is used together with knowledge as defined earlier in this report. The requirements will be defined and ranked using the MoSCow-method as described by René [73]. This method categorises requirements into four different groups. The four groups are: must-have, should-have, could-have and won't-have. More explanation about this method can be found in chapter 3.

Underneath, in table 18 and 19, the requirements can be found—the first table is for the functional requirements and the second one for non-functional requirements. Both the requirements are linked with to which part of the concept it applies to. In other words, the part of the final concept, the sensor part or the application part.

Problem ID	Part of product	Priority	Requirement
S1	Sensor	**Must-have**	Measuring the movement and heart rate of the baby continuously over a longer period
S2	Sensor	**Must-have**	Have an acceptable size
S3	Sensor	**Must-have**	Sending the data to a controller
S4	Sensor	**Must-have**	Being able to access and process the data
S5	Sensor	**Must-have**	Being able to place the sensor on multiple spots on the body
A1	Application	**Must-have**	Being able to process incoming data into visualisations
A2	Application	**Should-have**	Store the incoming data over a longer period
A3	Application	**Should-have**	Privacy regulations
A4	Application	**Should-have**	be able to be giving a update\feeback frequently to the user
S6	Sensor	**Should-have**	Being wireless transmission of the data from the sensor to the processor
S7	Sensor	**Should-have**	Indication of the amount of electricity left in the sensor module
S8	Sensor	**Should-have**	Low Calibration time (<15s)
S9	Sensor	**Should-have**	Start measurement when being connected

S10	Sensor	**Should-have**	Easy export of the data to an external drive
S11	Sensor	**Could-have**	Appealing design
S12	Sensor	**Could-have**	Last multiple days without removing to a different spot
S13	Sensor	**Could-have**	Integrated within a plaster
S14	Sensor	**Could-have**	Being able to receive updates, improving the measurement results
S15	Sensor	**Could-have**	Low cost to buy the product
A5	Application	**Could-have**	Setting menu where preferences can be changed
A6	Application	**Could-have**	Connected to multiple smart devices at the same time
S16	Sensor	**Won't-Have**	Measuring the cortisol level continuously
S17	Sensor	**Won't-Have**	Connection to a third-party app
S18	Sensor	**Won't-Have**	Fast Chargeable
A7	Application	**Won't-Have**	Customizable layout and other non-required options

Table 18: Functional Requirements

Problem ID	Part of product	Priority	Requirement
S19	Sensor	**Must-have**	No negative experience for the user (baby)
S20	Sensor	**Must-have**	No negative effects for the user(baby) regarding the placement
S21	Sensor	**Must-have**	Be able to work in different environments (At home/ Outside)
S22	Sensor	**Must-have**	No irritation for the skin when placed and afterwards
A8	Application	**Must-have**	Explanation of how to place the sensor understandable for the user
A9	Application	**Must-have**	Ease and intuitive to use for parents
A10	Application	**Should-have**	Multiple depths of feedback options
A11	Application	**Should-have**	The specialist being able to collect the data
A12	Application	**Should-have**	Should not cause a stress reaction for the parents (too much feedback)
S23	Application	**Should-have**	Fast contact is possible with the specialist
A14	Application	**Could-have**	Appealing design
A15	Application	**Could-have**	Additional tips and suggestion when sensing stress
A17	Application	**Could-have**	Affordable for people with various incomes

S24	Sensor	**Could-have**	Being able to receive updates, improving the measurement results
S25	Sensor	**Could-have**	Waterproof
S26	Sensor	**Could-have**	Easy to re-use
A18	Application	**Won't-Have**	Learning Algorithm which is able to analyse the data and improve the hypothesis of the data
S27	Sensor	**Won't-Have**	Be designed for a specific subgroup(s)

Table 19: Non-functional Requirements

5.3 Designing the final concept: Sensor Part

By designing the final sensor concept, first, the requirements are treated. A possible solution for the requirement is stated after every requirement. Hereafter, the final concept is described.

Description Requirements

S1): To meet this requirement, the sensor has to measure over an extended period with no intersections. This means that the power supply to the sensor should have enough capacity to hold it over an extended period. Also, the sensor should be placed so that it holds its place over a longer period.

S2): The sensor design needs to be built as small as possible. As a baby has way smaller body parts than adults, custom parts should be implemented (for example, a custom battery) to make it as small as possible.

S3): All of the sensors need to be connected to one central point. This central point reads the data simultaneously from all of the sensors. This central point should also control all of the microcontrollers attached to the sensors and send data to the sensors when needed.

S4): As described in the previous requirement, all of the sensors are attached to each other using a central controller. This means that all of the data will be accessible at the central controller, thereby processing all of the data.

S5): By using a sort kind of plaster mechanism to attach the sensor to the body, the user will choose between multiple spots on the body to attach the sensor.

S6): By using Bluetooth or Wi-Fi combined with the required chipset attached to the circuit of the sensors, this requirement should be no problem.

S7): A small LED that will blink when the battery needs to be charged, combined with an indication in percentages in the application attached to the sensor, should meet this requirement.

S8): The calibration time should be less than 15 seconds, this not to demotivate the users from setting up the sensors.

S9): To make the data accessible for specialists, the user should easily send the data directly to the specialist. Using a secured connection between the specialist and the user or by enabling the user to export the data to the mail, this requirement should be met.

S10): With the sensors attached to your baby for a longer period, the sensors will be visible to the environment for a longer period. This means that when the design is very ugly in the caretakers'

eyes, the caretakers could be demotivated to use the device. This scenario should be prevented at all cost.

S11): By making the plasters sticky enough to last for multiple days, combined with a waterproof design, the problem should be solved.

S12): As discussed earlier, the sensors will be connected to a central point that will receive and send data from the sensors. This means that this system will enable updates for the sensors.

S13): By using the cheapest (but reliable!) components, as many people can benefit from this device as possible.

S14): Easy connection to other “Smart” devices would enlarge usability in some homes.

S15): When a non-replaceable battery is used, a fast charge should be usable. This is to make the time of interruption in using the device as little as possible

S16): By making the device such that no negative influence may occur to the baby (such as not blocking the baby's movement and making sure that the baby will not connect with the electrical circuit).

S17): Make the plaster as tight attached to the baby as possible without causing any harm and making the application waterproof.

S18): By making the glue on the plaster too strong, there will be a danger where the glue can cause harm when the plaster needs to be removed. The skin should not be irritated or experience any harm when the sensor is placed or removed.

S19): By making the sensor as simplistic as possible, almost every parent need to be able to place and use the sensor correctly

S20): By making a system where the sensors can be re-used, for example, where the sticky side of the plaster can be replaced, non-essential waste and possible user frustrations can be prevented.

S21): Every baby is different. Not every baby has the same needs as the other. This means that later on, the researchers may design the product to improve the usability for a certain group of babies (with, for example, another not usual body type).

Final Design

To conclude, the final concept includes multiple sensors attached to a plaster connected to a central point to process the incoming data. The sensors to use are the accelerometer, pulse sensor and cortisol meter when possible, which will measure continuously as long as the sensor is powered. Multiple plasters should be considered for the detachment on the babies body—each plaster having its own sensor. The plaster should be sticky enough to hold up for a longer period but not be too tight to prevent irritation on the babies skin in any way. The plaster has a fairly small size to prevent any negative effects due to size. The (standard) plaster size is chosen of 50mmx72mm. When afterwards, the conclusion comes that this size is too big. The design should be changed to a smaller size.

Wireless communication methods should be considered for the communication between the sensors and the central processing point. The two main methods to be considered are Bluetooth and Wi-Fi. As described by Erina and Francesco [83], Wi-Fi has a potential further range than Bluetooth. Wi-Fi may cost more electricity to send the data, but with the compact but powerful batteries of the current day, this should not be a problem. Also, having connected multiple devices connected with Wi-Fi could create a small network for easy communication between all the devices. Further, Wi-Fi can extend further the possibilities regarding data transmission making the final decision to go to Wi-Fi.

Connected to each sensor should be a microcontroller to receive and send the data from the sensors to the Wi-Fi module (and therefore to the central data processing point). On the other end, another microcontroller should control the incoming data and the data processing at the central data processing point.

As mentioned earlier, the plasters with the sensors should be wireless. This means a battery should be included in the design of the plaster. The battery should deliver a fair amount of time to use the device without replacing the battery frequently. Two types of power supplies may be considered in the process. At first, you have standard batteries which you can buy in a store. This allows the user to easily and fast replace the battery in the device. These batteries also have potentially enough capacity to deliver enough electricity to the sensors to be used for multiple days. However, these batteries come in a fixed size, making it more challenging to implement in a design where everything has to be as small as possible. The other option, which has the preference of the researcher, will be a custom made battery with the option to fast charge. This option allows the custom design of how big and which size the battery should be. The only downfall of this option is the lack of possibility to replace the battery. When the battery is empty, it should be recharged manually by, for example, USB. However, this is not being conceded to be a very big problem for this product.

A simple schematic of the final concept can be found underneath in figure 16.

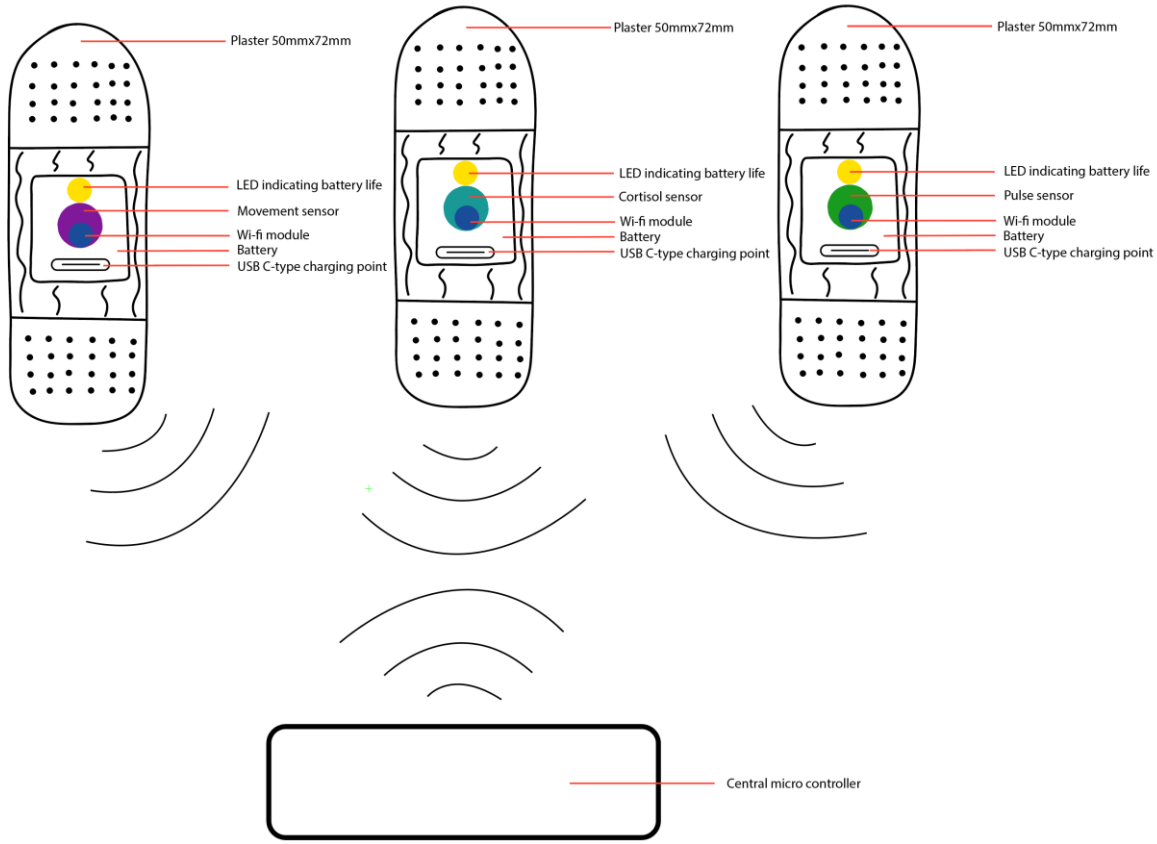


Figure 16: Simple schematic of the final concept

5.4 Designing the final concept: The Application

First, the earlier made specifications are looked into to help design the application. As briefly described earlier in chapter four, the application should include particular functionalities. The application should be connected to the sensors, make it simple for the user to connect the sensor to the application, making the data coming from the sensor understandable for the parents, give the parent the option to how much feedback the user wants to receive from the application and make an easy connection to a specialist. In addition, a logbook is considered, by the researcher, to be a great addition to the application. This logbook will help the parent to get an overview of the (amount of) past stress reactions.

In conclusion, the application should notify the parents of a possible stress reaction and guide the parent to a possible solution to decrease the number of stress reactions.

Specifications & functionalities

The application has to include multiple functions and options, as described in Table 18 and 19**.** Underneath, the requirements are stated with a description of what to do with the application's requirements.

A1): For this requirement, the researchers follow the regulations made by the GDPR [84]. However, this is not the only step to be made. Within the app, the terms and conditions should be available for the user to look into. If the user wants to use the app, he/she should first agree with the terms and conditions. When the user disagrees with the terms and conditions, the app cannot be used.

A2): To store the incoming data over a more extended period, two options may be considered. The first one is to store the data on the physical device in use. The second option is to store the data in a cloud service. As the second option probably costs a lot more, the benefits make it up. First, storing the data in the cloud prevents the telephone from having too much storage, making it force to delete the new incoming data. The second benefit of having the data stored in the cloud is that by using the cloud, sharing the data with others (professionals) is more easily. The drawback of putting the data in the cloud are privacy related. The data should be inaccessible for people who do not have the approval of the user to look into the data.

A3): To visualize the data coming from the sensor in an understandable way, a method should be used which is understandable for the majority of people. Graphs and tables are by the researcher considered to fit into this requirement. Within the visualisation, annotations should be used to highlight specific events to make them stand out.

A4): By using notifications, the user gets updates about the situation of the baby. Even when he/she is not actively using the application, the application continues to work. The number of notifications will be based on the changes in data from the sensors and the user's personal preference. The user can choose between getting notification after every stress reaction, getting notification after frequently occurred stress reaction or getting no notifications at all. This option is to make the number of notifications suitable for every parent and prevent the parent's potentially stress due to the number of notifications of the application.

A5): Multiple preferences options are found in the settings tab to make the application as comfortable and usable for the user. For example, the number of notifications can be found here.

A6): This requirement is met by developing the app for multiple platforms.

A7): This requirement is met by adding custom layout settings. Now not only the fonts can be customized, but also the colour scheme and other non-required options.

A8): These requirements should be used somewhere at the start of using the app. This requirement is to help the parents with placing the sensors on the baby. Without a good placement, the sensors cannot be used. This function makes sure that the sensors and the applications can be used properly.

A9): This requirement can only be done by first looking into the knowledge and abilities of the target group and secondly testing the application to the target group and look for inconveniences.

A10): The application should give the option about which feedback the parents want to receive. For example, one parent wants regular updates on where the baby's condition is stated. In contrast, other parents only want to receive a notification when something is wrong (to prevent stress coming from the regular giving notifications).

A11): When the parents are being counselled by a professional trying to observe the situation and make a hypothesis, the specialist should be able to use the data from the sensors. This data should easily be accessible for the specialist to improve the treatment.

A12): This requirement will be accomplished by testing the amount of feedback to the user. Beforehand, there will be some guidelines and options made to achieve this requirement.

A13): When the parents of the application are noticing a problem regarding the baby's stress level, making contact with a specialist should be made easy. Helping the parents (and therefore the baby) as quick as possible is needed to limit the damage stress can cause.

A14): Using standard colours, a simple design and non-complex interactions should help make the application appealing to most people.

A15): This requirement should be done with the help of specialists. In some cases, a simple suggestion may help the parents to influence the situation positively. However, the suggestion should be verified by a specialist to be 100% correctly to the situation. Wrong recommendations may negatively affect the problem, which should be prevented at all means.

A16): These tips have nothing to do with input from the sensors but rely on general statements. Some general cases are being discussed with the fitting solution to the situation. These tips may help the user when the user is in the same situation.

A17): This requirement describes an ethical dilemma that has to be solved at the end of the project. When bringing the products on the market, the price of the product should be based on the actual costs combined with the potential to reach as many people as possible, not to make as much money as possible.

A18): When having access to many samples of data coming from multiple babies, an algorithm could analyse the data and find solutions to improve the application. Think about how to interpret the incoming data.

Designing the app

In General

As earlier described, the application should include particular functionalities. By having these functionalities, the application should help the parents indicate the baby's stress. The application also could be a tool for parents to help to reduce the baby's stress. The application should have an option to give the right amount of feedback about the baby's current state to the parents without influencing the life of the parents and their relationship with the baby. This option will be the parents themselves choosing how many updates they want to receive. Further, the application should be a helpful tool for the parents to easily contact specialists when needed, as stated earlier in the interview with specialists. The application should be a useful tool to deliver the sensors' data to a specialist when asked. When having the parents' consent, the specialist should be able to easily download and observe the data from the baby to give additional feedback to the parents when needed. The application should also include a logbook which will help the parent getting an overview of the past stress reaction. This logbook also includes additional feedback from the parents.

The application's design should be as neutral and straightforward as possible so that it is suitable to use for most parents and does not discourage parents from using it. Every functionality should be easy to navigate through within the application. So, at the bottom of the app, there will be a possibility of switching between the different pages, making it easy to navigate. The placement is chosen because of the easy reachability for the user, as discussed underneath. The number of pages visible to click on will be limited to three to make the layout more simplistic for a better user experience. This idea of keeping everything as simple as possible for a better user experience will be applied and intergraded as much as possible in the entire application. By asking as little as possible user input, the user will more easily be motivated to give the input and have a better user experience.

Consuming that the first version of the application will be made to be used on a smartphone, the knowledge of the research of Hurff [84], should be considered. His research described the different reachability of multiple areas on a smartphone for an ordinary hand. The placement of the different buttons in the application should be based on the importance of the function combined with the reachability of the hand of a person. The more essential and regular used functions should be placed in the green area, where the less important and less used functions should be placed in the red area. The functions which fall in between should be placed in the orange area. The size of a specific area does also depends on the size of the phone. The larger the phone, the larger the red area. The different areas combined with the different sizes of different iPhones can be seen in the figure underneath.

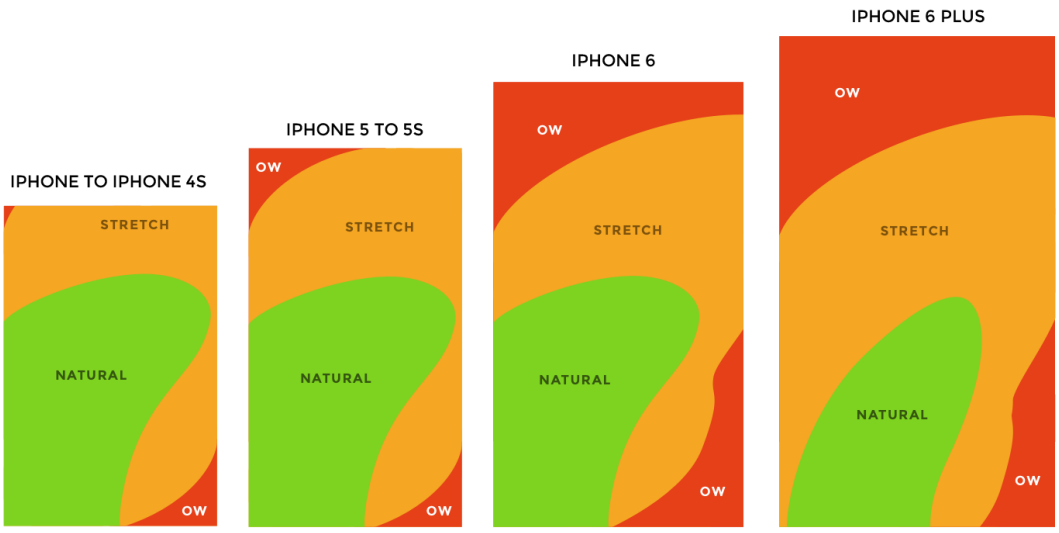


Figure 17: Thumb-zone mapping between different sizes iPhones right hand [84]

Home Screen

The home screen will be the first thing to see when opening the app for the first time. This screen will include multiple components based on getting the user started with the application. Included functionalities are being able to log in, register, terms & conditions, place the sensors, and connect the sensors. The application stimulates to make an account for using the application. With creating an account for the application, more functionalities will be unlocked. However, when people do not feel comfortable registering for the app and still want to use this app, this is also not a problem.

Live Monitor Page

This page brings the live data of the sensors to the user in an understandable way. On this page, the current status of the connected sensors (and the baby) can be found. This will mostly be done by a graph and a small summary that explains the incoming data.

Statistics

On this page, the incoming data of the sensors will be shown and visualized in multiple graphs. Also, the user's data which he has filled in within the application, such as the mood of the baby and parent in a particular period, can be seen. This page allows the user to see and understand more understandably what the incoming data from the sensor tells us. The time area of the graph, such as day, week and month, can be chosen. When the app senses a possibility of the baby having a stress reaction, it will label this data and in the graph. At last, the number of stress reactions over a particular time is also displayed on the page.

Logbook

This page displays the date and time when the baby had a stress reaction and asks the parents to be alert when the stress reaction occurs more often in the future. It will ask to validate the given alert by letting the parents write notes to the possible stress reaction. Also, additional notes may be added to the logbook, even when the sensors did not detect stress. The stress reactions and additional notes will be displayed underneath eachother. This allows the parents to look back at certain stress reactions later on and display the number of stress reactions of the past within a certain period.

Contact To Professional Page

On this page, multiple options are displayed to make contact with a professional. It gives the possibility to message a professional when having questions about the baby's behaviour and with the data coming from the sensors. When the questions are more urgent, it gives the possibility to call a professional and to send the professional the data of the sensors of a certain period. After the communication with the professional, it allows writing down notes of the conversation (the professional also may do this). All of the earlier contacts with the professional will be saved in a logbook which can be retrieved later when asked.

Settings

On this page, the app's preferences and functionalities can be adjusted for the user better experience. It gives the standard options the number of notifications, installed version of the app, profile specifications, help, and sending the data to a professional.

5.4 Concluding the specification

Haven chosen the final concept in the previous chapter, the requirements of the final concept were made in this chapter, relying on the knowledge gained during the last chapters and by using the MoSCow-method. After the requirements were stated, the possible solutions to the requirement were described, resulting in the design of the final concept.

This final concept consists of two different parts. The first part, the sensor part, should measure continuously if the baby has a stress response. This sensor should not cause any negative effects on the baby. The second part of the final concept, the application part, gives the parents feedback and visualisations about the incoming data from the sensors. The application further includes providing feedback on the incoming data, helping the parent with setting up and connecting the sensors, giving an overview of the data in the past, encouraging the parents to make a logbook and giving the parent the option to contact a professional easily

Both concept parts are globally designed in this chapter and will be realised in the next chapter.

6. Realisation

This chapter describes and discusses the realisation of the final concept. In this chapter, the final concept consisting of a sensor part and an application part will be realised, which can be used to evaluate in the next chapter. This chapter highlights the sensor part of the concept by describing and defining the components and software used to make the prototype and shows the data flow between the different parts. This chapter also states shows the development of the application.

6.1 Hardware To Use

For the realisation of the product, multiple hardware components are used. Underneath the different sensors and components with the connected microcontrollers are shown. The selected sensors, controllers, will be discussed. The proposed solution will be described in 3 levels, hardware, software (implementation) and data flow. At the end of this subsection, an overview of the connection and data flow between the different parts is displayed.

Pulse sensor

The pulse sensor made by pulsesensor.com [85] is an optical pulse sensor capable of measuring heartbeats in beats per minute in real-time. The sensor is placed on top of a blood vessel. When placed on a blood vessel, the sensor shoots light into the blood vessel, where oxygenated haemoglobin absorbs a part of the light. The other amount of light is being reflected and goes back into an emitter on the sensor. This means that how much light is returned into the emitter depends on how much blood there is in the blood vessel. With every pulse of the person's heart, the blood vessel will contain more blood, resulting in more absorption of the light by the blood(therefore, less light is returned to the emitter). By measuring the change of reflected light, the heart rate is measured.

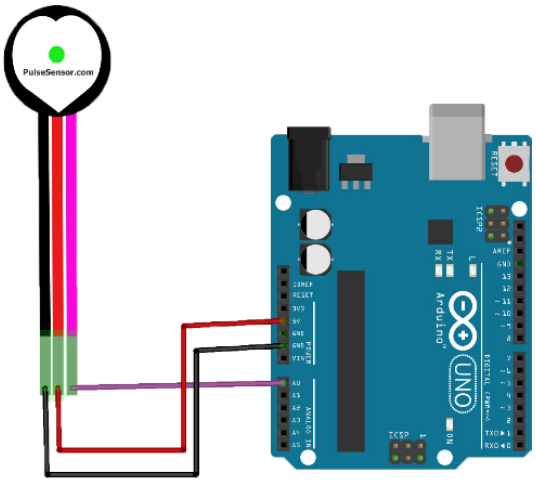


Figure 18: setting up the pulse sensor with the arduino

The implementation of the sensor is as follows: the sensor is connected to a microcontroller, the Arduino Uno. The purple pin from the sensor goes into the analogue pin of the Arduino (in this case, A0), the red pin from the sensor goes into the 5V pin of the Arduino, and the back pin form the sensor into the GND pin of the sensor. The schematic of the implementation can be found in figure 18. The schematic was made with Fritzing [75].

Acceleration/Gyroscope sensor

To measure the participant's movement, the accelerometer/gyroscope module GY-251/MPU-6050 made by InvenSense inc. [86] is used. This module measures acceleration and rotation in three dimensions, X, Y and Z. This is visualised in figure 19 from the datasheet[1]. The combination of the gyroscope and accelerometer will measure the sensor's roll, yaw, and pitch to measure the movement. Due to problems regarding the availability of the initial cortisol sensor, a second MPU-6050/GY-251 module is used within the realisation.

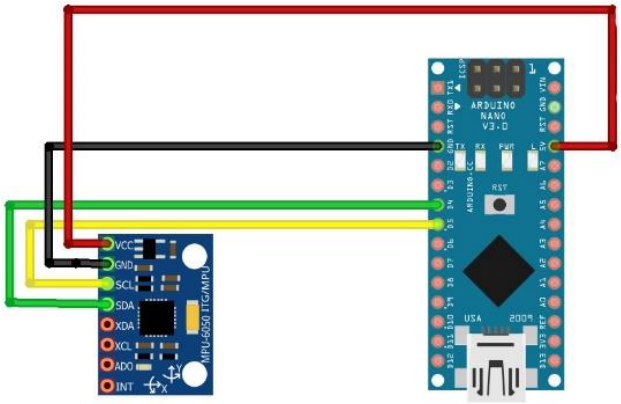


Figure 19: setting up the movement sensor with the Arduino

The implementation of the sensor is as follows: the sensor is connected to a microcontroller, the Arduino Nano. The VCC pin of the accelerator goes into the 5V pin, the GND pin of the sensor goes into the GND pin of the Arduino, the SCL pin of the sensor goes into the A5 pin of the Arduino, and the last SDA pin of the sensor goes into the A4 pin of the Arduino. The schematic on how to connect the sensor to the Arduino can be found in figure 18. This schematic is made with Fritzing [75].

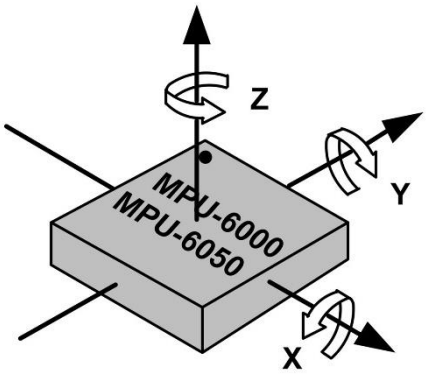


Figure 20: Different sensible rotations of the MPU6505 module

Arduino

In this realisation, two types of Arduino's are used. The first one is the Arduino Nano [87], and the second one is the Arduino Uno [87]. At first, three Arduino Nano's were purchased to make the system wireless. However, due to time constraints making it impossible to make the system wireless combined with a broken Arduino Nano, the researcher connected the pulse sensor with an Arduino Uno. By choosing to use wires for the connection between the microcontroller and the sensors instead of a wireless system, the Arduino will be placed on a different spot other than on the plaster, making the Arduino's size less important. Due to the non-

[1] *InvenSense inc., MPU-6000 abd MPU-6505 Register Map and Description Revision 4.2., Sunnyvale California, 2013*

importance of the size and convenience regarding practical reasons, time and costs, The first Arduino Uno was used instead of a third Arduino.

The specs of both Arduino's are quite similar; both devices have the ATmega328P microcontroller and a 16MHz CPU speed. However, there are two most significant differences between the two devices. The first big difference is the dimensions between the two. The dimensions of the Arduino Uno, 68.6mm x 53.4mm, are fairly bigger than the dimensions of the Arduino nano with its 45mm x 18mm. The second big difference is the number of available analogue pins. The Arduino Uno has eight analogue pins against the six analogue pins on the Arduino Nano.

Plaster

The plaster used in this realisation needs to be soft and suitable for sensitive skin but sticky enough to hold the sensor for multiple days. To accomplish this, two types of plasters are used.

For the accelerometer, the Hansaplast Silicone Soft Xl [88] is used. This plaster is marketed as being suitable to use on sensitive skin. This means that it should also be suitable for babies sensitive skin (for example, without having to worry about hurting the baby's skin when removing the plaster). It also claims that the plaster can be reused multiple times without losing its adhesiveness. The dimensions of this plaster are 72mmX50mm. This should be more than enough space to fit in the sensor and additional modules.

For the pulse sensor, the Fixomull stretch [89] is chosen. This kind of plaster is chosen because of its stretching behaviour. The pulse sensor needs to be placed as tight as possible to the skin for a correct measurement. With the stretching behaviour of the plaster, this should be easier to accomplish. Further, this Fixoumull plaster is also labelled as usable for fragile skin, making it suitable for babies as described above. The dimension of this plaster depends on how it is cut. The plaster comes in the form of a 10cm X 10m package. However, when this plaster is used for this project, it will also be cut around the plaster dimensions described above (so around7cm X 5cm).

Figure 22: Hansaplast Silicone Soft XL [89]

Figure 21: Fixomull Stretch [90]

6.2 Software To Use

Arduino

Two different Arduino sketches written in Arduino IDE 1.8.15 [90] are used within the realisation to control the Arduinos and, therefore, the sensors. The first sketch is written for the Arduino Uno connected to the pulse sensor, and the second sketch is written for both the Arduino Nano's connected to the MPU-6050/GY-251 module. Underneath, a small summary of the different codes is written.

The first sketch runs the communication between the pulse sensor, Arduino Uno and the Processing sketch. The communication between the pulse sensor and Arduino is done using the Pulse Sensor Playground library version 1.5.1. [91]. With a baud rate (bits per second) of 250000 between the Arduino and sensor, the values are being sent to the Arduino (serial), where the Arduino sends the data via a serial port (also with a baud rate of 250000) to the computer. The sketch starts by looking if the sensor indeed is working and sending data. If the sensor is working, the sketch calculates the average threshold value based on the first 1000 samples of the sensor. When the threshold is set, the raw values of the sensor and the calculated beats per minute (using the Pulse Sensor library) combined with the time is sent to the serial port of the computer.

The second sketch runs the communication between the MPU-6050/GY-251 module, the Arduino and the computer. It starts by addressing the communication registers of the module for setting the input. The gyroscope's input as the accelerator input is inputted and processed (thinking about error and precision) to get the right values. When using both values in a certain ratio, the roll, pitch and yaw are calculated. These values combined with the time are sent to the serial port at a baud rate of 19200 to the Arduino and to the computer. The full documentation on both codes can be found in the appendix.

CoolTerm

The programme CoolTerm V1.9.0.948 [92] is able to read multiple serial ports at once when the ports are available. It reads the data and puts the data in a text file to be used later in another programme. The reason to chose this programme over other programmes is the ability of the programme to read the multiple ports at the speed of the receiving data from the Arduino's. Other programs such as Processing [93] and Excel [94] could not deliver this performance.

Microsoft Excel Spreadsheet

The made text files containing the data of the sensors will be loaded into a Microsoft Excel spreadsheet [95]. This spreadsheet will make the charts that will be used to assess the data.

Schematic overview of the connected Hardware and flow of the data

Underneath in figure 23, a schematic can be found, including the different components described above, combined with the data flow. At the top of the schematic, it is displayed that the sensors connected on the plasters are sending their data to the microcontroller, the Arduino's. For the GY-251/MPU-6050 module, the data contains the roll, pitch and yaw. For the pulse sensor, the data contains the Raw_data of the sensor.

After the data from the sensors are sent to the Arduino's, the Arduino Nano's send the data of the sensor combined with the time of a timer, which starts at the beginning of the measurement, towards the laptop. The Arduino Uno connected to the pulse sensor will first determine the BPM based on the incoming raw_data and sends the BPM combined with the raw_data and the time of the timer, which starts at the beginning of the measurement, also towards the laptop.

The laptop receives the incoming data of the sensors via and USB cable. The laptop is able to read the incoming serial data via the programme CoolTerm. This programme will put all of the incoming data into .txt files, which later will be used to evaluate the data in Microsoft Excel Spreadsheet.

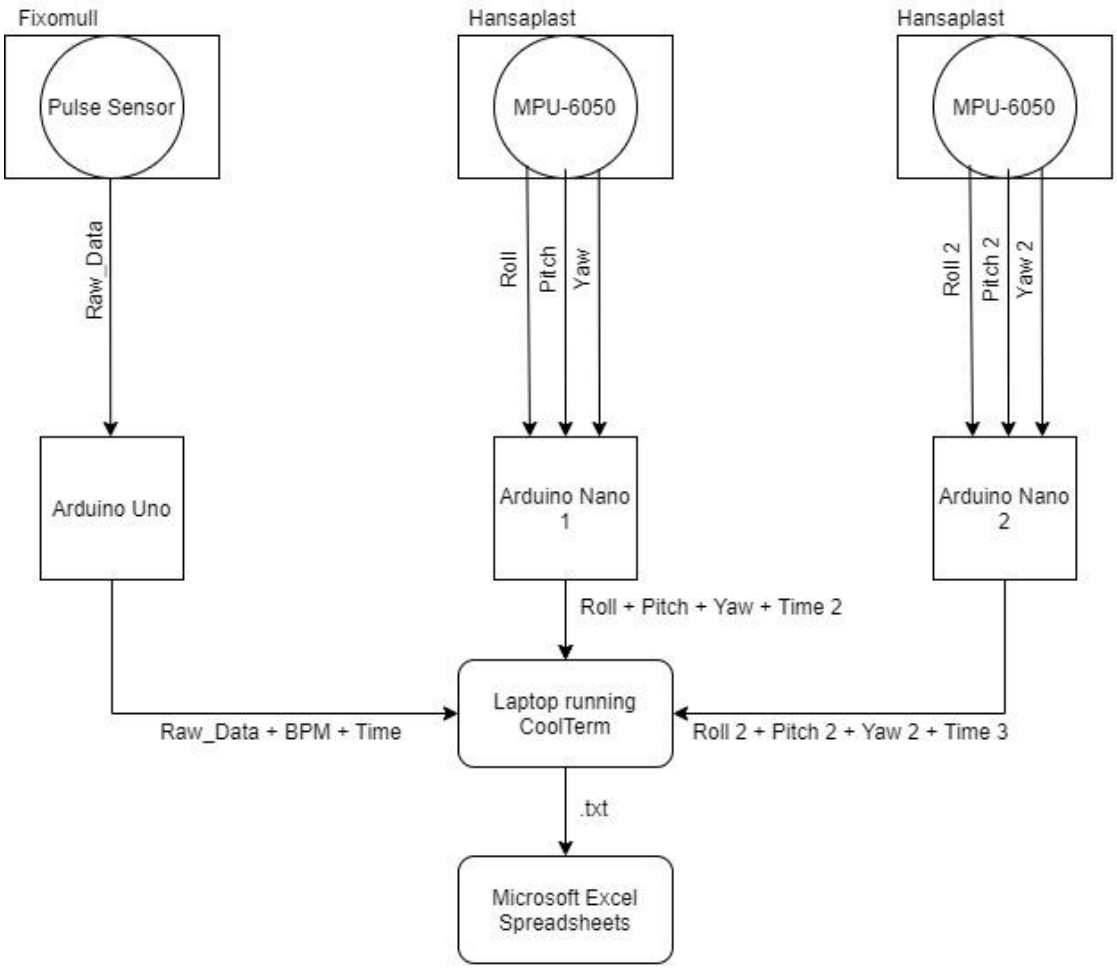


Figure 23: Schematic overview connected hardware and data flow

6.3 Placement of the sensors combined with the output

MPU-6050/GY-251

As said earlier, a restless baby could increase their general movement and stretch more than normal when experiencing stress. On the other hand, a baby could also decrease their movement when experiencing a stress reaction. To be able to map the baby's motility and, therefore, the general movement change of the baby, the sensor should be attached to a place on the body where the change in movement is being estimated to be high. In this case, the arms and legs are being evaluated to be the best spots for the measurements. Not only the general movement of the baby can be mapped in these places, but also the reachability to put the sensors on these spots is great.

Keeping in mind the advice of the professionals described earlier, that a good place to place the sensor would be the upper arm, the first MPU-6050/GY-251 module is placed there. The movement test consisted of standing normal with the arm pointed to the ground. After this, the arm is pointed forward and then pointed sideways. The last part consists of a more restless and fast up and down movement of the arm.

The second test was executed to better view the data's difference in intensity of the movement. First, the arm was being moved carefully. Secondly, the arm was being moved with more intensity, and in the last phase of the execution, the arm was being moved very heavily. The data is shown underneath in a graph made with excel.

As described earlier, the cortisol sensor is replaced by a second MPU-6050/GY-251 module. This second module is placed on the calf muscle of the user. Great reachability and the noticeable expected change of movement in this area are the reason for this area's placement. Almost the same procedure as with the placement on the upper arm is being executed to validate the placement. The researcher sat down on a chair, there he first points the leg forward, rotates the leg 90degrees to the right, rotates the leg back for 90degrees and finally, the leg is returned to the beginning position pointing to the ground. The second test was, as with by the arm, and intensity test. First, the researcher moved the leg up and down lightly, then medium and finally, with heavy intensity. The results can be seen underneath in figures 23, 24, 25 and 26. These charts made with excel will have a small summary of the data included underneath each figure.

Pictures of the module attached to the plaster combined with a short description can also be found underneath in figures 27 and 28.

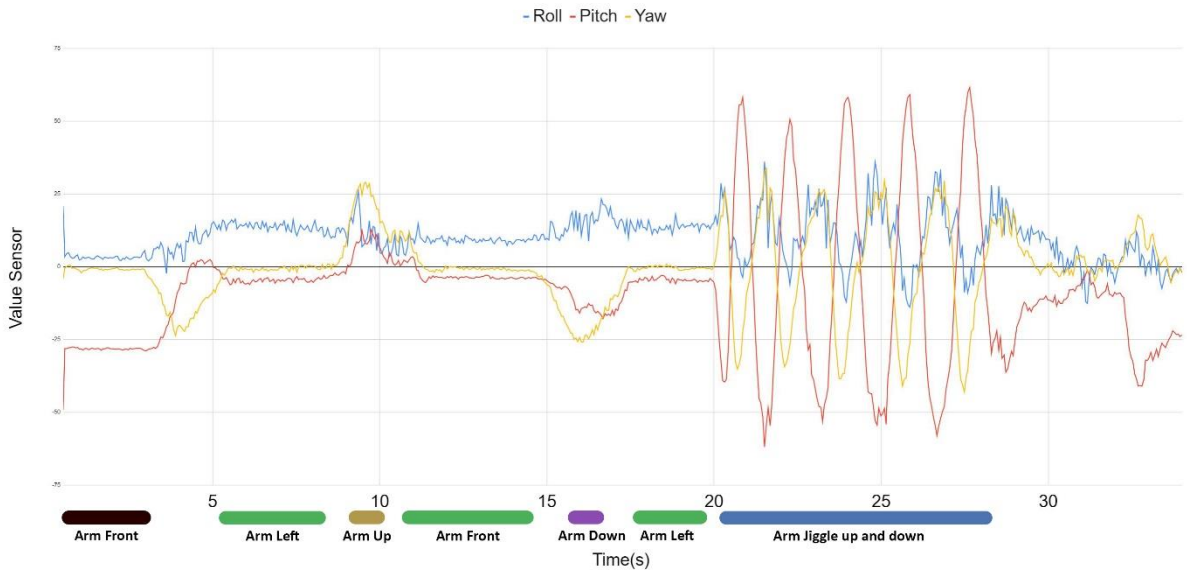


Figure 24: Output of the MPU-6506/GY-251 module connected to the upper arm, change in targeted movements

In figure 24, it is shown that the module can detect a change in the movement of the upper arm. The movement change is displayed as a change in the roll, pitch or yaw indicated with the red, yellow and blue lines (y-ass) over time (x-ass). For example, when the researcher moves his arm from in front of him to the left, it is shown in the chart by having the Pitch going up, the Yaw going down, and the Roll staying at almost the same value.

At the end of the chart, the arms wiggle indicates more strong and fast movements by having the maxima and minima laying higher and closer to each other.

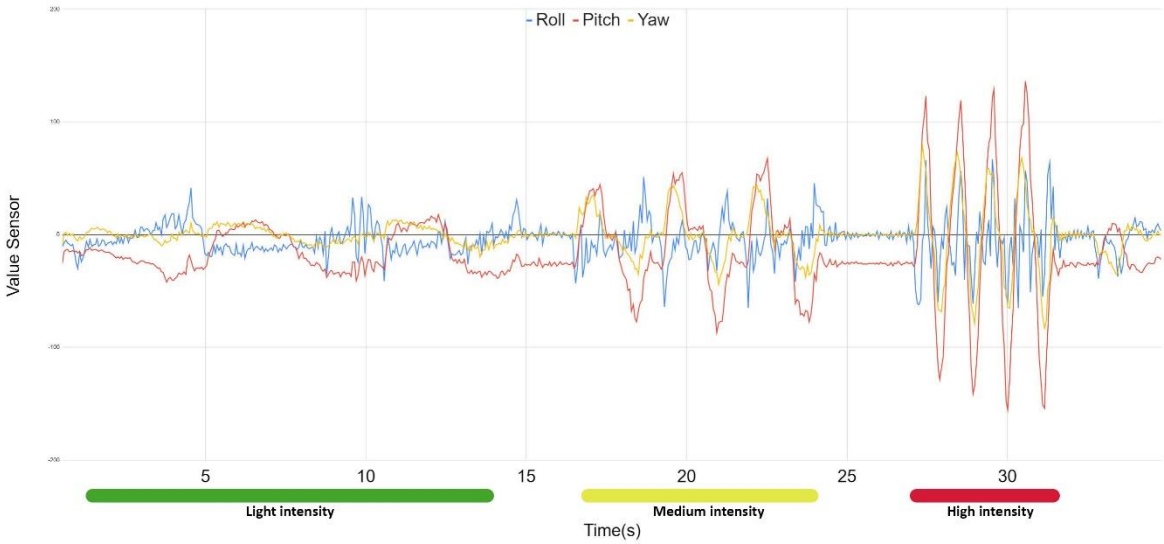


Figure 25: Output of the MPU-6506/GY-251 module connected to the upper arm, change in intensity of movements

In figure 25, it is shown that the module can detect the intensity of a movement when being placed on the upper arm. The movement intensity is displayed as a change in the roll, pitch or yaw indicated with the red, yellow and blue lines (y-ass) over time (x-ass). More intensive movements, such as at the right of the chart indicated by red, are characterised by having the maxima and minima laying higher(and lower) and closer to each other. More light intensive movement, as displayed at the left of the chart indicated by green, is characterised by the opposite.

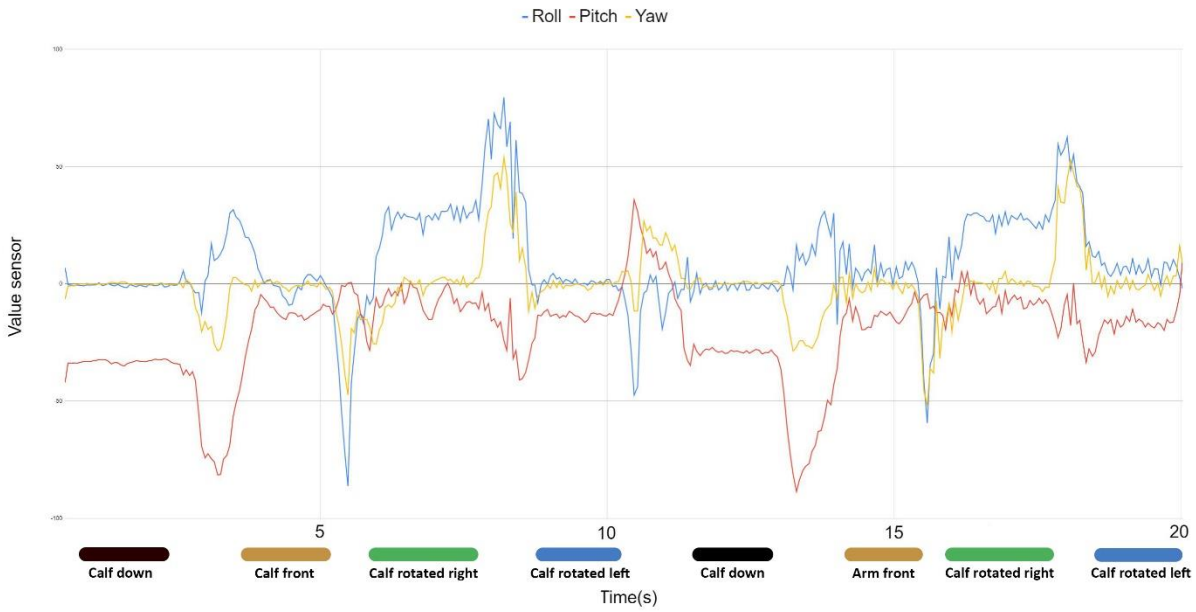


Figure 26: Output of the MPU-6506/GY-251 module connected to the calf, change in targeted movements

In figure 26, it is shown that the module can detect a change of movement when being placed on the calve muscle. The movement change is displayed as a change in the roll, pitch or yaw indicated with the red, yellow and blue lines (y-ass) over time (x-ass). For example, when the researcher rotates his leg from in front of him to the right, it is shown in the chart by having the value of the Pitch going down, the Yaw going down, and the roll going up.

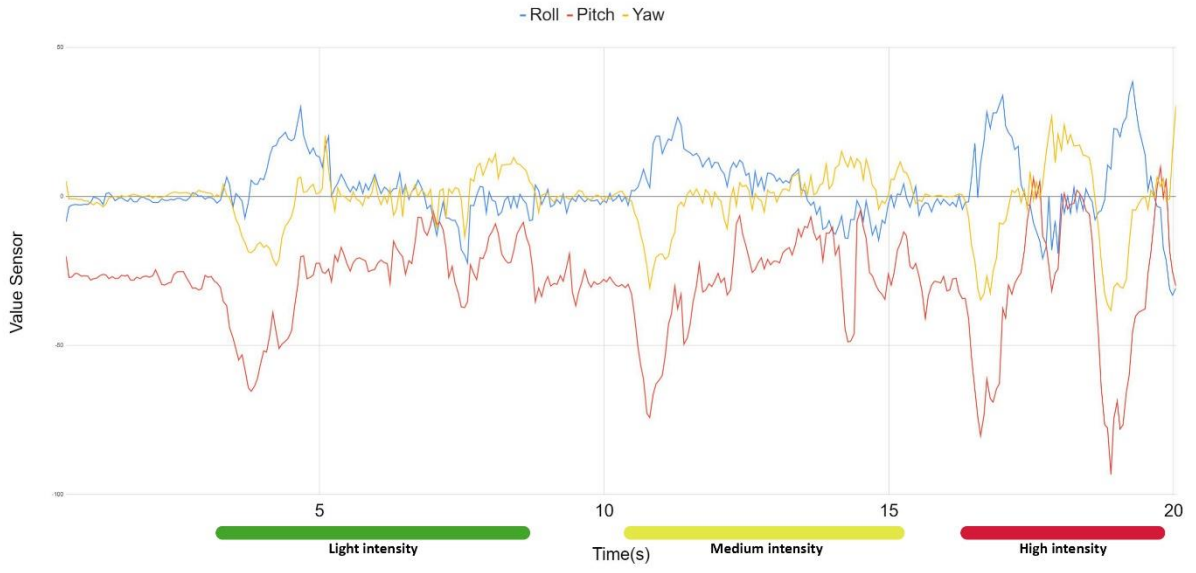


Figure 27: Output of the MPU-6506/GY-251 module connected to the calf, change in intensity

In figure 27, it is shown that the module can detect the intensity of a movement when being placed on the calve muscle. The movement intensity is displayed as a change in the roll,

pitch or yaw indicated with the red, yellow and blue lines (y-ass) over time (x-ass). More intensive movements, such as at the right of the chart indicated by red, are characterised by having the maxima and minima laying higher(and lower) and closer to each other. More light intensive movement, as displayed at the left of the chart indicated by green, is characterised by the opposite.

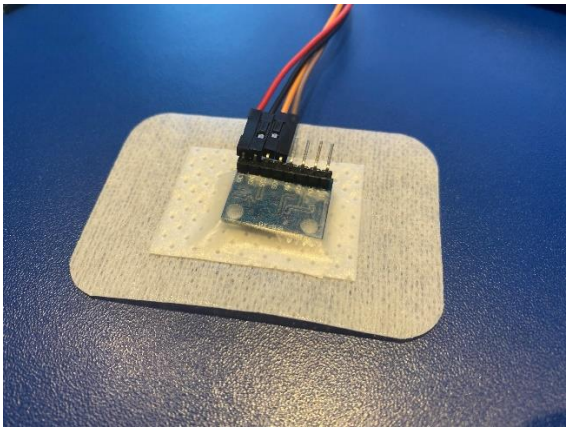


Figure 28: Accelerator/Gyroscope plaster outside

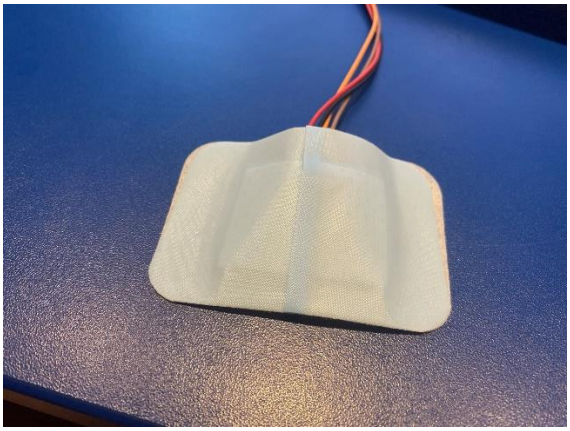


Figure 29: Accelerator/Gyroscope plaster inside

Figures 28 and 29 show how the sensor module is being placed within the plaster(s). In figure 28, it is seen that the sensor module is being taped on the inside of the plaster to ensure the sensor stays in the same place on the plaster when being used. In figure 29, a plaster is connected on top of the other plaster to close the plasters casing and, to be able to use the whole sticky side of the plaster for the placement on a person.

Pulse Sensor

For the measurement of the heartbeat, the pulse sensor should be placed on a spot where the veins are close to the surface, but the influence of possible (motion) noise is limited. As described by Mandal [96] and Valencell [97], there are multiple spots where the measurements can take place. For this research, three different areas were tested. The first area is the forehead, the second is the upper arm, and the last is the wrist.

First, the forehead was chosen as the first area to take into consideration. As seen underneath in figure 30 and as described by Valencell, this area gives a very clear signal. This place has relatively few problems regarding motion noise. The only drawback of this place is the easy exposure to sunlight when used outside, influencing the measurement results. Also, putting a sensor in this area is not very flattering.

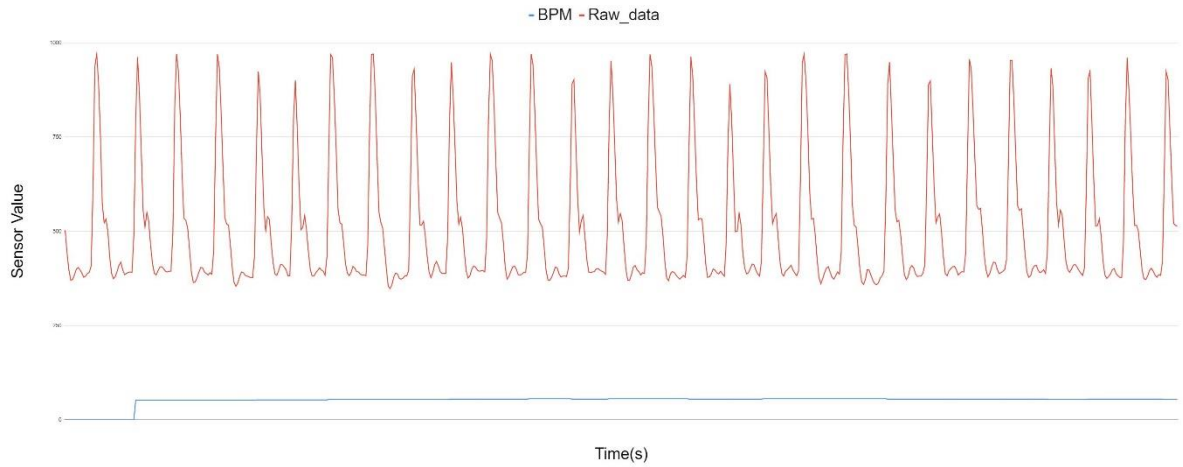


Figure 30: Measuring heart-rate pulse sensor- Forehead

The second area chosen to place the sensor is the upper arm. As described by Valencell, this area contains a lot of blood due to the large muscles in the area. The sensor attached to this spot could also easily be covered by cloths, making it more appealing to wear. The researchers found out that the signal was very weak when testing this spot, as seen in figure 31. However, the signal was enough to get the BPM of the researcher. This stayed the same, even when changing the placement of the sensor for a few centimetres.

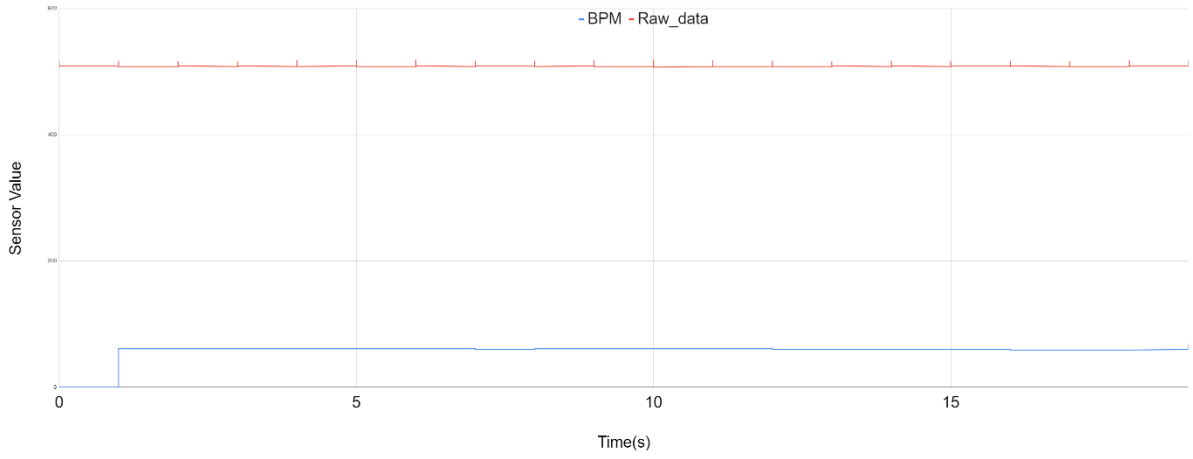


Figure 31: Measuring heart-rate pulse sensor - UpperArm

The third and last area chosen by the researcher was the wrist. As with the upper arm, this area is very convenient to cover the sensor by clothes or by putting it in a wristband or watch (as seen in some smartwatches). However, this place suffers from potential motion noise and potential problems regarding sunlight and skin tone, as described by Valencell. However, as seen in figure 32, the signal was better than on the upper arm and usable on the researcher.

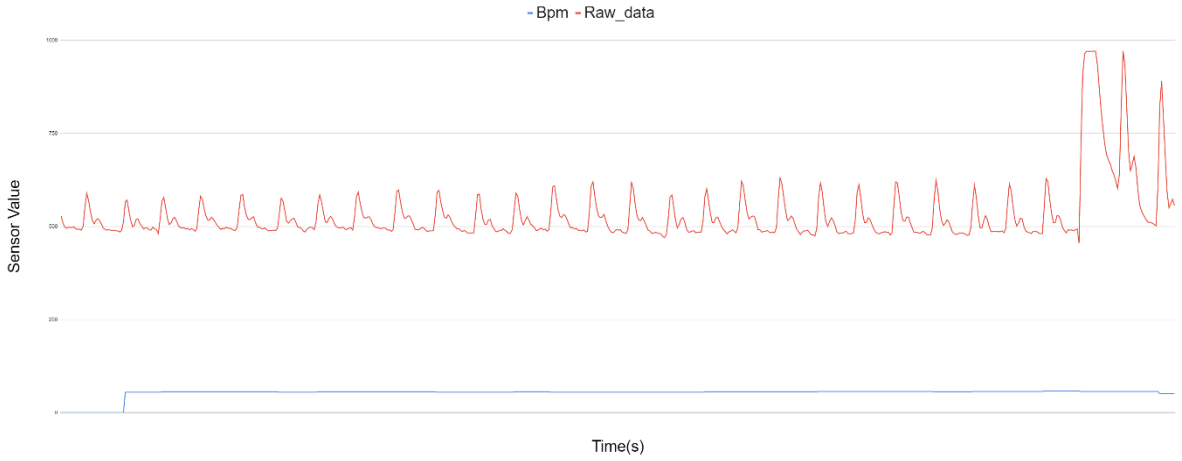


Figure 32: Measuring heart-rate pulse sensor – Wrist

6.4 Application

General

As described in the previous chapter, the main task of the application is to give the user the option to see the incoming data coming from the sensors, alert the user when a (possible) stress reaction occurs, let the user compare the data over a period, to help the user finding the cause of the stress reaction (when possible) and to allow the user to make a connection with a professional when needed easily.

To realize the described tasks above, the application is built up out of different tabs to make the application more user-friendly and the structure of the application clearer for the user. The various tabs of the application will be shown and explained underneath.

The realisation of the (concept) application is made with the program AdobeXD [78]. This programme gives the possibility of designing an interactive concept application without actually having to code the application. Having the application interactive allows the researcher to test the (concept) application later on. The application will be designed based on the use of a phone, in this case, an iPhone 12.

The realisation of the application starts with making a colour pallet to make sure the style throughout the entire app will be the same. The colours should be interpreted as neutral to ensure the colours will not distract the user and make it as appealing for as many people as possible. The colour pallet was based on the colour blue because this colour is mostly associated with a relaxing mood, as explained by Hanafy and Reham [98].

The colour pallet of the design with the HTML codes can be seen underneath in figure 33.

Figure 33: HTML Colour codes Application

The font used within the application is the Helvetica Neue [99]. This font is considered a professional and calm font that will not distract the user from using the app by the researcher. The different possibilities of this font are displayed underneath in figure 34.

Figure 34: Helvetica Neue font [99]

Log-in screen

Before the user can use the application, the user has to choose if he wants to use the application with a personal account or to use the application as a guest. The reason to work with a registration-based application is its possibility to make the application more personal. For example, the other tab named “contact” enables much more functionalities when being registered. When registered, the information can be saved in the cloud to allow the user to use the application on multiple devices on the same account and data. After the user has clicked on “use the application as a guest”, the user will get a small notification pop-up to convince the user the last time to make an account.

After being logged in for the first time, the Terms & conditions of the application are displayed. The terms and condition shown underneath in the screenshot is not the final version. Because of the minor importance of making real Terms &Conditions for the app, the finished Terms&Conditions will be made after the application will be brought to the market. To prevent any accounts from being lost due to the user forgetting his/her password, the common implemented “forgot your password” is added. Screenshots of the log-in screen are shown underneath in figure 35.

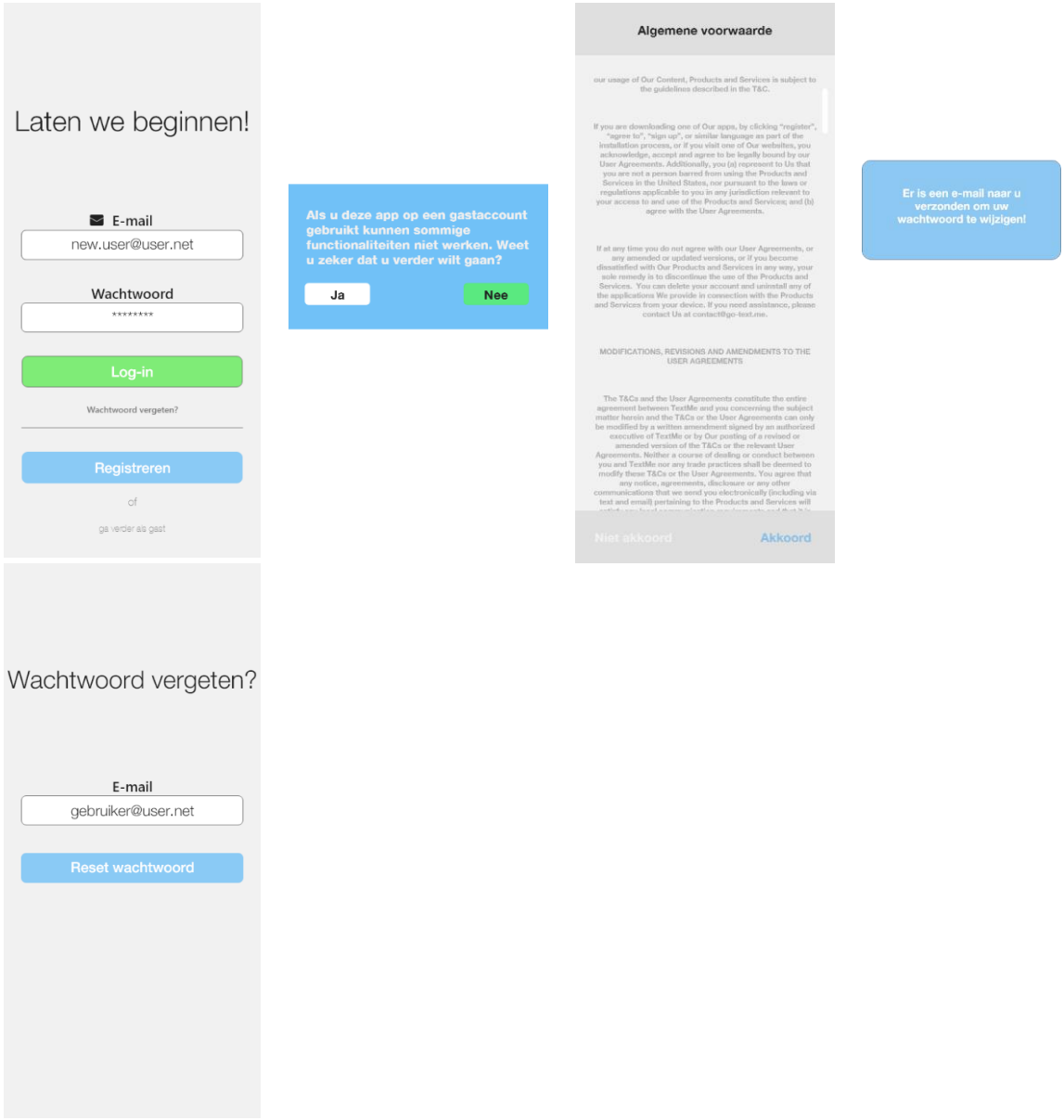


Figure 35: Screenshots of the Log-in page

Connecting the device

After the user is signed in with an account or guest account, the process of pairing a device (sensor) starts. This part of the application begins by displaying which devices are connected and giving the possibility of connecting a new device. When choosing to pair a new device, a new tab will display the available devices to connect with the application. After the user has clicked on the device to pair, it will display a small text summary of how to place the sensor on the baby with an additional picture. After the parents place the sensor, the application will check if the sensor is rightfully connected with the application and if the sensor is set correctly. When the sensor is not placed or connected correctly, the application will notify the user and suggest solving the problem. By following these steps, combined with the simple design of options,

almost every parent should correctly place the sensor on the baby and connect the sensor to the application.

After the sensor is connected and placed correctly, the application gives the options of how many notifications the parent wants to receive. This option is made to make the number of notifications fitting for every parent, preventing possible stress to some parents (as discussed earlier). When all the needed devices are connected, it shows the user the connected devices and leads them to the live monitor tab. The screenshots of the process of connecting the sensors can be found underneath in figure 36.

Figure 36: Screenshots of the connecting the device page

Live monitor

With the live Monitor page, the user can look into the data coming directly from the sensor. The user is now able to see if the baby, in the present time, is having a possible stress reaction or not. An additional info button is placed because of the possible unclarity of the raw data coming from the sensor, providing the user with additional information about the incoming data. The displayed information will be based on if the baby is having a possible stress reaction or not. When the incoming data of the sensor do not indicate a possible stress reaction, it displays the button “adding new device” to make it for the user easier to connect a new device. However, when the baby has a stress reaction, the colours changes to make this possible stress reaction

clearer. Also, an additional “go to statistics” button is displayed to lead the user to information of the present and the past. By comparing the past and present time data, the user have a better view of if he/she should actively do something or not (like going to a professional or not). The screenshots of the live monitor page can be found underneath in figure 37.

Figure 37: Screenshots of the Live Monitor page

Statistics

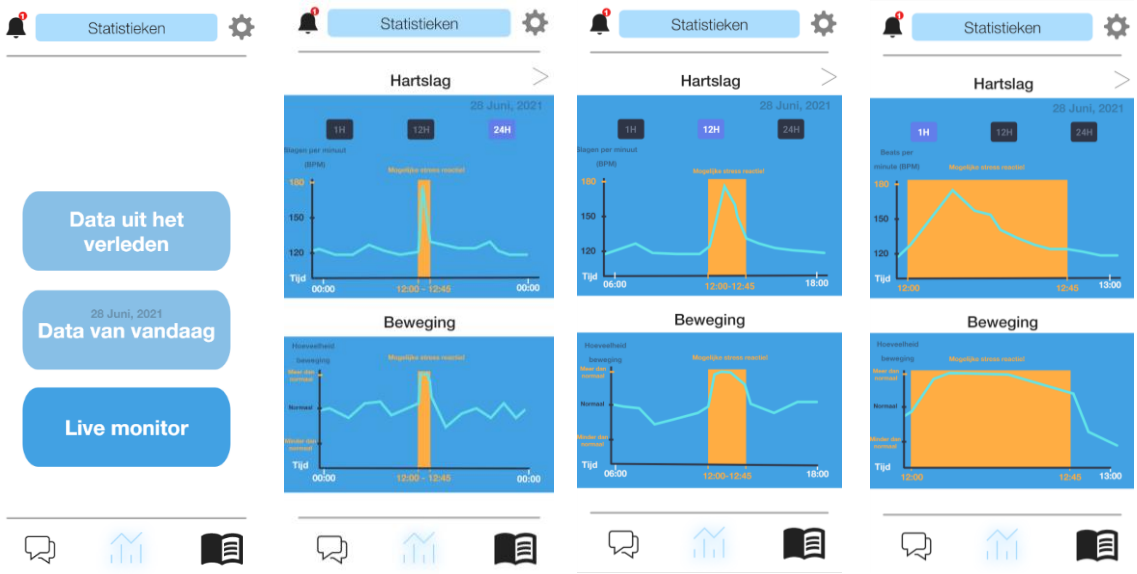
The incoming data of the sensor is stored in the application so the user can compare the older data with the new data. The first page starts by giving the option of which data should be displayed. The live monitor button to view the incoming data (so directing the user back to the previous page), viewing the data of today, or viewing the data of a period in the past.

To make the data more easily visual and therefore understandable for the parents, graphs are added. The beats per minute of the PulseSensor and the amount of movement are displaced in the periods: 24hours, 12 hours and 1hour. The different time periods are added to give the user a good impression of the incoming data of that day, with the possibility to zoom in or out to a certain situation.

With an orange background, a possible stress reaction(s) of a period is displayed. By doing so, the user will more accessible be able to compare the data of the possible stress reaction to the data of a not potential stress reaction. Further, the amount of stress reactions of a certain period, six months or last week, is being displayed. This gives the user a better view of the number of stress reactions has increased in the last period, and therefore, the possibility of toxic stress on their baby has increased in the last period.

Lastly, the mood of both the baby as the parent is displayed. Now, it is easier for the user to connect the amount of stress reaction with the mood of the user and the baby when there is a connection.

In short, this tab should allow the parents to see and examine the data from the sensors and the baby and user's mood over a certain period. Underneath in figure 38, the screenshots can be found of the statistics page.



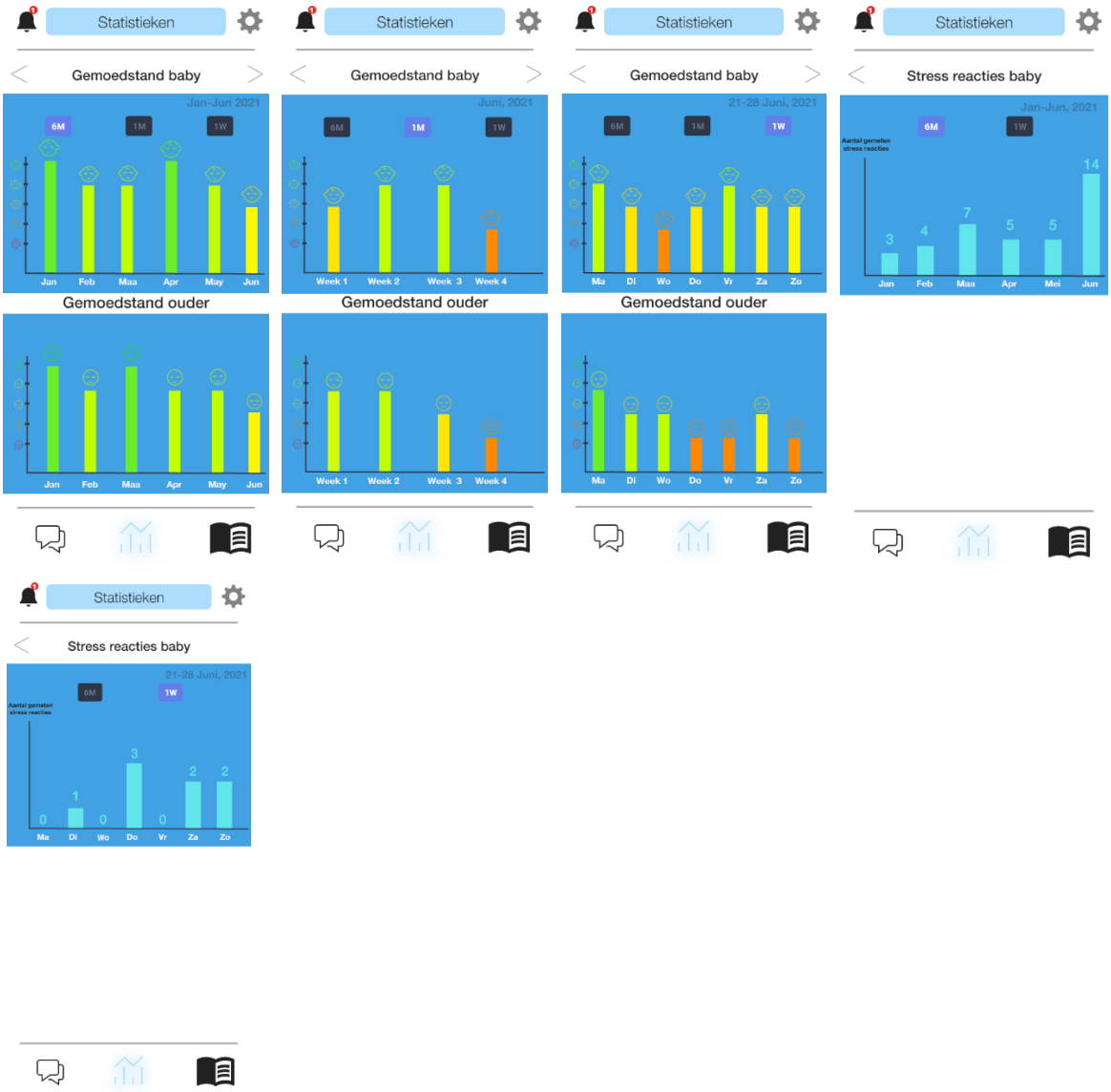


Figure 38: Screenshots of the Statistics page

Logbook + Notifications

By having a logbook built into the application, the user should better understand the past possible stress reactions, the filled-in additional notes to the stress reactions, and the extra notes. By every possible stress reaction (when filled in previously), the user is motivated to fill in a small amount of additional information to the potential stress reaction. This information contains filling in the mood of the baby and parent and describing the situation of the baby and parent. When multiple stress reactions occur in a short period, an additional notification is placed in the logbook, warning the parent of this increase of potential stress reaction. Also, this notification stimulates the parent to add an extra note to the logbook to make the logbook more complete and to be more alert when more possible stress reactions occur.

Extra notes may be added by the parent when the sensor is not sensing a possible stress reaction, but the parent still want to add something (important) to the logbook)

With this page, the user should be able to recall a particular situation and have a better overview of the baby's situation. Screenshots of the logbook page can be found underneath in figure 39.

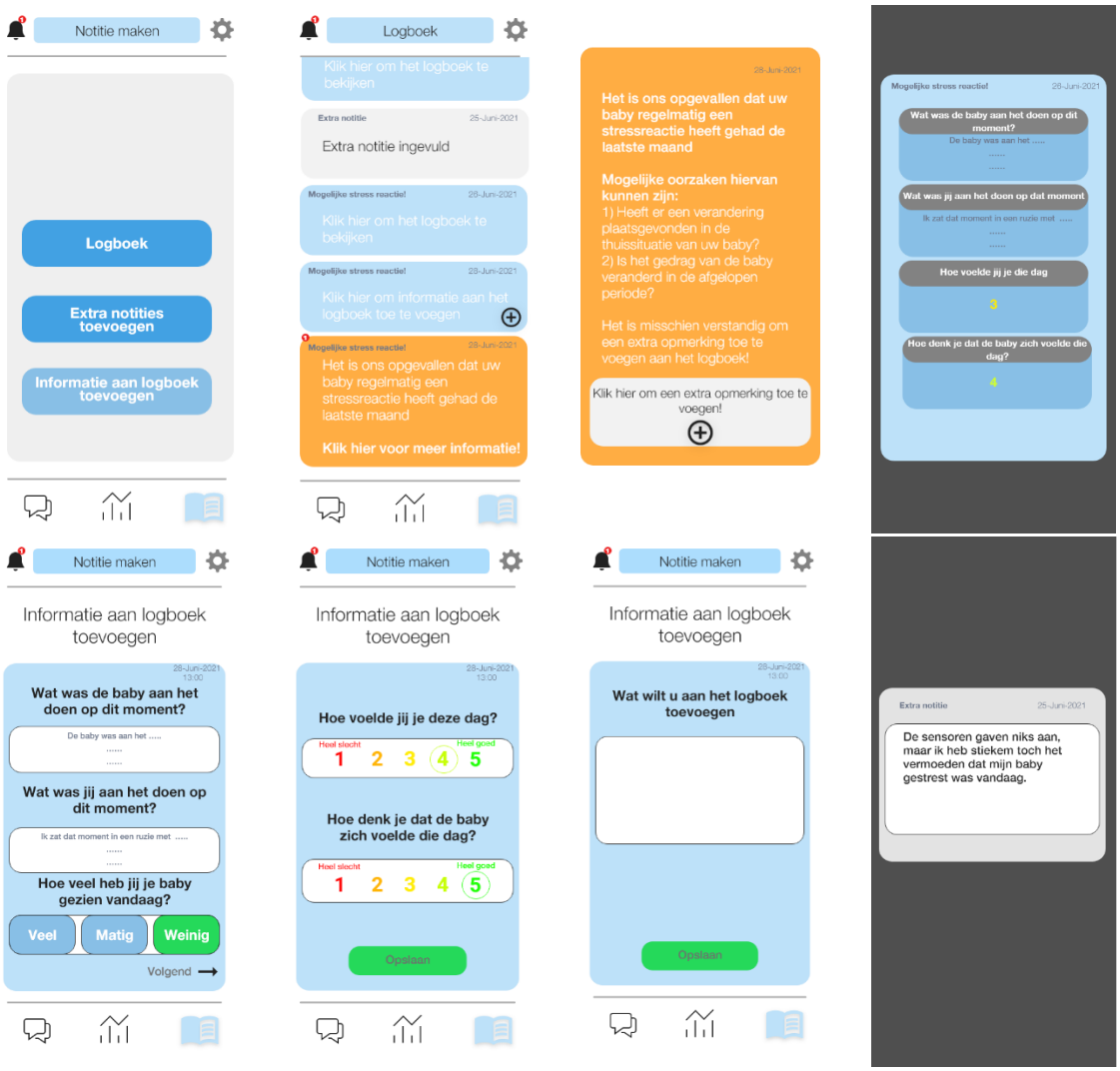


Figure 39: Screenshots of the Notifications and making notes page

Contact

This page is about being able to make contact with a professional easily. It starts by giving the option to add a certain professional the user wants to connect with or the option to simply choose for the professional the user had to contact earlier. When the specialist is chosen, the application displays various possibilities to use to make contact: option to call (not the personal phone of the professional by the work phone), to mail and to send a message. By giving this variety of options, the application should give every person a suitable option to contact a specialist.

A small summary containing the data, the method used for making contact and small notes of the meeting with the specialist (when being made) is also accessible for the user. The

user has the option to look into the previously made contact. By having this option, the user should always be able to look back to the previously made contact to prevent any possible confusion about the earlier discussed content. Screenshots of the contact page can be found underneath in figure 40.

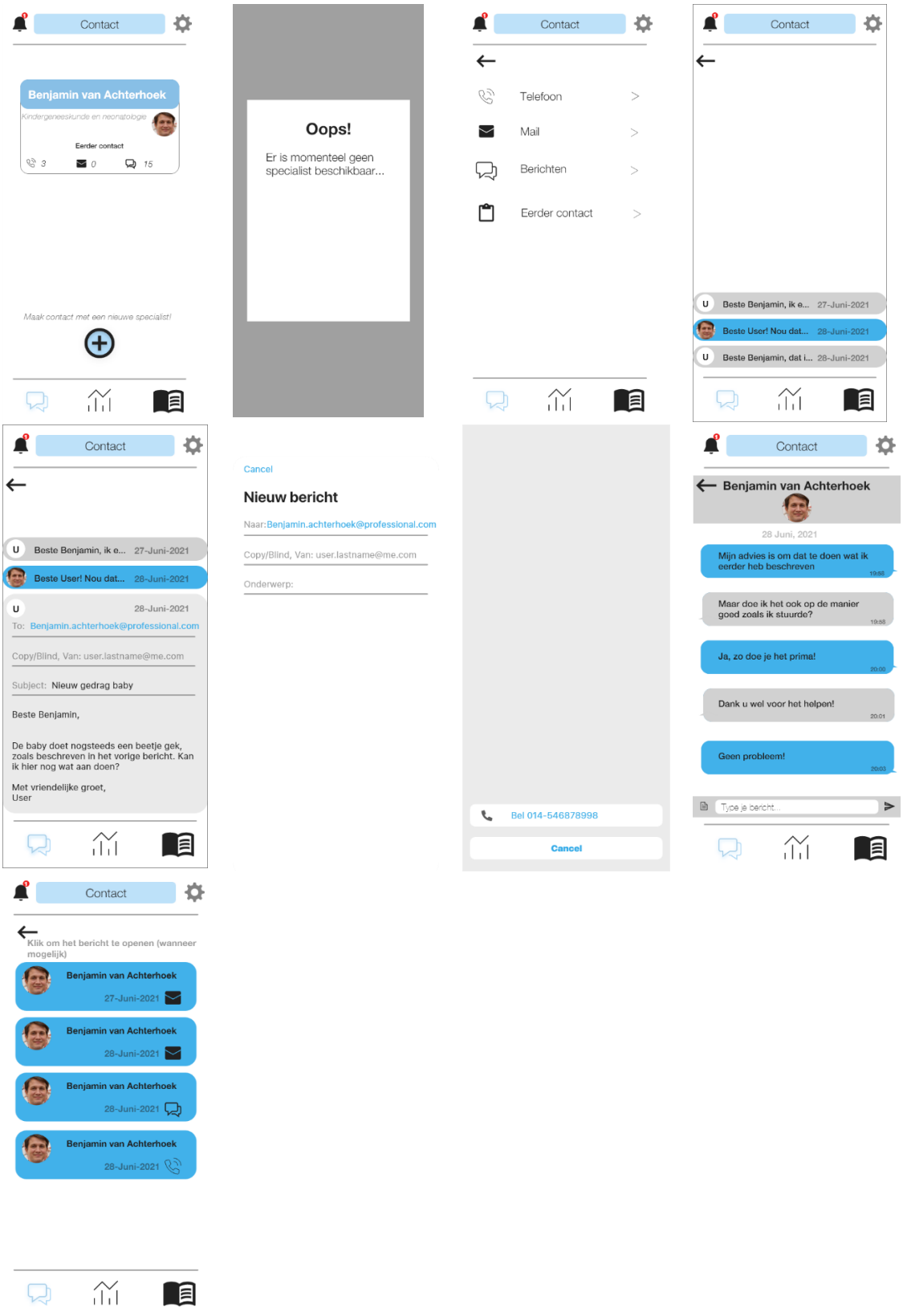


Figure 40: Screenshots of the Contact page

Settings

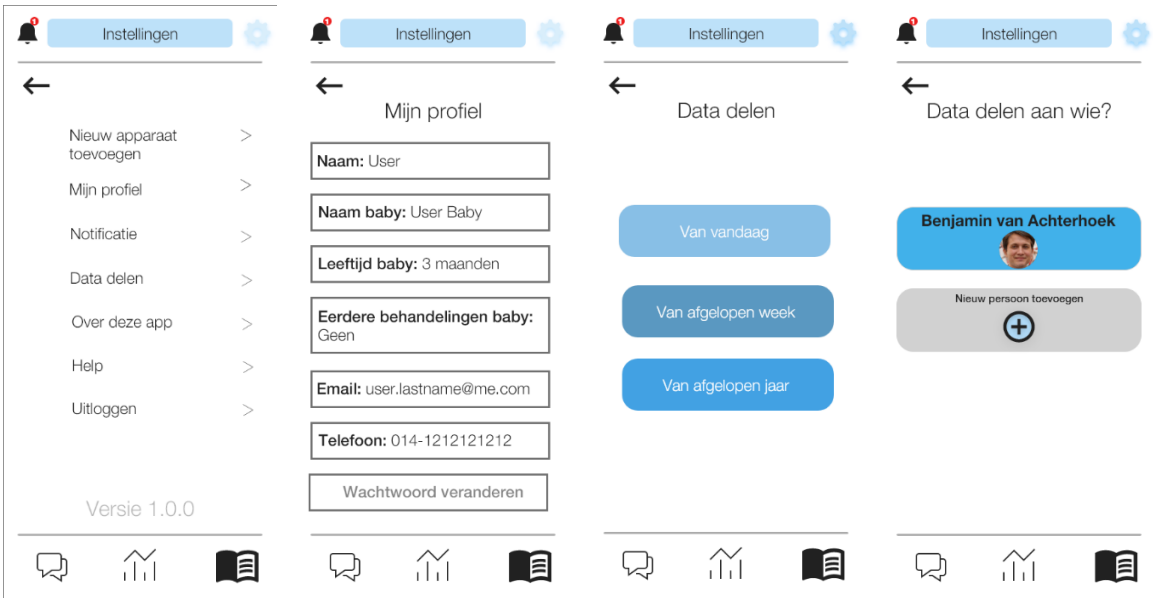
This last page of the application gives the user basic options. Adding a new device, profile, the number of notifications (per sensor), sharing data with someone else, about the app, help and log-out are implemented. Not every option is complete because of the irrelevance of working the option out in this stage of the project.

The option to highlight is the “Sharing data” option. This option gives the user the possibility to share the data of the sensors and the logbook. This option is implemented to be used in a scenario where the professional asks to see this data. When the professional is able to look into the data, it could improve the treatment. By giving the option of sharing the data of a day, a week and a year, the specialist should help the specialist not to be floated by a big amount of not useful data.

By simply giving the option in the application to share the data by Bluetooth or email, the option of sharing the data should not be too big of an effort for the user to do so.

Further, when the user clicks on the “Add new device” option, the user will be directed to the “add new device” page. The button is placed on this place because some people may find this a logical place for this option.

The screenshots of the setting page can be found underneath in figure 41.



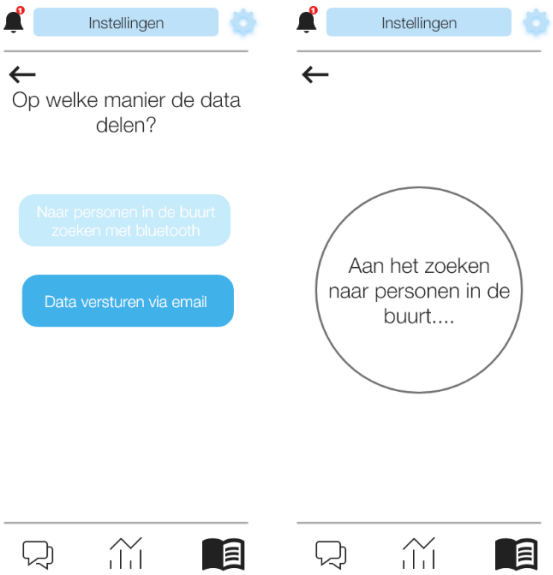


Figure 41: Screenshots of the Settings page

6.4 Final remarks on the realisation

Within this chapter, the made concept consisted of two parts; a sensor part and an application part were tried to realise. Firstly, the sensor part was realised based on the earlier made initial concept. However, not every component was implemented in the final realisation due to time constraints. This makes the realisation a little different from the initial concept. Nevertheless, the realisation is still functional and representative of the concept, making it suitable for user testing and evaluating the concept. The missing components and thus missing requirements will also be treated in the evaluation described in the next chapter. Secondly, the application is realised by using software capable of being used for usability testing. The application is made as to the described initial concept making the application ready to be evaluated In the next chapter.

In conclusion, the realisations made within this chapter representing the initial idea can now be used for user testing and be evaluated in the next chapter.

7. Evaluation

Within this evaluation chapter, the made realisations are evaluated. Two different evaluations are executed because the developed concept consists of two different parts, the sensor part and the application part. After the evaluations, it should be clear if the made realisations serve this project's purpose and thus if the (sub) research questions have been answered positively or not. Both the evaluations are examined and approved to be executed by the EEMCS Ethics Committee of the University of Twente[2].

7.1 Evaluating the sensors of the final concept

7.1.1 About the evaluation of the sensors

The evaluation of the sensors is designed to assess if people are able to place the sensors correctly on another person by using the beforehand made explanation, as shown earlier in figure 36. Further, this evaluation examines if the measured data of the evaluation could be used to detect a stress response.

The evaluation consisted of 7 participants between 19 and 25 years old**.** The participants are recruited by the use of convenience sampling. This method of recruitment was chosen because of the current limitations due to the coronavirus. The evaluation took place in the living room of the researcher. The living room was selected due to its comfortable big size and is considered a neutral environment. This place is a familiar spot for the participants to hang out, making it a comfortable room for the participants with a low chance of causing stress to the participants due to the environment, which could happen in a new environment.

Goal

As stated before, this user evaluation evaluates if people can place the sensors correctly on another person by using the beforehand made explanation and if the measured data of the evaluation could be used to detect a stress response. The evaluation consists of three parts. The first part examines the participant behaviour by asking one participant to put the sensor on the other participant by the hand of the explanation shown in the application, as seen in figure 36. This part looks if the explanation that is now being used in the application is sufficient and evaluates how much trouble the participants have by executing this task. Further, this part of the evaluation assesses the experience of having the sensors placed on the body. The requirements looked into in this evaluation are S2, S5, S11, S19, S20 and S22. Additional questions which will help the researcher to determine if the requirements are met are:

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[2] *University of Twente, Ethics Committee Computer & Information Science, Enschede, https://www.utwente.nl/en/eemcs/research/ethics/*

- Did the participant find any trouble when placing the sensor on the other participant?
- Did the participant think who has the sensor placed on his body think that the sensor module has an acceptable size?
- Did the participants think that the sensor module had an appealing design?
- Did the participant had any trouble wearing the sensor modules?
- Did the participant had any irritation on his skin during the evaluation due to the sensor modules?
- Did the participant had any trouble with the placement of the sensors?
- Did the participant had any negative experiences with the sensors during the evaluation?

The second part evaluates the sensors being able to detect a possible stress reaction of the participant. Within this second part of the evaluation, the participant is asked to sing a song to (hopefully) induce a stress response. After the participant has sung the song, the researcher asks some additional questions to better understand the participant's personal experience during the evaluation. The pulse and movement sensors will be measuring during this part of the evaluation. The gathered data will be processed after the evaluation. The requirements which will be examined in this part of the evaluation are S1, S3 and S8. Additional questions which will help the researcher to determine if the requirements are met are:

- Did the sensors measure the heart rate and movement continuously during the evaluation?
- Were the sensors able to detect a possible stress reaction?
- Did the sensors measure possible stress indicators in the form of specific changes of movement and/or heart rate?
- Did the sensors send all of the data to the micro-controller (and laptop)?
- Was the calibration time of the sensors under 15 seconds?

The last part of the evaluation executed by the researcher tests if the general requirements that involve the sensor modules' technical specifications have met the requirements. The requirements which will be examined in this part of the evaluation are S4, S6, S10, S15, S21, S26. Additional questions which will help the researcher to determine if the requirements are met are:

- Was the data accessible for the researcher afterwards?
- Was the researcher able to send the data to an external drive afterwards?
- Was the sensor integrated into a plaster kind of casing?

- Can this concept be used in various environments?

The requirements which will not be evaluated in the evaluation due to a lack of implementation or minor importance to the project are S6, S7, S9, S12, S14, S16, S17, S18, S24, S25 and S27.

Procedure

The procedure, as shown in table 21, is executed in the evaluation to maximize the evaluation results by minimizing the time it takes to execute. This procedure includes the tasks of the researcher and the participant. The material needed for this evaluation with an additional description can be found in table 20.

Number	Material	Description
1.	The sensor realisation including: 2 Arduino Nano + USB, 1 Arduino Uno + USB, 2 movement sensors, 1 pulse sensor, a few Hansaplast plasters and a few Fixomull stretch plasters.	For the measurement of the biomarkers of the participant.
2.	A laptop with the programme Coolterm installed.	To collect and store the incoming data coming from the Arduino's.
3.	Information Brochure	To inform the participant about the research and participation.
4.	Consent form	To collect the written approval of the participant to participate within the evaluation.
5.	Notebook + Pen	For the researcher to make additional notes during the evaluation and containing the interview questions.
6.	Screen 1	To display the explanation of how to place the sensors for the participants.
7.	Screen 2	To display the lyrics of the song for the participants.
8.	Phone	To record the audio during the evaluation.

Table 20: Materials used sensor evaluation

Step	Short Description	Long Description
1.	Giving the Information brochure and Consent form + setting up the pulse sensor and both movement sensors	A) By giving the information brochure and consent form, the participant can see the information about the project. The participant agrees on participating in the evaluation by signing the consent form.
2.	Describing project and the evaluation	A) The researcher explains the project, the goal of the project, its current state and the purpose of the evaluation to conduct. The participant will not have a better insight into the situation and what is expected in the assessment.
3.	Setting up the execution of the evaluation	A) The researcher makes sure to have his notebook ready, and the audio is recording.

		B) The researcher asks the participants if they have any questions. Also, the researcher states that they may always ask questions when feeling too within the evaluation.
4.	Executing the evaluation: Step 1	A) The researcher states the first task to the participants: The researcher will show the explanation, as seen in figure 36, on how to place the sensor to the other participant. B) The participant will try to place both the sensors correctly on the other participant. One movement sensor on the upper arm, one movement sensor on the calve and the pulse sensor on the forehead. C) When the sensors are placed, the participant who placed the sensor is asked to leave the room.
5.	Executing the evaluation: Step 2	A) The researcher states the second task to the participant: The participant is asked to sing a song to the researcher. The lyrics will be shown on the screen in front of the participant to help with the text.
6.	Asking the participant about his experience	A) The researcher asks the participant additional questions. The questions can be found in the appendix K: Questions of the evaluation of the sensors.
7.	Finalizing	A) The researcher let the participant know that this was the end of their participation. B) The researcher asks the participant if he has any additional questions on the project or the evaluation.
8.	End of the evaluation	A) The researcher thanks the participant for executing in the evaluation.

Table 21: Procedure used sensor evaluation

7.1.2 Results of the sensor evaluation

Underneath, the evaluation results will be discussed in the three different parts as explained above in 7.1.1. Within the various parts, the results and fitting requirements are being explained and evaluated. More explanations and the full notes of the researcher during the evaluation can be found in the appendix L: The results and notes per participant in the evaluation of the sensor part.

The first part of the evaluation assesses how well the participants could place the sensor modules on the other participant, combined with the participant's experience wearing the sensor modules. At the start of the evaluation, all of the participants were able to put the sensor modules in the prescribed area by using the explanation as shown in figure 36. By using an area instead of a certain spot, the participant may differ a little in placement when still placing the sensor correctly. All of the participants stated that the explanation about the sensors was sufficient for their needs, and in the end, all of the participants were able to put the sensor modules in the prescribed areas. However, 3 out of the 7 participants suggested extending and changing the explanation by adding more tips to the description and making the picture look more professional. Further, 6 out of the 7 participants considered the size of the sensor modules

to be a little too big to be used on babies. These participants stated that the size of the sensor should be way smaller because babies are way smaller than the now used adults. 3 out of the 7 participants suggested that they would like to see the sensor module to be between half and three-quarters of its current size. When wearing the sensor modules, none of the participants felt limited in their movement by the sensor modules. However, 5 of the 7 participants stated to be bothered by the wires attached to the sensor. The stickiness of the plaster was being considered to be very good. All 7 participants stated not having any pain or irritation on their skin when the sensor modules were being put on, during the evaluation, and when taken off. 5 of the 7 participants stated the sensor modules without the wires, as being in the original concept, to be not ugly or distracting. These participants stated the aesthetics of the sensor module to be neutral because it looks like an ordinary plaster. The other 2 participants would not say something about the design due to wires.

The second part of the evaluation looked further into the measured data of the sensors. This part of the evaluation primarily focused if the sensors can measure the indicators of a possible stress reaction. Out of 5 of the 7 evaluations, all the sensor modules could continuously gather and send the participants' data to the microcontroller (and laptop). However, in two evaluations, one out of the two movement sensors stopped recording for an unknown reason. The researcher afterwards considered that this error was caused due to a wiring problem. Further, the pulse sensor did measure continuously in all of the evaluations. However, out of the 7 evaluations, the data of only 1 evaluation can be used due to too much movement noise in the other 6 measurements. The participants' data and the feedback from the participants suggest that the pulse sensor moved on the forehead primarily due to the wires pulling on the sensor when moving the head, causing the movement noise. Additionally, the calibration time of the sensors did not take more than fifteen seconds. All in all, out of the seven evaluations, only two possible stress reactions could be concluded due to a change in the participant's movement. In these two cases, the participant stated afterwards to feel more restless within the evaluation but was unsure if he would label it as stress. In the other five cases, the participants said not to be stressed during the evaluation. In these situations, the general movement of the participants also stayed the same. The pulse sensor data was only once being considered to be acceptable to be used in the evaluation of a possible stress reaction. Because of this small number, the researcher cannot make conclusions on the performance of the pulse sensor in measuring a possible stress reaction.

The third part of this evaluation is mostly focusing on the performance of the sensor modules. To start with, the data measured by the different sensors were easily accessible for the researcher afterwards. Additional, the researcher could also easily send the data to another location, such as an external drive. However, the concept as realised in this research cannot be

used in various environments. Due to exposed electronics and the need for electricity and a laptop, the only suitable environment for using the realisation would be near the laptop in a dry environment. At last, the components used in the realisation are very cheap, and all of the components, except the plaster, which needs to be changed after every two or three placements on the body, can be used multiple times, making it not very expensive to buy.

7.2 Evaluating the application

7.2.1 About the evaluation of the application

The evaluation of the application is designed to assess the application's functionalities and design combined with examing the user's behaviour within the application. At first, participants were selected based on the target group, parents to which the baby has experienced stress problems. However, it was eventually not possible to reach this group. Therefore, the evaluation is conducted with two specialists in the field of infant mental health and one specialist in the field of making applications for the health care sector. The first two specialists were chosen because they work with the parents' target group and better understand this group's needs and thoughts. The other specialist was selected because of his experience with designing medical applications for parents. This specialist also has a better view of the needs and thoughts of the parent's target group and a better view on making applications for this specific group.

Due to corona regulations, the evaluations were conducted through an online platform called Zoom [79] for communication and a web browser for using the application. During the evaluation, the audio of both the researcher and participant was recorded combined with a video recording of the participant using the application. Also, additional notes were made by the researcher on the paper. The data captured during the evaluation will be stored on a secured local storage device located at the host temporary, and in the end, the data will be stored in a university-approved location, making it only reachable for the researcher. Also, the data of the participants will be stored anonymously to protect their identity.

The evaluation includes the specialists asking the specialist to execute specific tasks within a certain scenario in the application by using the thinking aloud method [100]. This will test their behaviour and thoughts when using the application. Later after the execution phase, questions are asked to capture their experience and additional thoughts. The semi-structured interview method is chosen to make sure the needed information is collected during the interview. This type of interview is also decided to go deeper into a specific subject when expected to be more helpful for the evaluation. The specific methods and materials used for this evaluation are described in the procedure, stated underneath in table 22 and 23.

Goal

As stated before, the evaluation is executed to assess the application's functionalities and design combined with examing the user's behaviour within the application. The evaluation is subdivided into four different parts. Each of these parts will be described underneath.

In the first part of the evaluation, it is examined whether the application is intuitive to use. The participant should be able to manoeuvre their way through the application easily by using the different icons and buttons and, therefore, should not have a lot of trouble achieving the goal of their action(s). Having an intuitive application prevents the user from getting annoyed and demotivated for using the application. The requirements which will be examined in this part of the evaluation are A8 and A19. Additional questions which will help the researcher to determine if the requirements are met are:

- Was the participant able to reach their goal within the app by using the route designed by the researcher?
- Did the participant find the application intuitive to use?
- Were all of the icons intuitive for their cause, according to the participant?
- Were there certain pages that were not intuitive to guide through?
- Where certain design elements In the application not intuitive (for example, due to colour or placement)?

The second category evaluates the quality of the built-in functionalities of the application combined with having the right number of features and giving the right amount of feedback to the user. An overall goal of the application is to give the parents the right amount of feedback on the sensors combined with the possibility of easily making contact with a specialist when needed. The built-in features are based on these goals. With the evaluation results, the researcher should better view if the application's amount of features are fulfilling its cause. For example, there could be too many features within the app, making the features only distracting without being useful. Also, the features implemented within the application could have been needed following the parents' advice but designed in the wrong concept, making it unsuitable for the application. At last, the application could also lack some features that the parents may consider imported. The requirements which will be treated in this category are A1, A4, A10 and A12. Additional questions which will help the researcher to determine if the requirements are met are:

- Did the participant find features superfluous to reach the goal of the application?
- Did the participant find features missing to reach the goal of the application?
- Did the features serve the purpose for which it was designed for?
- Did the participant find the amount of feedback/graphs sufficient to their needs?

- Did the participant found something not clear regarding the feedback/graphs?
- Did the participant find the number of contact options (including sending the data) with a professional sufficient to their needs?
- Did the participant find the effort to make contact with a specialist sufficient to their needs?
- Did the participant find it hard/too much work to fill in the information in the app?

The third category evaluates the general design of the application. The application now is designed to be as neutral as possible. No parent should be discouraged to use the app because of the design. For example, the application is now using negative feedback, which may be the wrong kind of feedback to the parents. Further, the use of colours and other design choices may be addressed. The requirements falling in this category are A5, A14. Additional questions which will help the researcher to determine if the requirements are met are:

- Did the participant find anything distracted by the UI of the application?
- Did the participant find anything distracted by the used feedback method of the application?

The last category is the general impression of the application. This category is discussed with the user to see if the application in their eyes the application achieves its purpose and get a better insight into the user's privacy issues. The requirements falling in this category are A2, A3. The questions to help determine if the requirements are met are:

- Did the participant think the application serves its purpose?
- Did the participant think it is a problem to make an account for the application?

The requirements that are not stated above to be evaluated in the evaluation are not considered significant enough to test in the evaluation or were not implemented in the application. These requirements are A6, A7, A11, A15, A17, A18.

Procedure

The procedure, as shown in table 23, is executed in the evaluation to maximize the evaluation results by minimizing the time it takes to execute. This procedure includes the tasks of the researcher and the participant. The material needed for this evaluation with an additional description can be found in table 22.

Number	Material	Description
1.	A latop connected to the internet with the installed programms: - Zoom - OBS - Webbrowser such as google chrome	For the measurement of the biomarkers of the participant.
3.	Information Brochure	To inform the participant about the research and participation.
4.	Consent form	To collect the written approval of the participant to participate within the evaluation.
5.	Notebook + Pen	For the researcher to make additional notes during the evaluation and containing the interview questions.
8.	Phone	A backup device is recording the audio during the evaluation.

Table 22: Materials used application evaluation

Step	Short Description	Long Description
1.	Describing project and interview	A) The researcher sends the information brochure and consent form to the participant by mail. The participant can see the information about the project once again. B) The participant agrees on participating in the evaluation by signing the consent form and sends the signed form back to the researcher.
2.	Giving the InformationBrochure and consent form + setting up the application	A) The researcher explains the project, the goal of the project, its current state and the purpose of the evaluation to conduct. The participant will not have a better insight into the situation and what is expected in the assessment.
3.	Setting up the execution of the evaluation	A) The researcher makes sure to have his notebook ready. The audio is recording on the phone, the application link is sent to the participants, and OBS records the application's video. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) The researcher asks the participants for having any questions and states that the participant may always ask questions when feeling too within the evaluation.
4.	Executing the evaluation: Step 1	A) <u>The researcher states the first scenario to the participant:</u> The participant has just purchased two types of sensors to be connected to the application. It is asked to pair

		these sensors with the application and to view the live feed. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) When the participant is eventually unable to complete the task, the researcher helps the participant completing the task.
5.	Executing the evaluation: Step 2	A) <u>The researcher states the second scenario to the participant:</u> The participant has received a notification of a possible stress reaction that day. It now wants to see what is meant with the notification and when the notification is sent. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) When the participant is eventually unable to complete the task, the researcher helps the participant completing the task.
6.	Executing the evaluation: Step 3	A) <u>The researcher states the third scenario to the participant:</u> The participant has questions about the application results and wants to get a specialist's feedback. The participant tries to make contact with a specialist. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) When the participant is eventually unable to complete the task, the researcher helps the participant completing the task.
7.	Executing the evaluation: Step 4	A) <u>The researcher states the fourth scenario to the participant:</u> The participant noticed that a possible stress reaction occurred today. The participant wants to know in which period the possible stress reaction occurred. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) When the participant is eventually unable to complete the task, the researcher helps the participant completing the task.
8.	Executing the evaluation: Step 5	A) <u>The researcher stated the fifth scenario to the participant:</u> The specialist asks if the participant may send the data to the caretaker. The participant tries to do so. B) The participant tries to complete the task by using the thinking aloud method as described in Chapter 3. C) When the participant is eventually unable to complete the task, the researcher helps the participant completing the task.
9.	Asking the participant about the experience	A) The researcher asks the participant additional questions in a semi-structured interview about the experience of using the application. The beforehand made questions

		can be found in the Appendix N: The questions of the application evaluation.
10.	Finalizing	A) The researcher lets the participant know that this was the end of their participation. B) The researcher asks the participant if still having any additional questions on the project or the evaluation.
11.	End the evaluation	A) The researcher thanks the participant for executing in the evaluation.

Table 23: Procedure used sensor evaluation

7.2.2 Results of the application evaluation

Underneath, the evaluation results will be discussed in the three different parts as explained above in 7.2.1. Within the various parts, the results and fitting requirements are being explained and evaluated. More explanations and the full notes of the researcher during the evaluation can be found in the Appendix O: The results and notes per participant in the evaluation of the application.

The first category, intuition, gathered roughly the same results between the different participants. Two of the three participants found the application intuitive to use, where one participant was not sure if he found the application intuitive to use. The biggest complaints about navigation through the application were the missing function of not always being able to go back to the previous step and at certain points and the not always logical designed paths to use. For example, which was stated by 2 of the 3 participants for being not logical, is not being able to go directly to the statistics page by clicking on a certain message/note in the logbook.

All of the participants stated, in general, not having great difficulty going to a particular function within the application. This prevented any frustration caused by using too much effort to complete the task. Although, one participant was not able to execute one scenario out of the five scenarios due to an unlogic path to follow, as stated by the participant.

The process within the application of connecting the sensor to the application is positively received by all of the participants. However, it is suggested to change the image of the baby to a small video of someone putting the sensors on the baby to make the explanation more clear and personal. Also, one participant suggested extending the amount of text within the explanation to make the explanation more understandable. Further, the waiting screen when connecting the sensor is highly appreciated by every participant. Having the confirmation about having the sensor placed and connected is being considered very important.

In addition, the general navigation through the application went very well in the evaluation. However, the path of going from the logbook page to the statistics page needed more time for the participants to find. One participant was even not able to do so. Also, two participants did not directly find the showing different time frames option on the statistics page.

Further, for the logbook page it is suggested to have the newer notifications on top and the older notifications at the bottom. The participants were intended to read from top to bottom, so they preferred a change in placement.

The second category, having the right number of features implemented in the application and giving the user the right amount of feedback, is also evaluated almost with the same results by the different participants. The option of being able to choose a different amount of notifications within the application is highly appreciated. The visualisations of the sensor data and the mood of the baby and parent was clear for the participants. However, the design could have been made more appealing when further being developed in the future. Further, having the logbook and additional notes within the application was considered nice to have. It does show the situation of the baby more elaborately for the parents. However, the specialists were not convinced that the notes will always be going to be filled in by every parent. It is considered that most parents where the baby is diagnosed having regular stress reactions are more tended to fill in the notes than other parents. The functionality of being able to contact a professional directly through the application was considered to be a valuable functionality. It was considered a good thing to have multiple methods available to contact the professional, but it was questioned if there is a significant benefit of being able to email and being message the specialist. One participant suggests that one of these two options can be removed. The 2 participants whose expertise lies in the mental health of infants highly appreciated having the option of sharing the data of the application directly to a specialist. They think that this could improve their treatment with the parents and baby.

The third category, the general design of the application, is primarily being evaluated as sufficient. The colours used in the application are neutral and serve their purpose. However, the professionals like to see a bit more fine-tuning when the application is being developed later on. Also, it was suggested to use a different colour in the logbook for the messages of possible stress reaction when the additional notes to this stress reaction are not filled in yet. The icons used in the application serve their purpose.

The fourth and last category of the evaluation, the general impression of the application, was received very well in the evaluation, with a few additional notes suggested. First, all of the participants think that the application as designed now serves its purpose. It is considered that the application is a good tool to use by and help the parents with the possible stress reactions of their baby. Further, having to make an account to use the application was not considered a problem for each participant. When further developing the application, the first functionality suggested to implement is designing the application to be used by both parents, each having their own account. This means that the logbook and data are shared, but both parents can use the

application separately. This functionality could be very valuable for situations when one parent is with the baby and the other is not. At last, one specialist suggested adding tips to certain situations within the application. Giving the parent tips to solve a potential problem of their baby would help the parents before contacting a specialist or searching on the internet for information. This makes the problem solved with more ease and faster and lowers the demand for specialists.

7.3 Concluding the evaluation chapter

This chapter includes two evaluations. The first evaluation evaluates the concept's sensor part, and the other part evaluates the application part. Due to corona, the evaluations were not conducted in the most conventional way, making the evaluation more difficult. However, both evaluations can be used to conclude if the research question can be answered. This full conclusion of the research can be seen in the next chapter. Underneath, the conclusions of both the evaluation parts are shown.

In conclusion of the first part of the evaluation, the realisation is, for now, a good start in the development of building a (sensor) device able to measure possible stress reactions. However, a lot of work still needs to be done to be able to use the realisation in real-life scenarios. About half of the made requirements are met. Most of the met requirements have to do with placing the sensor modules correctly and non-functional design issues. For example, the evaluation showed that it is easy for the participants to place the sensor modules on another person's body in the right location. Both the movement sensors were also rightfully placed by the participants to be able to measure correctly. And the general design and aesthetics of the sensor were sufficient enough for most of the requirements. However, the other half of the requirements that are not met include some important requirements needed to be used in real-life scenarios. For example, the device cannot be used in various environments. For example, within the evaluations, the sensor modules could, most of the time, not evaluate a possible stress reaction of the participant.

Concluding the second part of the evaluation, the concept application was positively received in the evaluation. The application, in general, serves the purpose it was designed for. Almost all of the more important requirements of the application were met following the design and evaluation of the application. It is considered to have great potential for further development. However, there are still numerous requirements that can be improved. For example, the general intuition of the application is being considered as something good, but there are still things to be changed to make this intuition better. The same goes for the design and logbook. The amount of feedback and the method of giving feedback was also well received but now relies strongly on an active parent willing to use the application actively. This could form a problem for some generally passive parents. The functionalities implemented in the application is

being considered sufficient but could be extended later on in further development. Following the evaluation, the most important (must-have/ should-have) requirements of the application are met.

All in all, the application can be concluded to be a great start in developing the actual application and seen as an answer to the fourth sub research question of this research *"How can current technology help notifying caretakers about the baby having a stress reaction(s)".* However, with the not fully functional working sensor realisation combined with the application still being in the development stage, the main research question *"Which unobtrusive device can monitor the stress level of children between 0-12 months and thereby notify the stress indicators of the children to the caretaker(s)."* is only partially answered. Both realisations, making the full concept, have the potential to answer the research question, but this is not proven within this research and so cannot be concluded to be the answer to the main research question.

8. Discussion & Future Work

8.1 Discussion

The topic investigated in this research seems to be at the fairly beginning of its exploration. Where multiple pieces of research treat stress on adults, the topic of stress on babies seems to be just getting started. There is still a lot of knowledge to gain and researches to execute to get more insights into which causes (toxic) stress on babies and which can be the solution.

This research tries to answer the problem of (toxic) stress related to babies. By not having the babies able to talk about their problems and feelings combined with their great vulnerability, they seem to be a challenging target group to work with. Assessing different methods to tackle the problem and discussing the problem is now mostly done by questioning the environment around the topic. This makes the answers to be very vulnerable to the bias of the environment. The environment does not always have the intention of answering the questions biased. However, with every person being different and experiencing the situation differently, it can be very hard to estimate the situations and thoughts of the investigated baby. Also, which makes researching the group of babies very difficult is, as already stated above, the vulnerability of the group of babies. Having the babies in the stage where the biggest developments happen when being at the most vulnerable stage of their life can bring some major problems when investigating this group. As said earlier, the babies cannot talk to the environment and can thus not state if something makes their situation worse or not. This group is not able to protect itself in situations when needed. When babies are being researched, the researcher researching the babies should be very sure about their methods and tests, even more than researching adults. The time it acquires to validate the research's importance, and safety can be very time-consuming. By needing multiple ethical checks by other committees and other involved specialists makes researching babies instead of adults a little demotivating. Within this research, the group of babies are used to be used in any kind of testing. However, the situation around babies and the situation regarding stress on babies are thoroughly researched.

The first two sub research questions are stated to answer the situation around the baby having a stress reaction. Hereby, the difficulty of this project is being emphasized by finding out the great variety of stressors combined with every baby reacting differently to these stressors. By answering these two sub research questions, It is found that, in general, the parents have the most considerable influence on the stress reaction of the baby, being the biggest influence on the stressors. However, the research could not primarily focus on this particular group because of the earlier explained diversity of stressors and personal experiences. This research should focus on how to measure the babies having the stress reaction over which method could find a possible

stressor within the baby's environment. The emphasis of the research should look at how to measure the body adaptions of the baby—for example, the increased heart rate, changes in movement and increased cortisol level.

By looking into the state-of-the-art and answering the third research question, it is found that a lot of the techniques to measure the various biomarkers of the stress response are already developed. However, most of these techniques are not targeted to be used on babies and are not marketed to be able to measure the stress response. In the end, it is concluded that the techniques that are more suitable for this project to measure the stress response and to be able to validly the stress reaction would be techniques able to measure the heart rate, change of movement, and an increased cortisol level. The heart rate and movement change are chosen because, following earlier research, these biomarkers are most likely to be changed in the stress response combined with their, as seen in the state-of-the-art general easy implementation within a product. Measuring the cortisol level was chosen because of the stated great capability of validating the baby's stress response. However, measuring this cortisol biomarker in a convenient way where a specialist does not have to help to get the results is questioned. It is seen that the best way to do so is a plaster(s) capable of doing this cortisol measurement without the help of other specialists. However, the plaster is just being developed at a university in another country.

After the background research was completed, a concept was developed consisting of two different parts. The first part consists of sensors three sensors able to measure the movement and the BPM of the participant. The second part is an application applying feedback to the parents on the situation regarding the baby's stress.

Within the realisation of the first sensor part, it became clear that the needed cortisol sensor was not going to be implemented due unavailability of the sensor. Nevertheless, the sensor was replaced by another movement sensor. Not having the cortisol sensor meant that validating the possible stress response would be less reliable due to falling away biomarkers to measure. However, it still was considered to be sufficient enough to be tested in the evaluation. The second application part was built as a concept. This meant that the application could not be used on the phone (which it was designed for) but was still able to be usability tested. This is not seen as a big limitation within this project because this research aims to not deliver a final product that can be brought to the market. However, this still means a lot of time and effort are asked when the application is developed to be brought on the market.

The evaluation of both the realisation did come with a few limitations. To start with, both the realisation could not be tested by the target group which is supposed to use the realisations. For the sensor part, this would mean the babies, and for the application part, it would be the parents whose baby is having stress-related issues. Due to ethical considerations combined with

time constraints and difficulties brought to the corona situation, it is eventually chosen to test both realisations with representative groups. The danger of using representative groups is that even if these groups are labelled as a representative, these groups may still give different results than the actual target groups of the research. As the target group is eventually not reached within this research, it is not certain which results may differ from when having tested on the actual target groups.

The first sensor realisation should be able to detect a possible stress reaction, following the literature. However, the evaluation of this part did eventually come with inconclusive results. It was considered to have picked up a few changing biomarkers indicating a stress reaction in just a few cases. Using participants who are close to the researcher made it very difficult to induce a stress reaction on these participants. This made the evaluation far more difficult resulting in less usable results. Also, because the eventual realisation was not containing all of the aspects of the previously stated concept, only a part of the sensor concept could be evaluated.

The second application realisation included the most important aspects stated in the earlier made concept of the application. The application thereby was a very good representation of the initial concept. However, also this application was not tested on the stated target group, as stated before. By having specialists working with the target group, it is assumed that the specialists were able to speak the opinion and thoughts representative to the parents' target group. However, this specialist group could subconsciously give biased answers to the questions because of their involvement in the situation. Where this seems to be not a very significant limitation, it could definitely influence this research.

All in all, this research was able to answer the research's subquestions but not the main research question. This research gives researchers a good foundation for future research and plenty of room to further develop the concept(s) described within this research and to develop new concepts.

8.2 Future Work

First, as earlier described, this research sets a base for further development to a concept that can detect and send the stress level of a baby to a caretaker. In this research, many different stress indicators and possible methods to measure these indicators are stated. However, It is advised for future work to look again into these topics because of the ever-changing new findings on these topics. The topics are fairly new, and a lot still needs to be researched and found on this topic. Gathering new information could lead to new and potential better views on solving the problem.

Secondly, within this research, the realisation of the concept lacks its full potential. Some components are not used, such as the cortisol sensor and wi-fi module, leading to unmet requirements. Future work should learn from this. This research has attempted to use the components in the concept idea for a reason. Therefore, it is strongly advised for future work to look into why these components are tried to be used within this research. There could be a chance that, apart from the actual realisation of this project, the components could be useful in their situation. Also, within the evaluation, the main concept is being considered good, but some functions are missing, such as the tips page and the lack of a few back buttons. When developing a similar application in the future, it is advised not to start over again but to look at the main concept of the application and try to solve the flaws found in the evaluation of the application and implement this in your application

Thirdly, within this research, it was not possible to evaluate the concept on the most important target groups within the context of the problem. By testing the concept to an on-paper representable group, there is a chance of not getting the same results as when being tested on the actual stakeholders' group. It is strongly advised for future work to evaluate the made concepts on the group of babies and parents to get a more reliable research result. Also, it is advised to test the concept in a more representative context for the problem. Within this research, it was not possible to properly test the realisation in the context of the problem. Testing the device in a real-life context could bring much more results and concluding remarks to the made concept.

Finally, this research is executed in a time span of roughly half a year. Within this period, the researcher had to research the situation, ideate, realise the concept and evaluate the concept. Due to the big size of the topic, it is advised by the researcher to execute similar research over a longer period. It is expected that research would bring far better results when being executed for a year or even longer. There would be far more time to go more into depth into the literature and develop the made concept further.

9. Conclusion

The problem of babies having to deal with toxic stress is the cause of executing this research. In the present day, the used methods to solve this problem are not considered the solution to the problem. Therefore, this research attempts to solve the problem by developing a device that can detect and send a babies' stress level to the caretaker(s). The research question for this research is stated as:

"Which unobtrusive device can monitor the stress level of children between 0-12 months and thereby notify the stress indicators of the children to the caretaker(s).".

The sub research questions are*:*

Sub research Question 1:	*"What are the known stressors of children between 0-12 months."*
Sub research Question 2:	*"What is the influence of the environment on the stress of children between 0-12 months."*
Sub research Question 3:	*"What are the best possibilities of using state-of-the-art technology to measure the stress indicators of children between 0-12 months."*
Sub research Question 4:	*"How can current technology help notifying caretakers about the baby having a stress reaction(s)."*

At the start of the research, the current situation of the problem is investigated and defined. It is concluded that a stress reaction in itself is not a bad thing. However, a frequent appearance of stress over a more extended period could have some profound negative influence on the current and future life of the baby. This regular body adaptation to a picked-up possible dangerous situation leading to a stress reaction could cause both physical and mental problems. In addition, as the baby's stress response is activated due to a change in the environment around the baby, it is found that the parents are, in all probability, the biggest influences on the number of stress responses of the baby. In ideal situations, the parents help the baby deal with stressful situations. However, there are also situations where the parents cause stressful situations for the baby (against their knowledge). A baby's sensitivity to a stressful situation leading to stress response, and the stress response itself differs per baby depending on personal experience and background. This can make measuring the stress response and thereby assessing a stressful situation of the baby difficult. The biological response combined with the current methods is researched to better view the possibilities of detecting the stress response. It is concluded that there are already many methods and techniques capable of detecting a baby's stress response.

Although, most of these devices are not designed to do so or are not proven to be effective. However, it is concluded that the best measurement techniques to detect a stress response consists of measuring the heart rate, brain activity, and movement.

After using the background found on the topic combined with personal creativity and evaluation with specialists, it is assumed that the best concept capable of solving the research question would be a concept where sensors attached on plasters measuring the movement, heart rate, and cortisol. After realising this concept, where it was eventually impossible to build the concept exactly as stated in the ideation phase, multiple participants still evaluated it. The evaluation assessed that the concept generally lays a good foundation for further development, but the main research question is not answered. The sensor part of the realisation misses multiple important requirements, failing to prove its capability to measure a possible stress reaction. Further, the application part of the evaluation did show that the application met almost every requirement, which seems to imply the application to be a success. However, as the application cannot be used in the real world, the application only serves as a good foundation for future work.

In short, the made realisations within this research are not capable of solving the main research question. However, all of the sub research questions are answered within this research, which can serve as a good foundation for future research on this topic.

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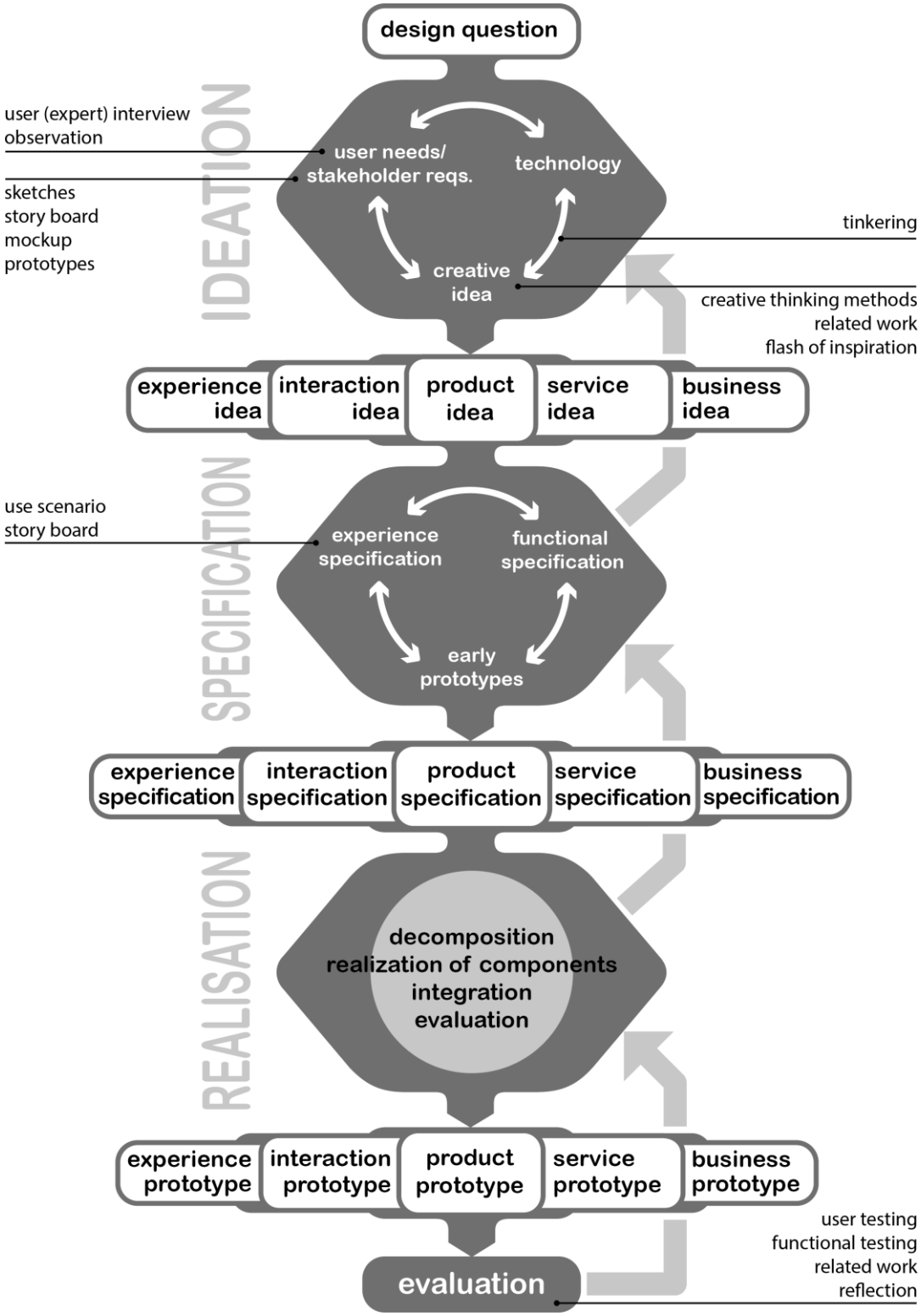
Appendix A: A design process for creative technology



Appendix B: Consent form interview specialists about the different ideas

Consent Form:

How High Is the Stress Level?

About the project and participation

Dear reader,

I would like to inform you about the research you have applied to participate in.

This research aims to develop a device that can objectively measure the stress level among babies by using current-day technology. With this device, the babies' environment should be able to detect the stressors of the baby and thereby be able to control the stress level of the baby. This device gives the caretaker the possibility to remove the babies' stressors when needed and prevent long-term effects from the babies caused by (toxic) stress.

This interview with you, the specialist, is planned to discuss multiple ideas made earlier by the researcher to discuss the best ideas to develop this device. Also, new ideas coming from the specialist are discussed. These new ideas may extend the possibilities of the researcher when designing the device. When the current and new ideas are not favoring the specialist, a conclusion is made to set a step back in the ideation phase and first come with new ideas.

The interview will be held once in an online environment such as Microsoft teams or Zoom. The interview will approximately take 30 minutes and is completely voluntarily to all the parties involved. A stable internet connection between the participant and researcher is required. The participant will beforehand fill in a consent form given by the researcher, which will be valid until 48 hours after the participation in the interview. Before these 48 hours, the participant may decide at any moment to withdraw his/her consent. The consent can be withdrawn at any moment during and after (until 48 hours) the research by the participant. The participant can ask questions about the research at any moment during and after the research. This information will always be provided to the participant when possible, except for the personal data of other parties involved in the research.

Data usage

During the interview, an audio recorder will record the voices of the participant and the researcher, which will afterwards be saved and written down on paper to get a clear overview of

the interview. The researcher will also make additional notes during the interview where additional reactions of the interviewee will be noted, such as facial expressions, with the intention to capture unintentional reactions from the interviewee on the information brought by the researcher. Own interpretation of the researcher within the researcher's data collection will be labelled to prevent any miscommunication about what is said during the interview by the participant. All data collected from the participant will be labelled as "the specialist" to keep the participant's identity anonymously. All data collected during the interview can be used at any moment in this research by the researcher.

The data collected in the interview will be analyzed and processed by the researcher within the researcher's Bachelor thesis. The data will only be used within this graduation report on behave of the University of Twente. The results of the research may be published on the website of the University of Twente and in other research papers from other researchers. The research results may also be used by companies who are interested in developing the device in this research.

The researchers of the project are the only persons who can access the collected data. The data will be stored on a local storage device located at the host temporary, and in the end, the data will be stored in a university-approved location. All data will be saved anonymously to protect the identity of the parties involved. The storage of the data will proceed as described by the AVG guidelines. Following these guidelines, the data will be stored over a time span of 10 years. After these ten years, the researcher may choose to delete the files. When other parties request data of this research, including the participant's involvement, the researcher will only share the data when having permission from all parties involved.

Within 48 hours after the interview, the participant may ask to delete his/her data collected and processed during the research. The data and results will thereby be erased as soon as possible and not be used or mentioned within the research. If, after 48 hours, the participant asks to delete the information, the request will be declined, and the data collected can still be used within the research.

Informed consent form

I hereby declare that I have been informed in a manner that is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. Parts of the interview can be quoted where only your function will be mentioned. I agree with my own free will to participate in this research.

I reserve the right to withdraw this consent without the need to give any reason, and I am aware that I may withdraw from the experiment at any time.

I agree to my interview being audio-recorded. Additionally, I agree that an anonymized transcription of the whole interview can be added as an appendix to the research. If my research results are to be used in scientific publications or made public in any other manner, they will be completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact the main researcher Sven Bormans or his supervisor Randy klaassen.

Contact information:

Researcher:

Sven Bormans - *Bachelor Creative Media*

Technology Student, Main researcher

s.r.bormans@student.utwente.nl

Supervisor:

Randy Klaassen – *Assistant Professor Human Interaction, Project supervisor*

r.klaassen@utwente.nl

Suppose you have any complaints about this research. In that case, you can direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethics-comm-ewi@utwente.nl).

Signed in duplicate:

…… ……

Name participant Signature

I have provided explanatory notes about the research. I declare myself willing to answer to the best of my ability any questions which may still arise about the research.'

…… ……

Name researcher Signature

Appendix C: Information Brochure interview specialists about the different ideas

Informatiebrochure:

How High Is the Stress Level?

Dit project vanuit de Universiteit van Twenten in samenwerking met ZGT en IMH Nederland genaamd “How high is the Stress Level?” zal onderzoeken welke mogelijkheden er bestaan omtrent het meten van stress onder baby’s doormiddel van het gebruik en combineren van hedendaagse technieken.

Een stress reactie onder baby’s kan door vele factoren in hun omgeving geactiveerd worden. De factoren die deze stress reactie activeren zal verschillen per baby en de omgeving. Wanneer deze factoren niet worden gevonden en/of hiermee niks wordt gedaan en hierdoor het stress niveau van de baby aanhoudt over een langere periode, kan dit negatieve gevolgen hebben voor de ontwikkeling van de baby zichtbaar voor de rest van hun leven.

Op dit moment hebben de onderzoekers van het project al onderzoek uitgevoerd en ideeën ontwikkeld die in hun ogen bruikbaar zijn voor verdere ontwikkeling binnen het project. Echter, zouden de onderzoekers de verworven informatie en gemaakte ideeën eerst willen bespreken en te evalueren met een deskundige in het vakgebied. Dit als advies en extra validatie betreft de relevantie en potentie van de gemaakte ideeën.

Het gesprek tussen de onderzoekers en de expert zal gaan over de ervaringen en expertise van de deskundige gelinkt met (toxic) stress bij baby’s. Verder zullen verschillende meetmanieren en de gemaakte ideeën besproken worden. Doordat de professioneel veel kennis zal hebben vergaard in de afgelopen jaren zal deze potentieel goede suggesties en toevoegingen kunnen leveren op de gemaakte ideeën.

In deze informatiebrochure zal in het kort het project “How high is the stress level” worden besproken met daaruit alle nodige informatie omtrent de participatie in het project. Dit bedoeld, om u te helpen in uw keus van deelname in dit onderzoek.

Deelname

De deelname in dit onderzoek is geheel op vrijwillige basis. De tijdsduur van het interview is geschat op 45 minuten maar kan hier van afwijken. Voor het interview zal u deze informatiebrochure met een consent form toegestuurd krijgen ter informatie van de deelname.

Wanneer de consent form is ingevuld, en u dus akkoord bent gegaan met uw deelname, kunt u uw consent nog terugtrekken tot 48 uur na het interview. Het terugtrekken uit het onderzoek kan op elk mogelijk ogenblik voor het interview, gedurende het interview en 48 uur na het interview. Elke mogelijke reden die u opgeeft om te stoppen zal voldoen om te kunnen stoppen.

Interviewprocedure

Het interview zal online plaatsvinden op het platform Microsoft Teams of Zoom, welke van deze twee zal vooraf naar u gecommuniceerd worden. De link die nodig is om te kunnen toetreden zal uiterlijk een dag vooraf worden toegestuurd door een van de onderzoekers. In het begin van het interview zal door de interviewer vragen worden gesteld omtrent mogelijke grenzen die u wilt opstellen. Dit houden onderwerpen in die waar u gedurende het interview niet over wilt hebben. Nadat de grenzen voor beide partijen duidelijk zijn zal de interviewer vragen naar de ervaringen van de professional van de door de professioneel gebruikte technieken en ervaringen aangaande de baby's met (toxic) stress. Hierbij wordt ook gevraagd welke technieken u gebruikt die u helpen in het vaststellen van een prognose bij een baby**.** Hierna, zullen verschillende meettechnieken die stressindicatoren van een baby kunnen meten worden besproken en geëvalueerd. Hierop wordt specifiek gevraagd of de specialist enige voor- of nadelen weet of heeft ondervonden bij het gebruik deze technieken (of van iemand in de omgeving). Misschien heeft de expert al enige voorkeuren voor een bepaalde techniek door een bepaalde reden die de onderzoekers kan helpen in het onderzoek. Als laatste worden de vooraf door de onderzoekers gemaakt ideeën besproken die ook sommige van de eerder besproken meettechnieken gebruiken. De onderzoekers vragen hierbij nogmaals naar de mening van de expert. Welke ideeën hebben de voorkeur bij de expert en is er misschien al een idee die in de ogen van de expert kan worden gebruikt verder in het onderzoek.

Gedurende het interview kunnen er, zoals eerder besproken, gevoelige onderwerpen besproken worden. Wanneer de expert deze niet wilt antwoorden dient de onderzoeker dit te respecteren en door te gaan naar een ander onderwerp. Ook wanneer er tijdens het interview de expert vragen heeft, zal deze op elk moment gesteld kunnen worden en beantwoord worden door de interviewer.

Gegevensverzameling

Gedurende het interview zal de audio van het gesprek opgenomen worden en opgeslagen worden op een voor andere niet toegankelijke locatie. Ook zullen er aantekeningen gedurende het interview worden gemaakt omtrent de reacties tijden en na een vraag. De gegevens zullen

naderhand gebruikt worden om het gesprek te kunnen samenvatten en goed te kunnen interpreteren voor de onderzoekers.

Gegevensbewaring

De gegevens worden, volgend de VSNU richtlijnen, 10 jaar veilig bewaard op een lokale solid state drive waar andere mensen behalve de onderzoeker geen toegang tot hebben. Volgend de AVG richtlijnen, zal de gegevens anoniem worden bewaard om de privacy van de betrokken partijen te waarborgen. Deze informatie is alleen toegankelijk voor de onderzoekers van het project.

Voor 48 uur na deelname in het interview kunt u ervoor kiezen om de door u verkregen informatie te laten verwijderen. De gegevens worden op dat moment volledig gewist en eventuele conclusies die daaruit zijn geschetst zullen niet meer gebruikt worden in het onderzoek. Na deze 48 uur zal het vragen voor de verwijdering van de verkregen gegevens helaas geen garantie meer bieden voor het verwijderen van de gegevens.

Gegevensgebruik

De gegevens verzameld in het onderzoek zal verwerkt worden binnen het onderzoek/afstudeeropdracht gegeven vanuit de Universiteit van Twente. De resultaten/conclusies kunnen worden gepubliceerd in wetenschappelijke artikelen en in de media. Ook kunnen andere partijen de gepubliceerde resultaten gebruiken in de ontwikkeling binnen hun eigen project. Hierbij worden alle gegevens, resultaten en conclusies volledig anoniem beschreven om uw privacy te waarborgen.

Wanneer u het niet eens bent met de gebruik en/of het delen omtrent uw data, kunt u altijd terecht bij de onderzoekers die dit met u zullen bespreken. De contactinformatie van de onderzoekers kunt u vinden onderaan deze brochure.

Onafhankelijk advies en vragen over het onderzoek

Wanneer u als deelnemer van het onderzoek verlangt naar onafhankelijk advies, of u eventuele klachten wilt indienen over het project kunt u deze indienen bij de secretaris van de ethische commissie van de Universiteit van Twente (Email: ethics-com-ewis@utwente.nl). Deze ethische commissie is onafhankelijk en zal dus ook met een objectieve blik kunnen werpen u kunnen helpen met de door u ingestuurde onderwerpen.

Wanneer u inhoudelijke vragen heeft, kunt u deze op elk moment vragen bij de onderzoekers van het onderzoek. De contactgegevens van deze onderzoekers staan onderaan de informatiebrochure en consent form.

Contactgegevens van het onderzoeksteam

Zoals eerder aangegeven kunt u op elk moment terecht voor vragen bij het onderzoeksteam van het project. De eerste voorkeur van het onderzoeksteam gaat uit naar contact naar de hoofdonderzoeker Sven Bormans. Wanneer dit door een reden niet schikt, is het geen probleem om een andere onderzoeker te contacteren.

Researcher:

Sven Bormans - *Bachelor Creative Media*

Technology Student, Hoofd onderzoeker

s.r.bormans@student.utwente.nl

(+31) 6 11 18 19 70

Supervisor:

Randy Klaassen – *Assistant Professor Human Interaction, Project begeleider*

r.klaassen@utwente.nl

Appendix D: Mind map with the different subjects of the project

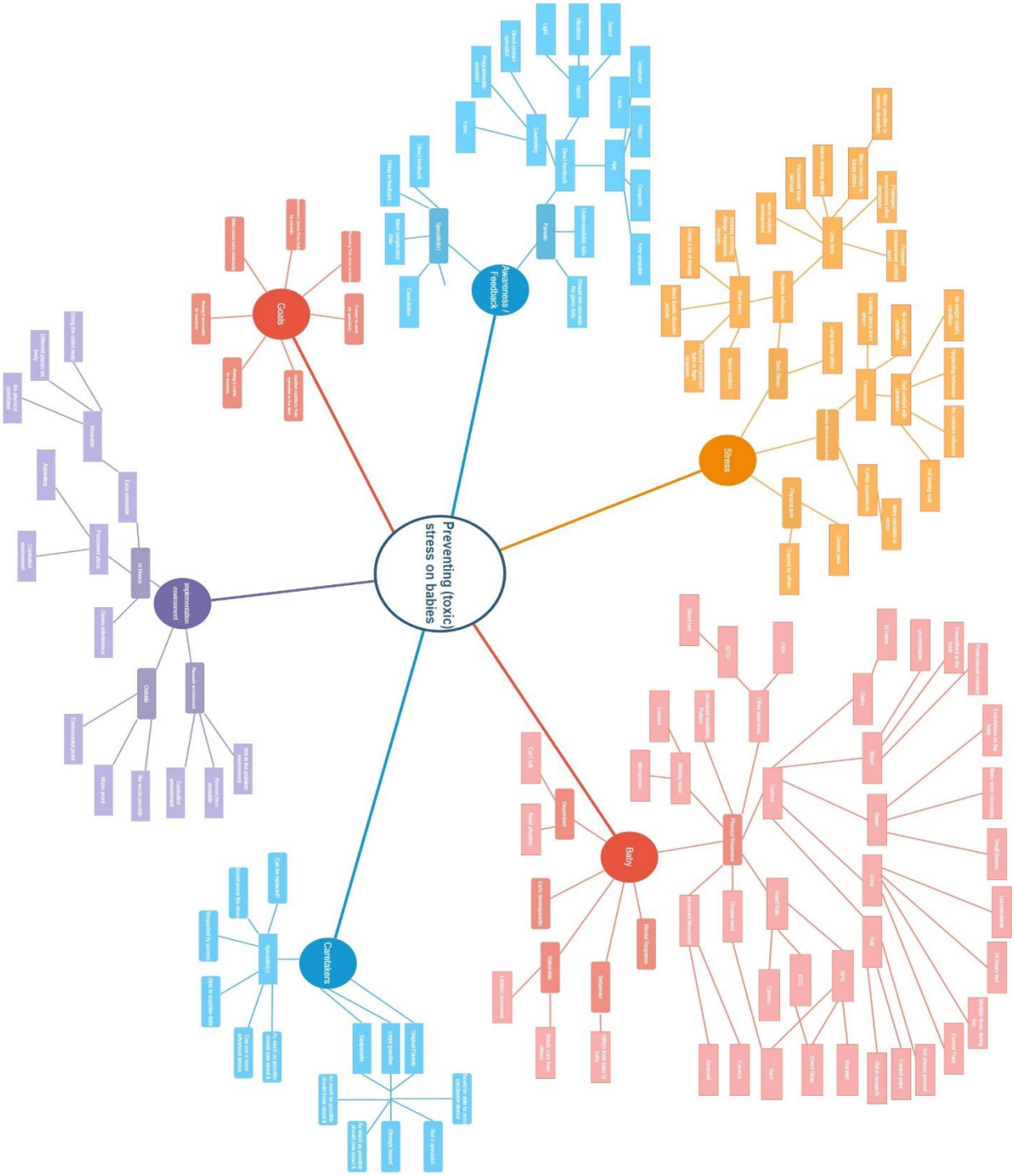


Figure 42: Mind-map with the different subjects of the project

Appendix E: 50 ideas selection

Number	Sensing / Feedback	Description	Physical/Environment	Comfortable baby	Comfortable Adult	Reliable (expected)	Doable	General preference	Previously tested	Total
1.	Sensing	GPS tracker, tracking the location of the baby when having a stress reaction	Environment	4	4	3	5	3	3	22
2.	Sensing	(under) pants / diaper that collects urine / cortisol	Physical	4	3	3	4	3	1	18
3.	Sensing	Onesie that collects urine and monitors movements	Physical	3	3	3	3	3	1	16
4.	Sensing	Leggings with sensors that can sense movements + blood-related measurements	Physical	3	3	3	3	3	1	16
5.	Sensing	Cap that measures brain activity and links it to stress and provides immediate feedback	Physical	3	3	3	3	2	2	16
6.	Sensing	Teat of the baby measuring cortisol in the mouth during the day, recharge with movements of the tongue	Physical	4	3	2	3	2	1	15
7.	Sensing	Camera that measures the movements of the baby	Physical	4	3	4	4	3	2	20
8.	Sensing	Bracelet that pricks blood every time to measure cortisol level	Physical	1	1	5	1	1	1	10
9.	Sensing	Onesy with sweat sensors that measure the cortisol level	Physical	3	3	3			2	11
10.	Sensing	Cap that can grab pieces of hair and measure for cortisol level	Physical	2	2	4	1	1	2	12
11.	Sensing	Camera on the baby showing the situation (must combination with something else)	Environment	4	3	4	4	3	3	21
12.	Sensing	Mic on the camera that listens and can	Environment	4	2	4	4	3	3	20

		identify stressors								
13.	Sensing	A mat that measures the movements of the baby	Physical	3	3	3	4	3	1	17
14.	Sensing	Gloves that perform measurements in terms of blood + movements	Physical	2	3	4	3	2	2	16
15.	Sensing	A ring that can measure heart rate / blood related things	Physical	2	2	3	3	2	2	14
16.	Sensing	Headband that measures sweat (and brain activity?)	Physical	3	3	3	2	1	2	14
17.	Sensing	Sock that provides real-time measurements of blood measurements / heart rate	Physical	3	4	4	4	4	3	22
18.	Sensing	Tut which collects saliva	Physical	4	2	2	2	1	1	12
19.	Sensing	Database with the baby's data from the past months to compare with machine learning / a certain self-learning algorithm	Environment/Physical	3	3	3	1	1	1	12
20.	Sensing	Algorithm that can learn from data from multiple babies (with labels on the behavior) to recognize and label stress	Physical	3	3	3	1	1	1	12
21.	Sensing	A bed with sensors on the bottom that measure the movements of the child	Physical	4	3	3	4	1	1	16
22.	Sensing	Lollipop with detachable flavors that traps saliva	Physical	2	2	3	2	1	1	11
23.	Sensing	Bracelet that measures sweat + blood related things	Physical	3	4	4	4	4	3	22
24.	Sensing	Plaster that you stick on and that is able to measure the cortisol level through sweat	Physical	3	4	3	2	5	2	19
25.	Sensing	A toy that keeps an eye on the environment	Environment	3	2	2	4	2	2	15

		(must be in combination with a real measuring instrument) by means of a mic / camera.								
26.	Sensing	Clip-on camera, which babies to measure the environment	Physical	3	1	3	4	2	1	14
27.	Sensing	A Clip on movement / sweat / breath meter	Physical	3	3	4	3	4	3	20
28.	Sensing	A milk bottle that collects the baby's saliva	Physical	4	3	3	2	2	1	15
29.	Sensing	Chest strap that does Heart / blood measurements + sweat	Physical	3	3	4	3	2	2	17
30.	Sensing	A (plastic?) Strip with which you can easily collect saliva from different places	Physical	3	4	3	2	2	1	15
31.	Sensing	A pillow that absorbs sweat / (can do other measurements?)	Physical	4	3	1	3	1	1	13
32.	Sensing	Performing a stressful situation can calibrate the devices / performing a stressful situation to see the reaction to be monitored and the data how deeply to get the reaction and from a conclusion	Physical	1	2	4	4	2	1	14
33.	Sensing	Heat sensors / camera that accurately monitors the temperature of the baby and gives a signal of potential stress in the event of sudden increases.	Physical	3	3	2	2	1	1	12
34.	Sensing	A camera that registers the movements of the child and compares this with the previous movements of the child	Physical	3	3	4	2	1	2	15
35.	Sensing	Microphone that monitors the noise level	Environment	4	3	4	4	3	3	21

		of the environment								
36.	Sensing	Bracelet that constantly monitors blood pressure + heart rate	Physical	3	3	4	4	4	3	21
37.	Sensing	A revolving toy that can be hung over a bed / reclining area to entertain the baby and at the same time keep an eye on it with a camera	Physical	4	3	3	4	2	1	17
38.	Sensing	Being able to perform cortisol measurements at home	Physical	3	4	4	3	4	1	19
39.	Sensing	Measuring how well certain parts of the brain are developing	Physical	3	3	3	2	1	2	14
40.	Feedback	Application where the user can directly contact a professional	Digital	/	5	/	5	5	/	15
41.	Feedback	Application containing the data of the baby, where the professional also monitor the data and lay contact when needed	Digital	/	5	/	5	5	/	15
43.	Feedback	a plush toy that tracks the sound of the environment and can be used as a feedback device	Physical	/	3	/	4	4	/	11
44	Feedback	physical alarm that goes off Immediate at a specialist when the baby is or may be stressed	Physical	/	3	/	5	3	/	11
45.	Feedback	Platform of professionals where other people can watch and compare data to what professionals say about it	Digital	/	4	/	4	3	/	11
46.	Feedback	Administering sedatives	Physical	/	0	/	0	0	/	0
47.	Feedback	A toy that goes off/starts playing when stress starts	Physical	/	3	/	5	3	/	11
48.	Feedback	A forum where results of the device can be	Digital	/	4		4	3	/	11

		discussed. specialists are also active on this platform and are labelled								
49.	Feedback	Lights on the device slowly getting brighter after a long period of stress	Physical	/	3	/	5	3	/	11
50.	Feedback	App that indicates all data and sounds an alarm when necessary	Digital	/	4	/	5	3	/	12

Table 24: 50 ideas selection

Appendix F: Processing the interview with the professionals

Specialist 1

Specialist 2

Researcher

Best spot to place the sensor

"In front of view you can see a Schematic of a babie's body. We are now wanting to place a sensor with approximately the size of a regular knot. Which places on the body do you prefer to put the sensor and which places do you advise against to place the sensor?"

Specialist 1 emphasizes when choosing the right spot for the sensor the importance of not hindering the contact with the babies's parents, movement of the baby and not interfering the feeding of the baby. The specialist also want it to be an easy accessible spot for the parents.

Specialist 2 firstly state to prefer to place the sensor on the back of the baby. This place is not accessible for the baby to reach for which decreases the chance of the baby to swallow the sensor. The specialist does not prefer feet or hands. This placement gives an increased swallowing hazard and will not be nice to wear over a prolonged period of time.

Both specialist come to the conclusion that for answering this question a distinction should be made between very young babies and older babies. For very young children they both come to the conclusion that they prefer the forehead and feet. For older people they prefer the upperarm. Not the chest (problems during putting on or off the clothes) and chest (These group prefer to lay down on their back.

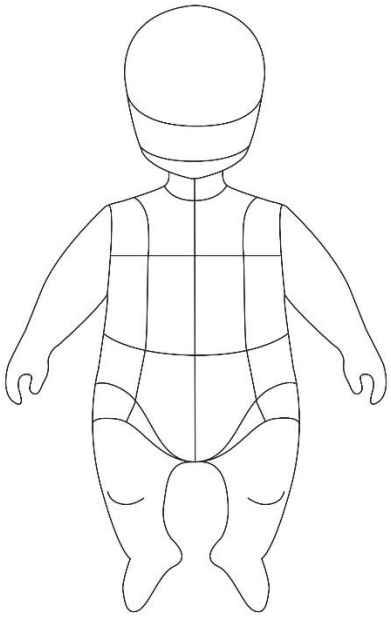


Figure 43: Schematic of a babys' body

The ideas

"What are your thoughts about the ideas, what are strong points and what are the weak points"

Idea 1: Clip-on

Specialist 1: First stated that using a clip-on for the placement maybe could negative influence the movement of the baby. Also when not placed correctly it could go loose easily. It has to have some big clipping power for good placement. Measuring the cortisol maybe a better idea in the urine? Urine of a baby does not always stays in the diaper so maybe a good idea with the clip-on concept.

Specialist 2: Maybe we could measure the cortisol in the urine in the diaper?

Conclusion researcher: the idea of a clip-on has not been received with much enthusiasm. Both saw many flaws in the design which resulted them to think and brainstorm about an other idea. This idea will be treated later on.

Idea 2: Cortisol plaster

Specialist 1: The specialist stated that only measuring one biomarker is not enough to find out if the baby is having stress. The measuring technique (sensor on a plaster) has some great potential. She asked if the other sensor can be used on the plaster. Note that the plaster should not cause any harm to the babys' skin.

Specialist 2: Thinks it is a very interesting idea. Agrees with specialist 1 that only measuring the cortisol is not enough. The measuring technique (sensor on a plaster) is very interesting, especially when thinking about the freedom of movement. She asked if it maybe is an idea to put other sensors on the plaster.

Conclusion researcher: The measurement technique of having a plaster has some great potential. The measurement itself lacks of variety.

Idea 3: Bracelot/sock

Specialist 1: Verry common technique to place the sensors. Is not very enthusiastic about the idea. When babies pass the age of 3 months they will be able to remove the sock and bracelet themselves.

Specialist 2: Wanted to add the cortisol measurement to the idea. Also agrees with specialist 1 that having the sensors placed is not a very good idea. The babies can remove the socks after 3 months and the chance of loosing a sock and never finding it back again is very big. Not very useful when it is a very expensive sock. Specialist 2 does see some potential in the bracelet. She thinks parents would like it more than the sock because it generally being considered normal to wear a bracelet in todays society (lot of people wear a bracelet).

Conclusion researcher: Using a sock for the measurement is not a very good idea. The bracelet can be taking into consideration.

Idea 4: Processing cortisol samples at home

Specialist 1: Specialist 1 does see some great potential for this idea when used clinical. The very much likes the direct feedback it provides (she misses this on her work sometimes). She does not see this device work in a home environment (a specialist in required when using this device). She suggest to combine this idea with the cortisol sticker.

Specialist 2: Really likes this idea to be used in a clinical environment. Agrees that it should not be used at home by the parents themselves.

Conclusion researcher: Being used in a clinical environment and giving direct feedback are the strongest points of this device. It should only be used by professionals, not at home with the parents.

Idea 5: Camara measuring the movement of the baby

Specialist 1: Specialist 1 does not like this idea. Privact is a big issue here and the professional thinks that parents will act differently when being filmed (if they even want a camera in their home). Also, the specialist stated that professionals need to examine the data, which is not preferable. Being able to directly see the data and conclusion of the data would be ideal.

Specialist 2: Specialist 2 also does not like the idea. Privacy issues and the potential low willingness of parent to place a camera in their home could potentially be a big problem.

Conclusion researcher: Using a camera is not well received by the specialists. They see too many problems regarding privacy and changed behaviour.

Idea 6: Camera measuring the home situation when the child is having a stress reaction

Specialist 1: Specialist 1 emphasizes that this idea only can determine a small portion of potential stressors. The idea misses the nuance. The idea could be a addition to another idea. She comes back to the privacy problems discussed with idea 5

Specialist 2: Specialist 2 sees this idea as a great addition to another idea. Also here she suggests that parents maybe will behave differently when being filmed. This could be a problem. The specialist also does not see people taking the camera everywhere they go, missing a lot of data. The specialist sees some potential to this idea when a hypothesis is made by a specialist that the stressor is within the home environment of the baby. The camera could be given to the parents.

Conclusion researcher: Having the same privacy issues as the previous idea, this idea is better received than the previous idea. Having this idea as an addition of another idea could bring some insights into the possible stressors of the baby. However, it would miss a great portion of potentials stressors.

Putting the ideas in order (most potential-least potential)

Specialist 1: 1,2 | 3(with the bracelot) | 6 (as addition) | 3(with the sock), 4, 5

Specialist 2: 3 (bracelot) | 2 | 4 | 6| 1, 5

Additional notes

Researcher: The idea of measuring the heart beat combined with having multiple sensors on a plaster is very much preferred by the specialists. They see the most potential in this (half) new idea and should be considered when selecting the final idea to develop.

Feedback for the parents

"The gathered data and the conclusion of the data can be send to the parents on multiple different ways. With both of you working with parents, which type of feedback do you think the parents prefers"

Specialist 1: Specialist 1 states the following; You want to coach the parents on recognizing the stress of the baby. The best options for this is to frequently give direct feedback, but not from minute to minute. The gathered data should not only be available for the parents but also easy accessible for the specialist. The possibility to get feedback from a specialist on the short term would be very nice. Then, everything is fresh in the memory and easily to reproduce and discuss with the specialist. Maybe implement the above functionalities in some kind of application.

Specialist 2: Specialist 2 agrees with everything specialist 1 says. She added that the group of parents also matters when giving feedback. She thinks that lower educated people just want to see the conclusion of the data, were higher educated people want to be able to see the data.

Conclusion researcher: Keeping in mind that the target group differs and have to be kept in mind when developing the type of feedback it will give. Also direct feedback is preferred. Having the data to be available for both the parents and the specialist is very much preferred. This will help the treatment of the professional.

Appendix G: Arduino Code for the PulseSensor

```
/*
  This code displays the data coming from the data combined with the
measured heartbeat.

  The code is heavily inspired by the example code made by Yuro Gitman.
  Adjustments made by Sven Bormans ~ s2154900 ~ June, 2021
*/

// Define using interrupts to use the sensor
#define USE_ARDUINO_INTERRUPTS true
// load in the PulseSenor library
#include <PulseSensorPlayground.h>  // Include the pulseSensor Library
PulseSensorPlayground pulseSensor; // adding the Library functions

//  Constant varaibles
const int pulseInputPin = 0;    // Pulse Sensor PURPLE WIRE connected to
ANALOG PIN 0
const int incomingSignal;       // holds the incoming raw data. Signal
value can range from 0-1024

// Non-constant variables
int Threshold = 0;          // Value of the threshold with value 0
float timer;                // to keep track of time during the
measurement

// setup
void setup() {
  // Set baudrate and timer
  Serial.begin(250000); // Baudrate at 25k to get the best communication
between sensor and arduino

  // Set communication
  pulseSensor.analogInput(pulseInputPin);     // Define the inputPin
connected to the sensor, which is A0
  pulseSensor.setThreshold(Threshold);        // Define which values
determines the Threshold, start threshold is 0 because still needs to be
calculated
  pulseSensor.setSerial(Serial);              // Define that the
connection is Serial
  pulseSensor.setOutputType(SERIAL_PLOTTER);  // Set the ouputType to
plotter

  // look if  sensor is  working
  if (pulseSensor.begin()) {
    delay(50);                                // small delay to prevent
overflow
```

```
  }
  //   calculate the threshold value for the pulseSensor
  calculateThreshold();
}

// loop
void loop() {
  timer = millis();     // define the timer to time in milliseconds

  // using the sensor
  getBPM();         // give the BPM of the heart
  getValueSensor(); // give the Values measured by the pulseSensor
  sendData();       // send the data to the serial port
}

// sending the data to the Serial Print
void sendData() {
  // Different values with a komma in between to later on be able to
later on split the data in the processing process
  Serial.print(timer / 1000); // timer
  Serial.print(",");
  Serial.print(signals[0]);   // BPM
  Serial.print(",");
  Serial.print(signals[1]);   // raw data
  Serial.println();
  delay(50);                  // delay to prevent overflow
}

// calculating the threshold
void calculateThreshold() {
  int comparableValue = pulseSensor.getLatestSample();  // get the
latest sample of the sensor and assign to new integer
  float n = 1;                                          // values that
sets the amount of testData
  int averageThreshold = 0;                             // local
varaiable to store the threshold, begin value to set to zero
  long counterData = 0;                                 // value to
store all of the inputsignal
  //calculate the average of 1000 samples
  while (n < 1000) {
    comparableValue = pulseSensor.getLatestSample();        // update
the sensorData
    if (comparableValue > 250 && comparableValue < 800) {   // if data
is reliable enough
      counterData += comparableValue;                       // add the
data the calculation
      averageThreshold = (counterData / n);                 // Calculate
```

```
average
      n++;                                                    // increase
step
    } else {
      delay(500);                                             // wait a
little for reliable data
    }
  }
  pulseSensor.setThreshold(averageThreshold);                 // define
the threshold data
  delay(50);                                                  // prevent
overflowing
}

// set value sensor
void getValueSensor() {
  signals[1] = pulseSensor.getLatestSample(); // send the data of the
sensor to the signsl to send
}

void getBPM() {
  int BPM = pulseSensor.getBeatsPerMinute();  // define Beats per Minute
  if (pulseSensor.sawStartOfBeat()) {         // Constantly test to see
if "a beat happened".
    signals[0] = BPM;                         // send the data of the
sensor to the signal to send
  }
}
```

Appendix H: Arduino Code for both the movement modules

```
/*
   This code sends the data of the sensor to the serial port of the
arduino.

   This code is heavily based on the Arduino and MPU6050 Accelerometer
and Gyroscope       Sensor Tutorial
   by Dejan, https://howtomechatronics.com

   final adjustments and tweaks made by Sven Bormans - s2154900 - June,
2021
*/

// include the wire library for communication
#include <Wire.h>
//constant variable
const int MPU = 0x68; // MPU6050 I2C address to make it slave
// variables to hold sensor data
float AccX, AccY, AccZ; // data coming from accelerometer
float GyroX, GyroY, GyroZ; // data coming the Gyroscope
float accAngleX, accAngleY, gyroAngleX, gyroAngleY, gyroAngleZ; //
angles of the accelerometer and gyroscope
float roll, pitch, yaw; // The directions of rotation
float AccErrorX, AccErrorY, GyroErrorX, GyroErrorY, GyroErrorZ; // error
variables
float elapsedTime, currentTime, previousTime; // time variables
int c = 0; // amount of reading when checking error

//setup
void setup() {
  Serial.begin(19200);                // set th baudrate to 19200 for
good communication between sensor and mpu6505
  //communication with mpu6505
  Wire.begin();                       // Initialize comunication
  Wire.beginTransmission(MPU);        // Start communication with MPU6050
// MPU=0x68
  Wire.write(0x6B);                   // Talk to the register 6B
  Wire.write(0x00);                   // Make reset - place a 0 into the
6B register
  Wire.endTransmission(true);         //end the transmission

  // Call this function if you need to get the IMU error values for your
module
  calculate_IMU_error();
  delay(20);
}
//loop
void loop() {
  // reading the accelerometer
  Wire.beginTransmission(MPU);
  Wire.write(0x3B); // Start with register 0x3B (ACCEL_XOUT_H)
  Wire.endTransmission(false);
  Wire.requestFrom(MPU, 6, true); // Read 6 registers total, each axis
```

```
value is stored in 2 registers
  //For a range of +-2g,divide the raw values by 16384
  AccX = (Wire.read() << 8 | Wire.read()) / 16384.0; // read X-axis
value accelerometer
  AccY = (Wire.read() << 8 | Wire.read()) / 16384.0; // read Y-axis
value accelerometer
  AccZ = (Wire.read() << 8 | Wire.read()) / 16384.0; // read Z-axis
value accelerometer
  // Calculating Roll and Pitch from the accelerometer data
  accAngleX = (atan(AccY / sqrt(pow(AccX, 2) + pow(AccZ, 2))) * 180 /
PI) - 0.58; // AccErrorX ~(0.58) See the calculate_IMU_error()custom
function for more details
  accAngleY = (atan(-1 * AccX / sqrt(pow(AccY, 2) + pow(AccZ, 2))) * 180
/ PI) + 1.58; // AccErrorY ~(-1.58)

  //read gyroscope
  previousTime = currentTime;        // Previous time is stored before
the actual time read
  currentTime = millis();            // Current time actual time read
  elapsedTime = (currentTime - previousTime) / 1000; // Divide by 1000
to get seconds
  Wire.beginTransmission(MPU); // set communication port
  Wire.write(0x43); // Gyro data first register address 0x43
  Wire.endTransmission(false);
  Wire.requestFrom(MPU, 6, true); // Read 4 registers total, each axis
value is stored in 2 registers
  // for a 250 degree range, divide by 131
  GyroX = (Wire.read() << 8 | Wire.read()) / 131.0; // read X-axis value
Gyroscope
  GyroY = (Wire.read() << 8 | Wire.read()) / 131.0; // read Y-axis value
Gyroscope
  GyroZ = (Wire.read() << 8 | Wire.read()) / 131.0; // read Z-axis value
Gyroscope
  // Correct the outputs with the calculated error values
  GyroX = GyroX +  GyroErrorX; //
  GyroY = GyroY + GyroErrorY;//
  GyroZ = GyroZ + GyroErrorZ; //

  // Currently the raw values are in degrees per seconds, deg/s, so we
need to multiply by sendonds (s) to get the angle in degrees
  gyroAngleX = (gyroAngleX + GyroX) * elapsedTime; // deg/s * s = deg
  gyroAngleY = (gyroAngleY + GyroY) * elapsedTime;
  yaw = (GyroZ * elapsedTime) * 10;
  // Complementary filter - combine acceleromter and gyro angle values
  roll = (0.960 * gyroAngleX + 0.040 * accAngleX) * 10;
  pitch = (0.960 * gyroAngleY + 0.040 * accAngleY) * 10;
  // print values on the serial monitor
  sendData();

}

void sendData() {
  Serial.print(currentTime / 1000); // make time to seconds for better
reading
```

```
  Serial.print(",");
  Serial.print(roll);               // print roll
  Serial.print(",");
  Serial.print(pitch);              // print pitch
  Serial.print(",");
  Serial.println(yaw);              // print yaw
  delay(50);                        // delay to prevent overflow
}

void calculate_IMU_error() {
  // We can call this funtion in the setup section to calculate the
accelerometer and gyro data error. From here we will get the error
values used in the above equations printed on the Serial Monitor.
  // Note that we should place the IMU flat in order to get the proper
values, so that we then can the correct values
  // Read accelerometer values 200 times
  while (c < 200) {
    Wire.beginTransmission(MPU);
    Wire.write(0x3B);
    Wire.endTransmission(false);
    Wire.requestFrom(MPU, 6, true);
    AccX = (Wire.read() << 8 | Wire.read()) / 16384.0 ;
    AccY = (Wire.read() << 8 | Wire.read()) / 16384.0 ;
    AccZ = (Wire.read() << 8 | Wire.read()) / 16384.0 ;
    // Sum all readings
    AccErrorX = AccErrorX + ((atan((AccY) / sqrt(pow((AccX), 2) +
pow((AccZ), 2))) * 180 / PI));
    AccErrorY = AccErrorY + ((atan(-1 * (AccX) / sqrt(pow((AccY), 2) +
pow((AccZ), 2))) * 180 / PI));
    c++;
  }
  //Divide the sum by 200 to get the error value
  AccErrorX = AccErrorX / 200;
  AccErrorY = AccErrorY / 200;
  c = 0;
  // Read gyro values 200 times
  while (c < 200) {
    Wire.beginTransmission(MPU);
    Wire.write(0x43);
    Wire.endTransmission(false);
    Wire.requestFrom(MPU, 6, true);
    GyroX = Wire.read() << 8 | Wire.read();
    GyroY = Wire.read() << 8 | Wire.read();
    GyroZ = Wire.read() << 8 | Wire.read();
    // Sum all readings
    GyroErrorX = GyroErrorX + (GyroX / 131.0);
    GyroErrorY = GyroErrorY + (GyroY / 131.0);
    GyroErrorZ = GyroErrorZ + (GyroZ / 131.0);
    c++;
  }
  //Divide the sum by 200 to get the error value
  GyroErrorX = GyroErrorX / 200;
  GyroErrorY = GyroErrorY / 200;
  GyroErrorZ = GyroErrorZ / 200;}
```

Appendix I: Consent Form Sensor Evaluation

Consent Form:

How High Is the Stress Level?

About the project and participation

Dear reader,

I would like to inform you about the research you have applied to participate in.

This research aims to develop a device that can objectively measure the stress level among babies by using current-day technology. With this device, the babies' environment should be able to detect the stressors of the baby and thereby be able to control the stress level of the baby. This device gives the caretaker the possibility to remove the babies' stressors when needed and prevent long-term effects from the babies caused by (toxic) stress.

This experiment aims to test if the system designed by the researchers is able to pick up the stress reaction of the participants. By combining a stressful game, the data of the sensors, the observation of the researcher, and the participant's answers, the validations of the working of the data can be confirmed or debunked.

The experiment will be held once in a controlled environment. You will get three sensors attached to your body that will record your heartbeat, respiration rate and movement when playing a video game. The experiment will approximately take 30 minutes and is completely voluntarily to all the parties involved. You will beforehand fill in a consent form given by the researcher, which will be valid until 48 hours after participation in the experiment. Before these 48 hours, you may decide at any moment to withdraw your consent. The consent can be withdrawn at any moment during and after (until 48 hours) the research. You can ask questions about the research at any moment before, during and after the research. This information will always be provided to you when possible, except for the personal data of other parties involved in the research.

Data usage

During the experiment, an accelerometer and pulse sensor will record the heart rate, respiration rate and movement of the participant, which will afterwards be saved, processed and

summarized to get a clear overview. The researcher will also record the audio of your voice and his own and make additional notes during the assessment where other reactions of the interviewee will be written down, such as facial expressions and other physical movements, with the intention to capture unintentional reactions from the participant on the assignments brought by the researcher. Own interpretation from the researcher of the researchers' data will be labelled to prevent any misunderstanding about the collected data from the experiment.

All data collected from you will be labelled as "X" to keep your identity anonymously. All data collected during the experiment can be used at any moment in this research by the researcher.

The data collected in the interview will be analyzed and processed by the researcher within the researcher's Bachelor thesis. The data will be used within this graduation project on behave of the University of Twente. The results of the research may be published on the website of the University of Twente and in other research papers from other researchers. The research results may also be used by companies who are interested in developing the device in this research.

The researchers of the project are the only persons who can access the collected data. The data will be stored on a local secure storage device located at the host temporary, and in the end, the data will be stored in a university-approved location. All data will be saved anonymously to protect the identity of the parties involved. The storage of the data will proceed as described by the AVG guidelines. Following these guidelines, the data will be stored over a time span of 10 years. After these ten years, the researcher may choose to delete the files. When other parties request data of this research, including the your involvement, the researcher will only share the data when having permission from all parties involved.

Within 48 hours after the interview, may ask to delete his/her data collected and processed during the research. The data and results will thereby be erased as soon as possible and not be used or mentioned within the research. If, after 48 hours, you asks to delete the information, the request will be declined, and the data collected can still be used within the research.

Informed consent form

I hereby declare that I have been informed in a manner that is clear to me about the nature and method of the research as described in the aforementioned information brochure. My

questions have been answered to my satisfaction. Parts of the interview can be quoted where only your function will be mentioned. I agree with my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason, and I am aware that I may withdraw from the experiment at any time.

I agree to my experiment being recorded. Additionally, I agree that an anonymized transcription of the whole interview can be added as an appendix to the research. If my research results are to be used in scientific publications or made public in any other manner, they will be completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact the main researcher Sven Bormans or his supervisor Randy Klaassen.

Contact information:

Researcher:

Sven Bormans - *Bachelor Creative Media*

Technology Student, Main researcher

s.r.bormans@student.utwente.nl

Supervisor:

Randy Klaassen – *Assistant Professor Human Interaction, Project supervisor*

r.klaassen@utwente.nl

Suppose you have any complaints about this research. In that case, you can direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethicscommittee-cis@utwente.nl).

Signed in duplicate:

…… ……

Name participant Signature

I have provided explanatory notes about the research. I declare myself willing to answer any questions that may still arise about the research to the best of my ability.'

…… ……

Name researcher Signature

Appendix J: Information Brochure Sensor Evaluation

Informatiebrochure:

How High Is the Stress Level?

Over

Dit project vanuit de Universiteit van Twenten in samenwerking met ZGT en IMH Nederland genaamd “How high is the Stress Level?” zal onderzoeken welke mogelijkheden er bestaan omtrent het meten van stress onder baby’s doormiddel van het gebruik en het combineren van hedendaagse technieken.

Een stress reactie onder baby’s kan door vele factoren in hun omgeving geactiveerd worden. De factoren die deze stress reactie activeren zal verschillen per baby en de omgeving. Wanneer deze factoren niet worden gevonden en/of hiermee niks wordt gedaan en hierdoor het stress niveau van de baby aanhoudt over een langere periode, kan dit negatieve gevolgen hebben voor de ontwikkeling van de baby zichtbaar voor de rest van hun leven.

Op dit moment hebben de onderzoekers van het project een concept product ontwikkeld die zij willen gaan testen op verschillende personen. Dit product zou de stressreactie moeten kunnen oppikken van u wanneer deze aanwezig is. Wanneer dit bij het experiment inderdaad blijkt te kloppen zal dit verifiëren dat het product inderdaad een stressreactie kan meten en mogelijk verder ontwikkeld worden.

Tijdens het experiment zal u een video spel gaan spelen die mogelijk een stressreactie in uw lichaam bij u activeert. Doormiddel van verschillende sensoren op uw lichaam die uw hart ritme, ademhaling en beweging monitoren is de verwachting deze stressreactie te kunnen meten. Deze sensoren zullen van tevoren door de onderzoeker met u geplaatst worden.

In deze informatiebrochure zal in het kort het project “How high is the stress level” worden besproken met daaruit alle nodige informatie omtrent de participatie in het project. Dit bedoeld, om u te helpen in uw keus van deelname in dit onderzoek.

Deelname

De deelname in dit onderzoek is geheel op vrijwillige basis. De tijdsduur van het experiment is geschat op 30 minuten maar kan hier van afwijken. Voor het interview zal u deze informatiebrochure met een consent form te zien krijgen ter informatie van uw deelname.

Wanneer de consent form is ingevuld, en u dus akkoord bent gegaan met uw deelname, kunt u uw consent nog terugtrekken tot 48 uur na het experiment. Het terugtrekken uit het onderzoek kan op elk mogelijk ogenblik voor het interview, gedurende het interview en 48 uur na het interview. Elke mogelijke reden die u opgeeft om te stoppen zal voldoen om te kunnen stoppen.

Experiment procedure

Het experiment zal plaatsvinden in de kamer van de onderzoeker. Deze plek zal er voor zorgen dat het experiment zo spoedig mogelijk verloopt. In het begin van het experiment zal de onderzoeker nogmaals het onderzoek aan u voorleggen en deze informatiebrochure met consent form aan u geven. Hierna worden er vragen aan u gesteld omtrent mogelijke grenzen die u wilt opstellen. Dit houden onderwerpen in waar u het niet over wilt hebben en opdrachten in die u niet wilt uitvoeren. Nadat deze duidelijk zijn zal de onderzoeker sensoren op uw bevestigen en u vragen om een video spel te gaan spelen. In dit videospel zal mogelijk uw lichamelijk stressreactie worden geactiveerd die de sensoren op uw lichaam zullen gaan meten. Na het experiment zal de onderzoeker u nog vragen stellen omtrent uw beleving tijdens het spelen van het spel. Aan het eind zal de onderzoeker u nog vragen op mogelijke vragen vanuit uw kant en de sensoren van u af halen.

Gedurende het experiment kunnen er gevoelige onderwerpen besproken worden. Wanneer u deze niet wilt antwoorden dient de onderzoeker dit te respecteren en door te gaan naar een ander onderwerp. Ook wanneer er tijdens het experiment vragen heeft, zal deze op elk moment gesteld kunnen worden en beantwoord worden.

Gedurende het experiment worden dus verschillende fysieke eigenschappen gemeten. Wanneer er uit de metingen blijkt dat u een mogelijke afwijking heeft (zoals een hartritme stoornis) zal dit met u besproken worden wanneer dit nog niet bij u bekend is.

Gegevensverzameling

Gedurende het experiment zal uw hart ritme, ademhaling en beweging gemonitord worden en opgeslagen worden op een voor andere niet toegankelijke locatie. Ook zal er een audio opname van uw stem en de onderzoeker gemaakt worden en zullen er aantekeningen gedurende het experiment worden gemaakt omtrent uw reacties tijdens het experiment. De gegevens zullen naderhand gebruikt worden om het gesprek te kunnen samenvatten en goed te kunnen interpreteren voor de onderzoekers.

Gegevensbewaring

De gegevens worden, volgend de VSNU richtlijnen, 10 jaar veilig bewaard op een lokale, door de universiteit goedgekeurde harde schijf, waar andere mensen, met uitzondering van de onderzoekers, geen toegang tot hebben. Volgend de AVG richtlijnen, zal de gegevens anoniem worden bewaard om de privacy van de betrokken partijen te waarborgen.

Voor 48 uur na deelname in het interview kunt u ervoor kiezen om de door u verkregen informatie te laten verwijderen. De gegevens worden op dat moment volledig gewist en eventuele conclusies die daaruit zijn geschetst zullen niet meer gebruikt worden in het onderzoek. Na deze 48 uur zal het vragen voor de verwijdering van de verkregen gegevens helaas geen garantie meer bieden voor het verwijderen van de gegevens.

Gegevensgebruik

De gegevens verzameld in het onderzoek zal verwerkt worden binnen deze afstudeeropdracht gegeven vanuit de Universiteit van Twente. De resultaten/conclusies kunnen worden gepubliceerd op de website van de Universiteit van Twente en in andere onderzoeken. Ook kunnen andere partijen de gepubliceerde resultaten gebruiken voor de ontwikkeling binnen hun eigen project en/of bedrijf . Hierbij worden alle gegevens, resultaten en conclusies volledig anoniem beschreven om uw privacy te waarborgen.

Wanneer u het niet eens bent met de gebruik en/of het delen omtrent uw data, kunt u altijd terecht bij de onderzoekers die dit met u zullen bespreken. De contactinformatie van de onderzoekers kunt u vinden onderaan deze brochure.

Onafhankelijk advies en vragen over het onderzoek

Wanneer u als deelnemer van het onderzoek verlangt naar onafhankelijk advies, of u eventuele klachten wilt indienen over het project kunt u deze indienen bij de secretaris van de ethische commissie van de Universiteit van Twente (Email: ethicscommittee-cis@utwente.nl). Deze ethische commissie is onafhankelijk en zal dus ook met een objectieve blik kunnen werpen u kunnen helpen met de door u ingestuurde onderwerpen.

Wanneer u inhoudelijke vragen heeft, kunt u deze op elk moment vragen bij de onderzoekers van het onderzoek. De contactgegevens van deze onderzoekers staan onderaan de informatiebrochure en consent form.

Contactgegevens van het onderzoeksteam

Zoals eerder aangegeven kunt u op elk moment terecht voor vragen bij het onderzoeksteam van het project. De eerste voorkeur van het onderzoeksteam gaat uit naar

contact naar de hoofdonderzoeker Sven Bormans. Wanneer dit door een reden niet schikt, is het geen probleem om een andere onderzoeker te contacteren.

Onderzoeker:

Sven Bormans - *Bachelor Creative Media*

Technology Student, Hoofd onderzoeker

s.r.bormans@student.utwente.nl

(+31) 6 11 18 19 70

Begeleider:

Randy Klaassen – *Assistant Professor Human Interaction, Project begeleider*

r.klaassen@utwente.nl

Appendix K: Questions of the evaluation of the sensors

Underneath the beforehand made questions of the evaluation of the sensor part are stated. These questions are asked in a semi-structured interview with the participant.

Question	Description
1.	How old are you?
2.	Do you have experience with similar kinds of sensors?
3.	How easy did you find it to place the sensor on the other participant?
4.	Was the explanation given by the researcher sufficient for you to correctly place the sensors?
5.	a) Did you think the sensors were sitting comfortable? b) Was there a moment in the evaluation were you thought the sensor was limiting your movement? c) Did you feel any pain or irritation on the skin caused by the sensors during the evaluation?
6.	a) Was there a moment in the evaluation where you felt restless? b) If so, would you label this moment as stress?
7.	a) What do you think about the size of the sensor module? b) Do you think the sensor module is looking appealing? c) When being used on babies in the user scenario it is designed for, is there something you would suggest to change?

Appendix L: The results and notes per participant in the evaluation of the sensors

Participant 1

The first part:

- The participant had no problem placing the sensor on the other participant
- The participant find the instruction to place the sensor sufficient but had some questions about how professional the picture looked of the instruction looked
- The participant had a general opinion about the aesthetics of the sensor module →"just a regular plaster, nothing weird".
- The participant liked the ease and lack of irritation due to the sensor module when removing the sensor afterwards.
- The participant had no issues of irritation or movement limitations when due to the sensor on the skin. Sometimes the wires were being considered to be annoying because of the pulling in some situations.
- The participant has doubts about the size of the sensor module. It is now considered to be a little bit too big to be used on a baby. The participant does not suggest which size the sensor module should be.

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye. A red line indicates a sudden change of movement as seen in figure 44 and 45.

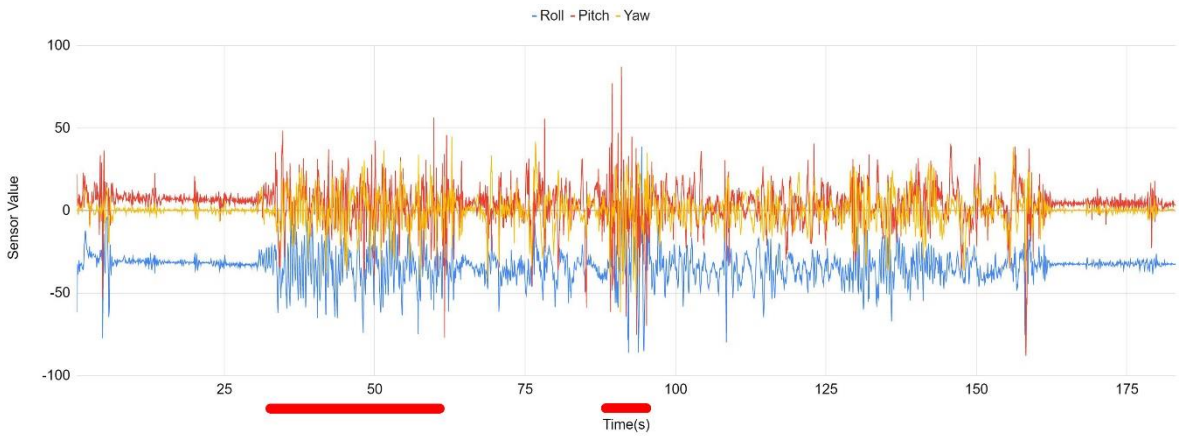


Figure 44: Evaluation participant 1 with movement sensor 1

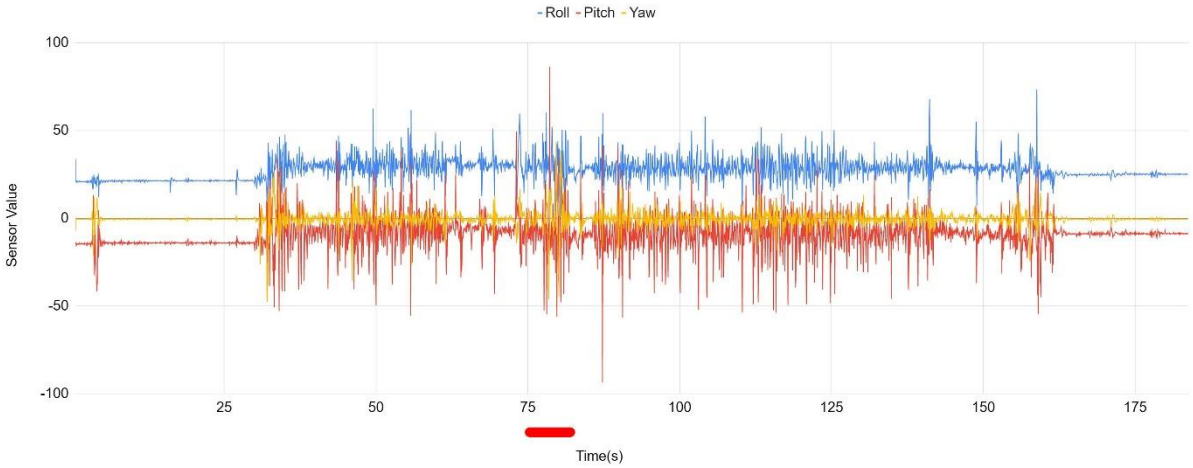


Figure 45: Evaluation participant 1 with movement sensor 2

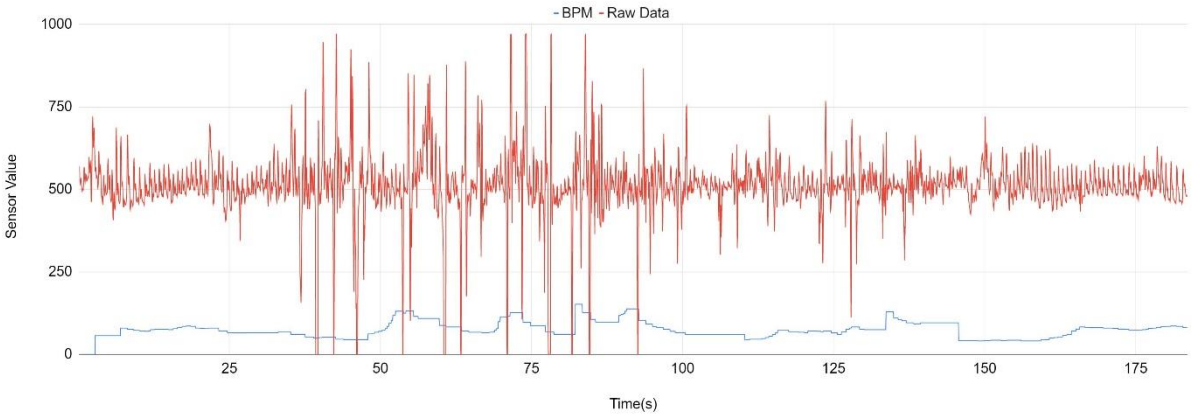


Figure 46: Evaluation participant 1 with pulse sensor

- The movement sensors both continuously measured the amount of movement of the participant during the evaluation.
- The participant was starting to move more in general when starting to sing.
- Two moments of a sudden increased movement of the participant are noticed—the first one being with both sensors, the second one only by looking at the arm movement.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to process the data.
- The participant stated after the evaluation not having a stressful moment(s) during the evaluation.
- A possible stress reaction(s) can not be concluded from the data.
- The sensors did measure continuously during the evaluation
- The data of the sensors was sent to the micro-controller (and laptop)
- The calibration time of the sensors was under 15 seconds

In conclusion,

The met requirements are: S1, S3, S5, S8, S11, S19, S20 and S22.

The requirements which are not met is: S2.

Participant 2

The first part:

- The participant stated not having trouble with placing the sensors.
- The explanation about the placement of the sensor is being conceded as sufficient by the participant
- The participant thinks the sensor module looks fine, because it just looks as a plaster.
- The participant has no experience with the same or similar sensor modules.
- The participant has no trouble(s) wearing the sensor modules.
- The participant stated that his movement was not limited due to the sensors. However, the participant was moving more carefully due to the wires attached to the sensors.
- The participant suggests removing the wires of the sensors when the concept is being developed further
- The participant did not experience any irritation on his skin due to the sensor modules during the evaluation
- The participant state the sensor module to be too big to be used on babies, but does not state the size it should be.
- The participant did not have any negative experiences with the sensor during the evaluation

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye. A red line indicates a sudden change of movement as seen in figure 47 and 48.

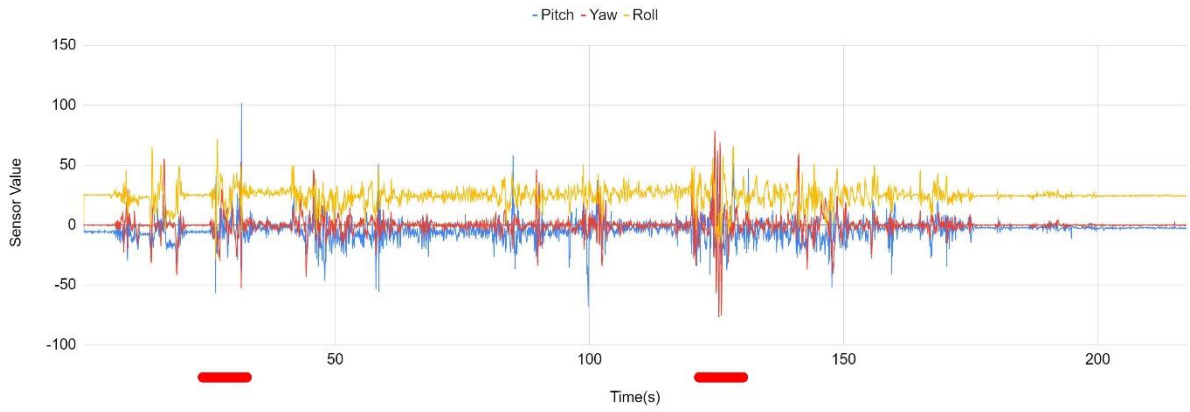


Figure 47: Evaluation participant 2 with movement sensor 1

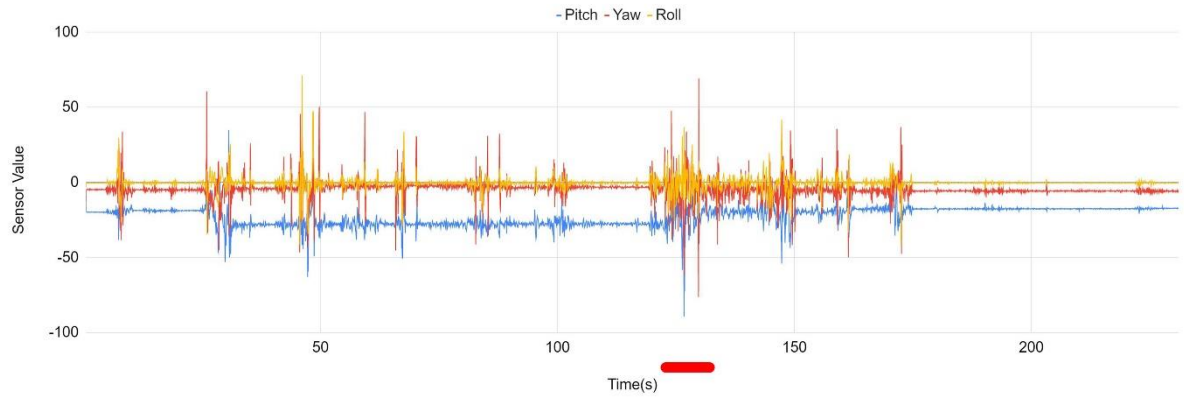


Figure 48: Evaluation participant 2 with movement sensor 2

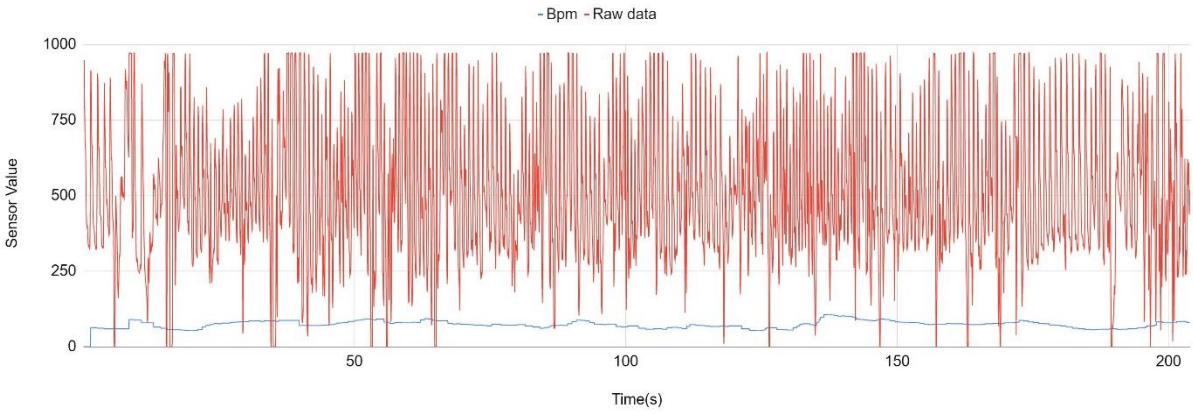


Figure 49: Evaluation participant 2 with pulse sensor

- The second movement sensor noticed two moments of sudden increased movement of the participant.
- The overall movement of the participant stayed the same during the evaluation.
- The data of the pulse sensor strongly differs from the previous participant.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to be able to process the data.
- The participant stated after the evaluation not having a stressful moment(s) during the evaluation.
- A possible stress reaction(s) can not be concluded from the data.
- All of the sensors did measure continuously during the evaluation.
- All of the sensors did send all of the data to the micro-controller (and laptop).
- The calibration of the sensors time was under 15 seconds.
- The participant thinks that the sensor module right now is a little bit too big. The participant can not explain how big it should be.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

Participant 3

The first part:

- The participant did make the comparison between the sensors used in this project and the sensors in the participants' smartwatch
- The participant did felt limited in the movement and acted extra careful due to the wires.
- The participant has no opinion on the design of the sensor module due to the wires attached.
- The participant had one trouble wearing the sensors due to the wires. The participant stated the wires pull quite hard on the sensors making them sit uncomfortably.
- The participant stated the size of the sensor modules to be too big. The participant suggests shrinking the sensor models by roughly half their size.

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye.

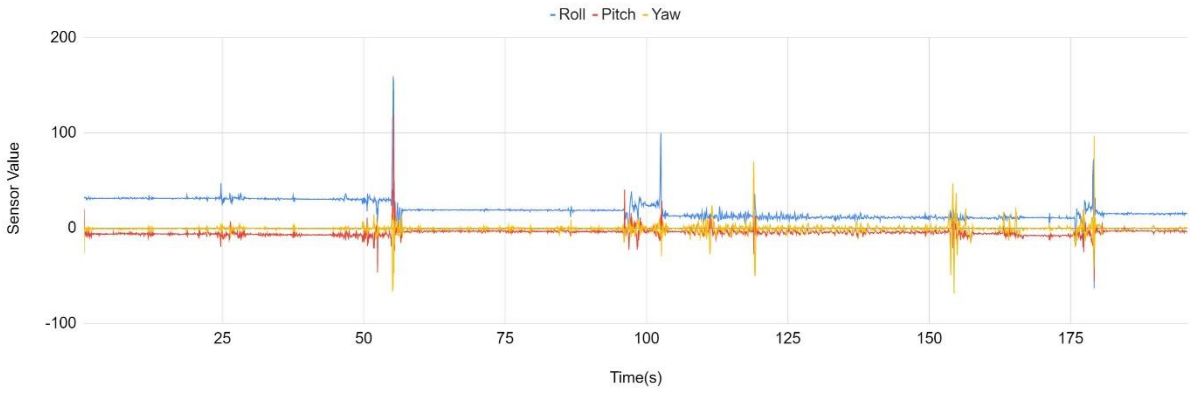


Figure 50: Evaluation participant 3 with movement sensor 1

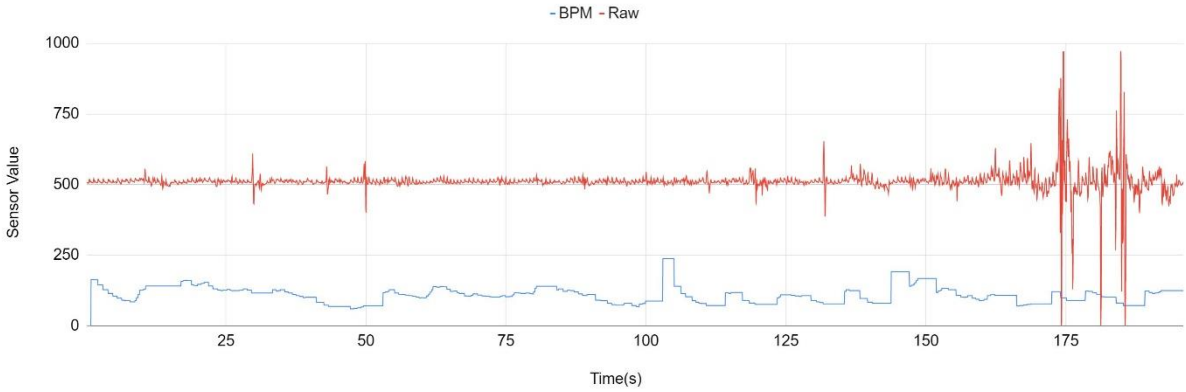


Figure 51: Evaluation participant 3 with pulse sensor

- Only one movement sensor was able to continuously measure the amount of movement of the participant during the evaluation. The other movement sensor had problems regarding a sudden loose wire during the evaluation.
- No moment of a sudden increased movement of the participant is noticed. However, a slight increase of movement is considered during the singing. The amount of movement is more at the end of the song than at the beginning.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to be able to process the data.
- The participant stated after the evaluation not having a stressful moment(s) during the evaluation.
- A possible stress reaction(s) can not with certainty be concluded from the data. However, the amount of movement increased over time during the evaluation, making it possible to have sensed a stress indicator.
- The participant did felt uncomfortable when starting singing and labelled this to stress.
- The calibration time of the sensors was under 15 seconds
- The size of the sensor module is being considered too big. The participant suggests making the module halve its size as it now is.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

Participant 4

The first part:

- The participant had experience with the used sensors. The participant has used the sensors earlier in a project.
- The participant had no problem with placing the sensors.
- The participant thinks the explanation of placing the sensor is sufficient but could be extended to make it potentially more clear for more people.

- The participant had trouble wearing the sensor modules. However, the participant did felt a little limited in movement due to the attached wires.
- The participant had not any irritation on the skin due to the sensor modules afterwards.
- The participant did not find the sensors very appealing, due to the wire. If the cable was removed, the participant would label the aesthetic of the sensor module to be neutral.
- The participant thinks the sensor module has an acceptable size.

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye. A red line indicates a sudden change of movement as seen in figure 52.

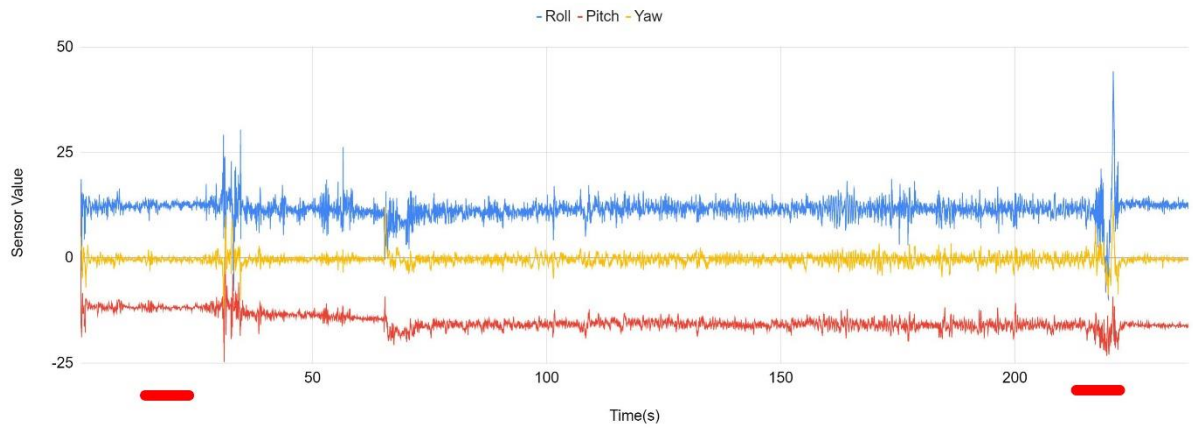


Figure 52: Evaluation participant 4 with movement sensor 1

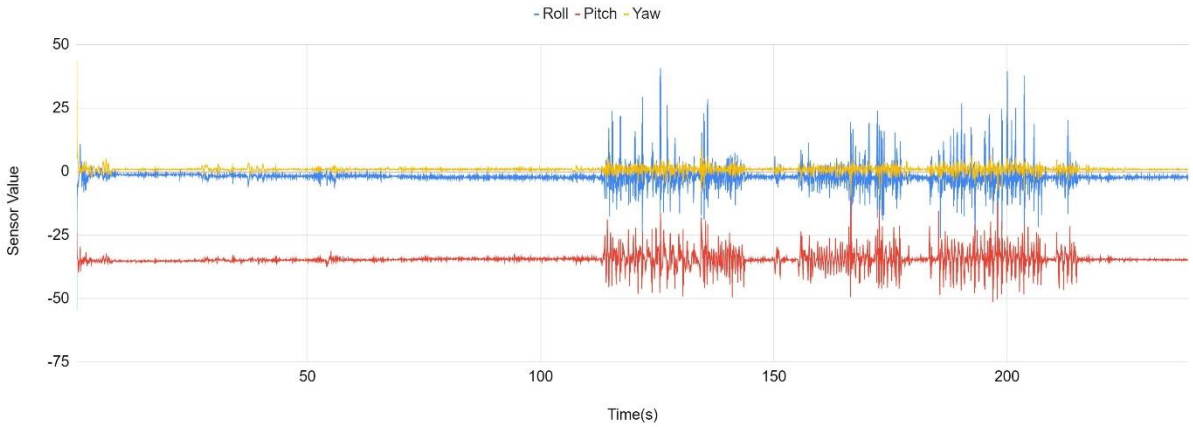


Figure 53: Evaluation participant 4 with movement sensor 2

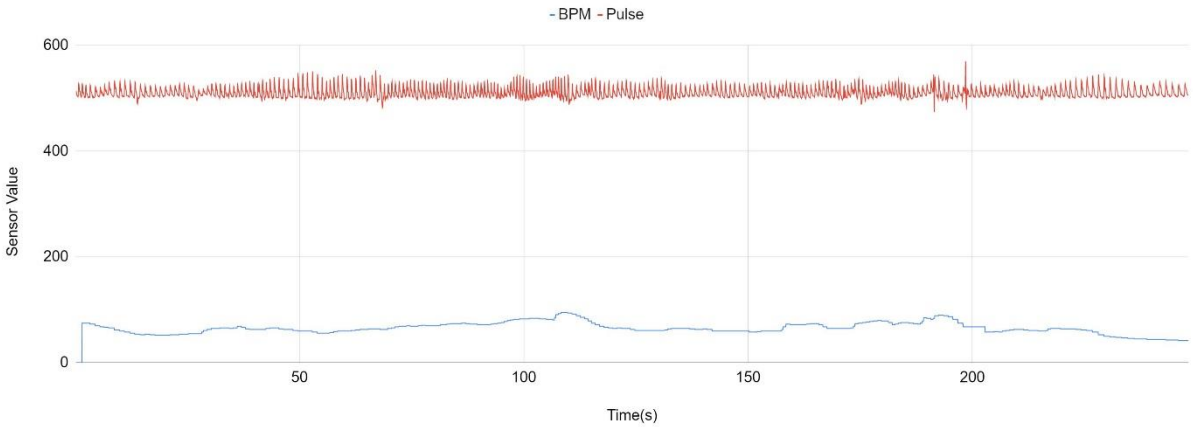


Figure 54: Evaluation participant 4 with pulse sensor

- The movement sensors both continuously measured the amount of movement of the participant during the evaluation.
- Two moments of an increased participant movement are noticed—one at the beginning and one at the end.
- The second movement sensor indicates a period of almost no movement at the beginning and a period of more movement at the end. This could be labelled as a stress indicator. However, the participant stated after the evaluation not having any stressful moment(s) during the evaluation.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to process the data.
- A possible stress reaction(s) can not be concluded from the data.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

Participant 5

The first part:

- The participant did not have any trouble when placing the sensor on the other participant
- The participant had experience with the pulse sensor. The participant had used this sensor in a project.
- The participant was neutral on the topic if the sensor has an appealing design or not. The participant says that it looks like an ordinary plaster which is not something good or bad in the participants' eyes.
- The participant did not have any trouble wearing the sensor modules.
- The participant had not any irritation on the skin due to the sensor modules.
- The participant state the sensor module to be too big. The participant state the sensor module should be half its size it is now.
- The participant does not think the plasters would last more than a day.

- The participant had not any negative experience with the sensor modules during the evaluation

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye. A red line indicates a sudden change of movement as seen in figure 55.

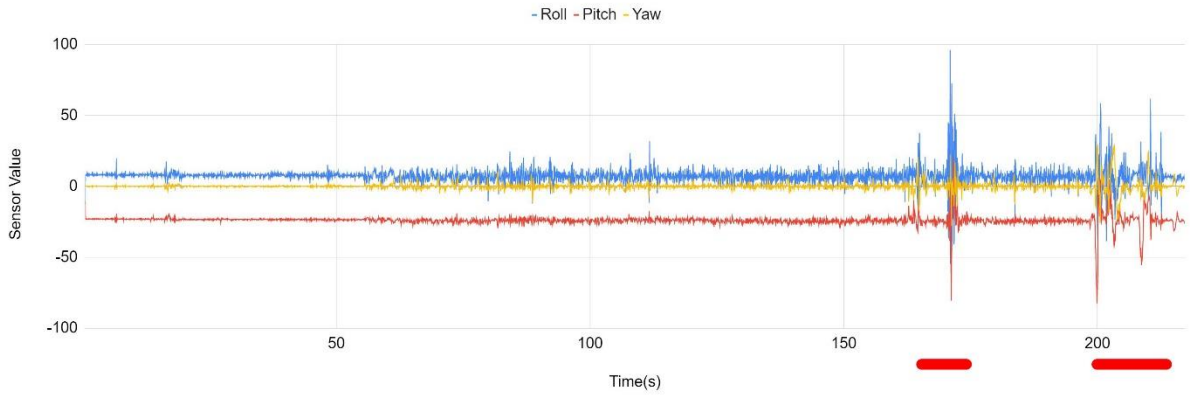


Figure 55: Evaluation participant 5 with movement sensor 1

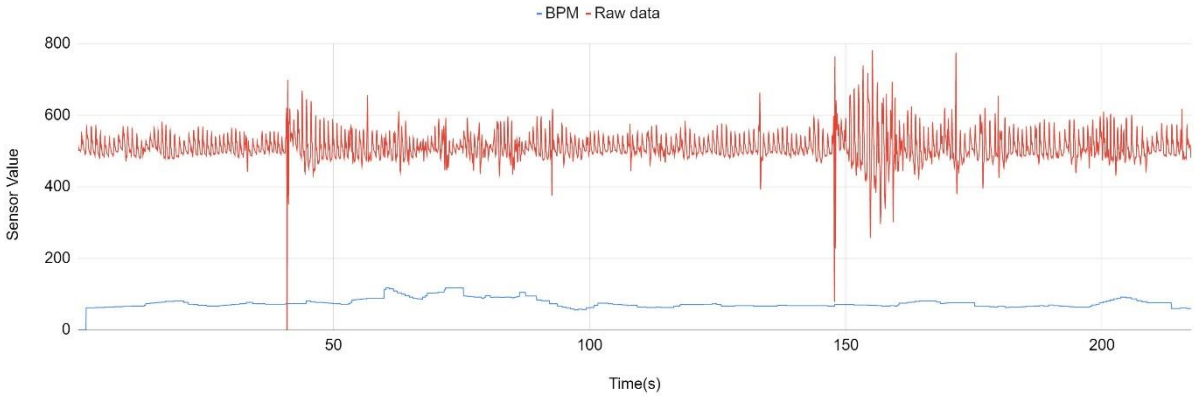


Figure 56: Evaluation participant 5 with pulse sensor

- Only movement sensor continuously measured the amount of movement of the participant during the evaluation.
- Two moments of an increased movement of the participant are noticed. Two at the end
- The general amount of movement of the participant stayed the same during the evaluation.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to be able to process the data.

- The participant stated after the evaluation not having any stressful moment(s) during the evaluation.
- A possible stress reaction(s) can not be concluded from the data.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

Participant 6

The first part:

- The participant had no trouble when placing the sensor on the other participant.
- The participant did find the explanation about how to place the sensors sufficient.
- The participant had no trouble wearing the sensor modules. However, the participant labelled the pulse sensor attached to the forehead as being "strange".
- The participant felt not limited in movement due to the sensor modules.
- The participant thinks the size of the sensor modules is too big. The participant suggests the sensor module be half the size it is now.
- The participant stated the aesthetics of the sensor modules to be neutral due to their plaster design.

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye. A red line indicates a sudden change of movement as seen in figure 57 and 58.

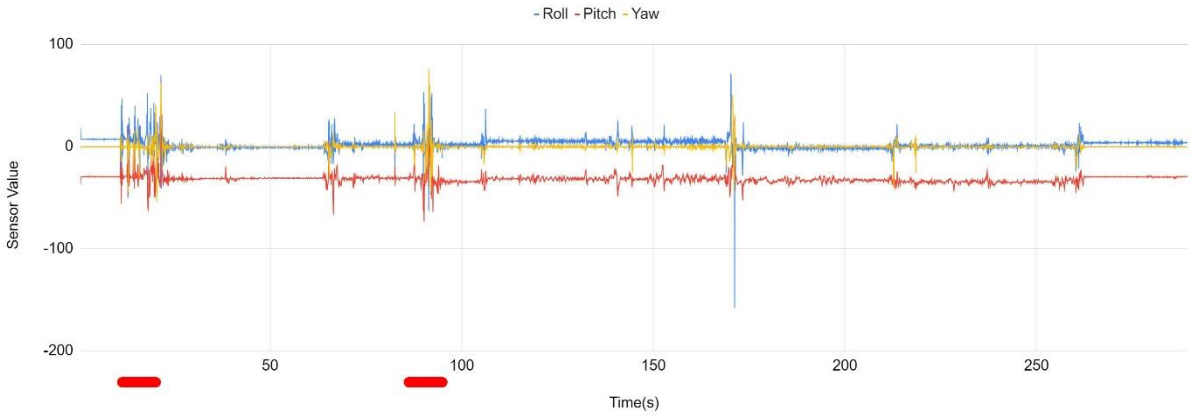


Figure 57: Evaluation participant 6 with movement sensor 1

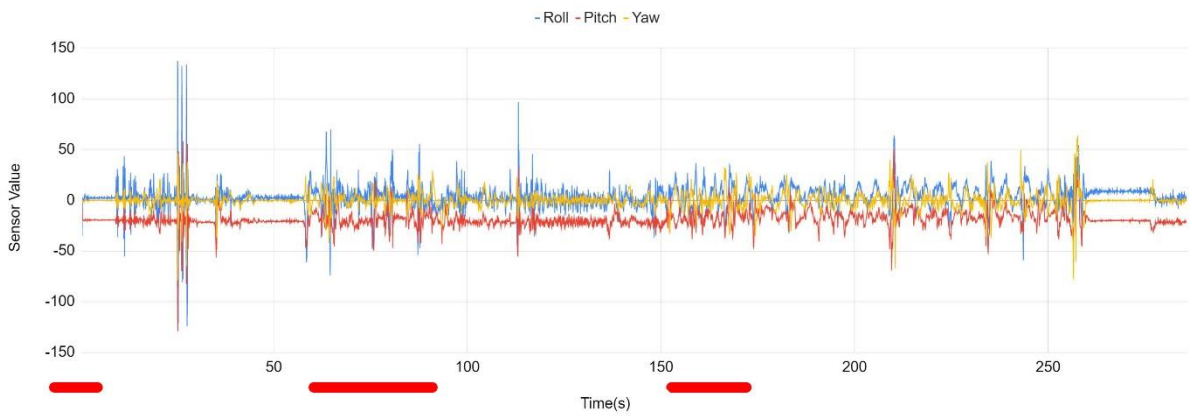


Figure 58: Evaluation participant 6 with movement sensor 2

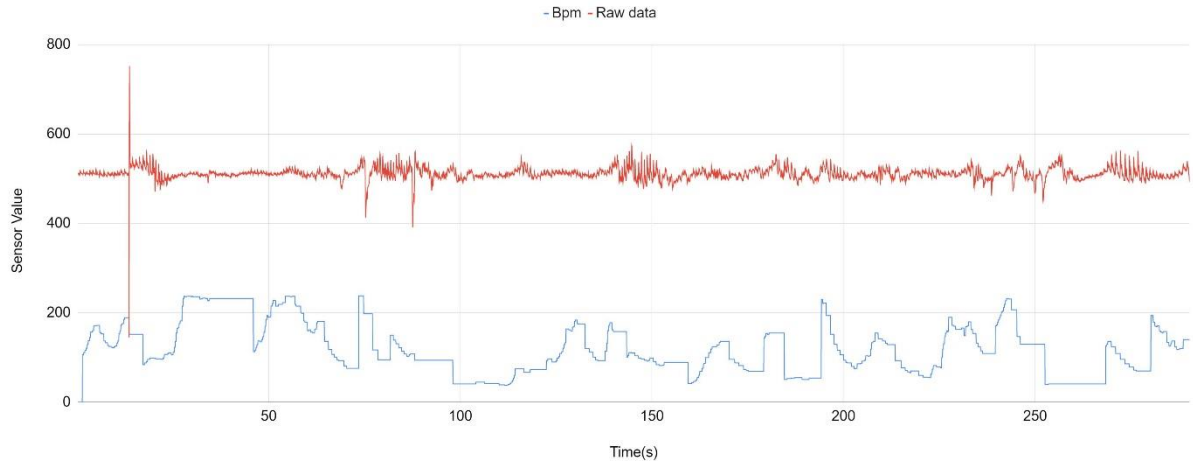


Figure 59: Evaluation participant 6 with pulse sensor

- The movement sensors both continuously measured the amount of movement of the participant during the evaluation.
- Three moments of an increased movement of the participant are noticed. One at the beginning and two in the middle.
- The general movement of the participant seems to increase during the evaluation. This can potentially be a stress response.
- The participant states after the evaluation to have experienced stress during the evaluation.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to be able to process the data.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

Participant 7

The first part:

- The participant had no trouble placing the sensor modules to the other participant.
- The participant thought the explanation about how to place the sensor is sufficient.
- The participant stated having no trouble wearing the sensor modules.
- The participant felt limited in movement due to the wires. If the wires were removed, the participant would not felt limited in movement.
- aesthetics of the sensor modules are being stated by the participant as to be neutral due to their plaster design.
- The participant had no irritation on the skin due to the sensor.
- The participant thinks the size of the sensor modules is too big. The participant does not state how big the sensor module should be.

The second part:

The data of both accelerators and the pulse sensor can be seen in the charts underneath. With the charts, it is examined if the amount of movement and/or the BPM of the participant has changed during the evaluation. For the movement sensors, an increase of movement in a certain period can be assessed when the peaks of the line are suddenly higher and/or if the amount of peaks in a period has increased or decreased. In other words, if the amount of peaks is denser in a certain period. For now, this is done by eye.

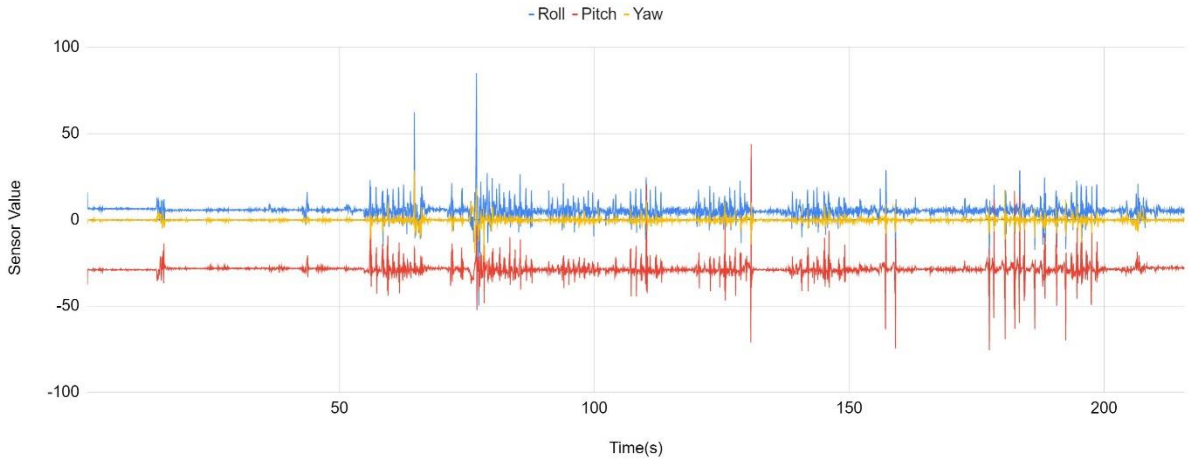


Figure 60: Evaluation participant 7 with movement sensor 1

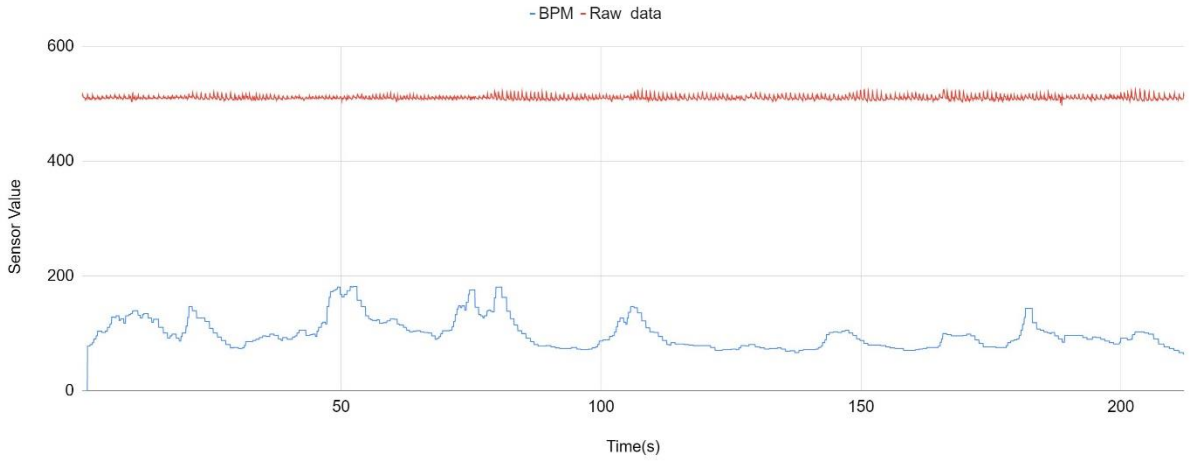


Figure 61: Evaluation participant 7 with pulse sensor

- One movement sensor continuously measured the amount of movement of the participant during the evaluation. The other movement sensor did not measure correctly due to a for the researcher unknown reason.
- No moments of an sudden increased movement of the participant are noticed.
- The general movement of the participant increased after a third of the evaluation.
- The pulse sensor did not collect any data which can be used for the evaluation due to the (movement) noise of the sensor.
- The sensor's data is successfully sent to the microcontroller (and the laptop) to be able to process the data.
- The participant stated after the evaluation not having a stressful moment(s) during the evaluation.
- A possible stress reaction(s) can not be concluded from the data.

In conclusion,
The met requirements are: S1, S3, S5, S8, S11, S19, S20, S22
The requirements which are not met are: S2

The researcher evaluating part three of the evaluation

- The researcher was able to access all of the data coming from the different sensors afterwards when the sensors were able to measure during the evaluation.
- The researcher was able to easily send the data to an external drive afterwards.
- The sensors are now connected to the micro-controller with wires, not by a wireless protocol due to time contains.
- All of the sensor modules were integrated into a plaster kind of casing
- All of the components used are considerable cheap, making the concept not potential expensive to buy in the future.
- These sensor modules cannot be used in various environments. The researcher states that the sensor modules can only be used within a certain period of a power source and laptop due to the wires. Also, the concept right now can not be used in wet environments due to the exposed electrical parts.
- The plasters were used multiple times and only being replaced approximately three times during the evaluation. The other parts of the concept were used for every assessment. This made the concept easy to re-use multiple times when changing the plaster after two of three placements on the body.

In conclusion,
The met requirements are: S4, S10, S15, S21, S26.
The requirements which are not met are: S6, S21

Appendix L: Information Brochure Application Evaluation

Informatiebrochure:

How High Is the Stress Level?

Over

Dit project vanuit de Universiteit van Twente in samenwerking met ZGT en IMH Nederland genaamd “How high is the Stress Level?” zal onderzoeken welke mogelijkheden er bestaan omtrent het meten van stress onder baby’s doormiddel van het gebruik en het combineren van hedendaagse technieken.

Een stress reactie onder baby’s kan door vele factoren in hun omgeving geactiveerd worden. De factoren die deze stress reactie activeren zal verschillen per baby en de omgeving. Wanneer deze factoren niet worden gevonden en/of hiermee niks wordt gedaan en hierdoor het stress niveau van de baby aanhoudt over een langere periode, kan dit negatieve gevolgen hebben voor de ontwikkeling van de baby.

Op dit moment hebben de onderzoekers van het project een concept product ontwikkeld. Dit product bestaat uit twee delen: een meetgedeelte en een applicatie. Het meetgedeelte is al getest op verschillende personen. Dit gedeelte zou de stressreactie moeten kunnen oppikken van de baby wanneer deze stress aanwezig is. Nu de manier van meten is afgerond wordt de applicatie verder onderzocht. Welke functionaliteiten en feedback methodes er in de applicatie moeten worden verwerkt wordt in deze evaluatie onderzocht. Met dit interview willen de onderzoekers een beter beeld krijgen met welke functionaliteiten in de applicatie u de gemeten informatie zou willen krijgen als u het product zou gebruiken. De vragen in het interview zal dan ook gericht zijn naar uw voorkeuren op functionaliteiten binnen de applicatie.

In deze informatiebrochure zal in het kort uw deelname aan het project “How high is the stress level” worden besproken met daaruit alle nodige informatie omtrent de participatie in het project. Dit bedoeld, om u te helpen in uw keus van deelname in dit onderzoek.

Deelname

De deelname in dit onderzoek is geheel op vrijwillige basis. De tijdsduur van het interview is geschat op 30 minuten maar kan hier van afwijken. Voor het interview zal u deze informatiebrochure met een consent form te zien krijgen ter informatie van uw deelname aan het interview. Wanneer de consent form is ingevuld, en u dus akkoord bent gegaan met uw

deelname, kunt u uw consent nog terugtrekken tot 48 uur na het plaatsvinden van het interview. Het terugtrekken uit het onderzoek kan op elk mogelijk ogenblik voor het interview, gedurende het interview en 48 uur na het interview.

Interview procedure

Het interview zal online plaatsvinden op het platform Microsoft Teams of Zoom, welke van deze twee zal vooraf naar u gecommuniceerd worden. De link die nodig is om te kunnen toetreden zal uiterlijk een dag vooraf worden toegestuurd door een van de onderzoekers. In het begin van het interview zal door de interviewer vragen worden gesteld omtrent mogelijke grenzen die u wilt opstellen. Dit houden onderwerpen in die waar u gedurende het interview niet over wilt hebben. Hierna zal de onderzoeker het gemaakte product met de werking van het product aan u uitleggen. Wanneer deze aan u is duidelijk gemaakt zal de onderzoeker naar u mening vragen over het product in de context wanneer u het product zou gebruiken.

Aanvullend komende de manieren van feedback aan bod. De onderzoeker zal hierbij als eerste verschillende manieren van feedback aan u voorleggen en vragen naar welke manier van feedback bij u de voorkeur heeft en waarom. Daarnaast wordt er nog aan u gevraagd of u nog andere manieren heeft bedacht die van toepassing zouden kunnen zijn en hoe u kijkt naar deze manier tegenover de eerder besproken manieren.

Gedurende het interview is er de mogelijkheid dat er gevoelige onderwerpen besproken worden. Wanneer u deze niet wilt antwoorden dient de onderzoeker dit te respecteren en door te gaan naar een ander onderwerp. Ook wanneer u tijdens het interview vragen heeft, zal deze op elk moment gesteld kunnen worden en beantwoord worden.

Gegevensverzameling

Gedurende het interview zal de audio van het gesprek met het beeld van de applicatie worden opgenomen. Dit zal worden opgeslagen op een voor anderen niet toegankelijke locatie. Ook zullen er aantekeningen gedurende het interview worden gemaakt omtrent de reacties tijden en na een vraag. De gegevens zullen naderhand gebruikt worden om het gesprek te kunnen samenvatten en goed te kunnen interpreteren voor de onderzoekers.

Gegevensbewaring

De gegevens worden, volgend de VSNU richtlijnen, 10 jaar veilig bewaard op een lokale, door de universiteit goedgekeurde harde schijf, waar andere mensen, met uitzondering van de

onderzoekers, geen toegang tot hebben. Volgend de AVG richtlijnen, zal de gegevens anoniem worden bewaard om de privacy van de betrokken partijen te waarborgen.

48 uur na deelname in het interview kunt u ervoor kiezen om de door u verkregen informatie te laten verwijderen. De gegevens worden op dat moment volledig gewist en eventuele conclusies die daaruit zijn geschetst zullen niet meer gebruikt worden in het onderzoek. Na deze 48 uur zal het vragen voor de verwijdering van de verkregen gegevens helaas geen garantie meer bieden voor het verwijderen van de gegevens.

Gegevensgebruik

De gegevens verzameld in het onderzoek zal verwerkt worden binnen deze afstudeeropdracht gegeven vanuit de Universiteit van Twente. De resultaten/conclusies kunnen worden gepubliceerd op de website van de Universiteit van Twente en in andere onderzoeken. Ook kunnen andere partijen de gepubliceerde resultaten gebruiken voor de ontwikkeling binnen hun eigen project en/of bedrijf . Hierbij worden alle gegevens, resultaten en conclusies volledig anoniem beschreven om uw privacy te waarborgen.

Wanneer u het niet eens bent met de gebruik en/of het delen omtrent uw data, kunt u altijd terecht bij de onderzoekers die dit met u zullen bespreken. De contactinformatie van de onderzoekers kunt u vinden onderaan deze brochure.

Onafhankelijk advies en vragen over het onderzoek

Wanneer u als deelnemer van het onderzoek verlangt naar onafhankelijk advies, of u eventuele klachten wilt indienen over het project kunt u deze indienen bij de secretaris van de ethische commissie van de Universiteit van Twente (Email: ethicscommittee-cis@utwente.nl). Deze ethische commissie is onafhankelijk en zal u kunnen helpen met de door u ingestuurde onderwerpen.

Wanneer u inhoudelijke vragen heeft, kunt u deze op elk moment vragen bij de onderzoekers van het onderzoek. De contactgegevens van deze onderzoekers staan onderaan de informatiebrochure en consent form.

Contactgegevens van het onderzoeksteam

Zoals eerder aangegeven kunt u op elk moment terecht voor vragen bij het onderzoeksteam van het project. De eerste voorkeur van het onderzoeksteam gaat uit naar contact naar de hoofdonderzoeker Sven Bormans. Wanneer dit door een reden niet schikt, is het geen probleem om een andere onderzoeker te contacteren.

Onderzoeker:

Sven Bormans - *Bachelor Creative Media*

Technology Student, Hoofd onderzoeker

s.r.bormans@student.utwente.nl

(+31) 6 11 18 19 70

Begeleider:

Randy Klaassen – *Assistant Professor Human Interaction, Project begeleider*

r.klaassen@utwente.nl

Appendix M: Consent form Application Evaluation

Consent Form:

How High Is the Stress Level?

About the project and participation

Dear reader,

I would like to inform you about the research you have applied to participate in.

This research aims to develop a device that can objectively measure the stress level among babies by using current-day technology. With this device, the babies' environment should be able to detect the stressors of the baby and thereby be able to control the stress level of the baby. This device gives the caretaker the possibility to remove the babies' stressors when needed and prevent long-term effects from the babies caused by (toxic) stress. This device consists of two parts. The first part being the sensors and the second part being the application.

The interview discusses the topic of different functionalities and feedback methods within the concept application built by the researcher. The interview aims to question you about your opinion on the application and observe your behaviour within the application. The questions thus also have the intention to gather information about which functionalities and feedback method you prefer.

The interview will approximately take 30 minutes and is completely voluntarily to all the parties involved. You will beforehand fill in a consent form given by the researcher, which will be valid until 48 hours after participation in the interview. Before these 48 hours, you may decide at any moment to withdraw your consent. The consent can be withdrawn at any moment during and after (until 48 hours) the research. You can ask questions about the research at any moment before, during and after the research. This information will always be provided to you when possible, except for the personal data of other parties involved in the research.

Data usage

During the interview, an audio recorder will record your voice and the voice of the researcher combined with a screen capture of you using the application. This data will afterwards be saved and summarized on paper to get a clear overview of the interview. The researcher will also make additional notes during the interview where other reactions of the interviewee will be

written down, with the intention to capture unintentional reactions from the interviewee on the information/questions brought by the researcher. Own interpretation from the researcher of the researchers' data will be labelled to prevent any misunderstanding about the collected data from you. All data collected from you will be labelled as "X" to keep your identity anonymously. All data collected during the interview can be used at any moment in this research by the researcher.

The data collected in the interview will be analyzed and processed by the researcher within the researcher's Bachelor thesis. The data will be used within this graduation project on behave of the University of Twente. The results of the research may be published on the website of the University of Twente and in other research papers from other researchers. The research results may also be used by companies who are interested in developing the device in this research.

The researchers of the project are the only persons who can access the collected data. The data will be stored on a local secure storage device located at the host temporary, and in the end, the data will be stored in a university-approved location. All data will be saved anonymously to protect the identity of the parties involved. The storage of the data will proceed as described by the AVG guidelines. Following these guidelines, the data will be stored over a time span of 10 years. After these ten years, the researcher may choose to delete the files. When other parties request data of this research, including your involvement, the researcher will only share the data when having permission from all parties involved.

Within 48 hours after the interview, may ask to delete his/her data collected and processed during the research. The data and results will thereby be erased as soon as possible and not be used or mentioned within the research. If, after 48 hours, you asks to delete the information, the request will be declined, and the data collected can still be used within the research.

Informed consent form

I hereby declare that I have been informed in a manner that is clear to me about the nature and method of the research as described in the aforementioned information brochure. My questions have been answered to my satisfaction. Parts of the interview can be quoted where only your function will be mentioned. I agree with my own free will to participate in this research. I reserve the right to withdraw this consent without the need to give any reason, and I am aware that I may withdraw from the interview at any time.

I agree to my interview being recorded. Additionally, I agree that an anonymized transcription of the whole interview can be added as an appendix to the research. If my research results are to be used in scientific publications or made public in any other manner, they will be completely anonymous. My personal data will not be disclosed to third parties without my express permission. If I request further information about the research, now or in the future, I may contact the main researcher Sven Bormans or his supervisor Randy Klaassen.

Contact information:

Researcher:

Sven Bormans - *Bachelor Creative Media Technology Student, Main researcher*

s.r.bormans@student.utwente.nl

Supervisor:

Randy Klaassen – *Assistant Professor Human Interaction, Project supervisor*

r.klaassen@utwente.nl

Suppose you have any complaints about this research. In that case, you can direct them to the secretary of the Ethics Committee of the Faculty of Electrical Engineering, Mathematics and Computer Science at the University of Twente, P.O. Box 217, 7500 AE Enschede (NL), email: ethicscommittee-cis@utwente.nl.

Signed in duplicate:

…… ……

Name participant Signature

I have provided explanatory notes about the research. I declare myself willing to answer any questions that may still arise about the research to the best of my ability.

…… ……

Name researcher Signature

Appendix N: The questions of the application evaluation

Underneath the beforehand made questions of the evaluation of the application are stated. These questions are asked in a semi-structured interview with the participant.

Question	Description
1.	How old are you?
2.	Do you have experience with similar kinds of apps (apps that are connected to a medical device/ app which gives feedback to stress)
3.	What is your general opinion on the design of the app? (think about the use of colours, fonts, thinks they may find distractive and general navigation)
4.	Did you find any trouble when executing the previous tasks?
5.	Did you find the information about connecting the sensors with the application sufficient enough?
6.	a) Were the visualized data in the statistics tab understandable? b) is there something that could be improved? c) Is there some kind of data(visualization) missing in your eyes? d) When filling in the amount of feedback you wanted to receive in the application you filled in …, why did you chose this option?
7.	a) Did you find it to be easy to contact a specialist? b) When you wanted to contact the caretaker, you chose to use communication via …, why did you choose this option?
8.	When filling in an additional note, did you find this to be a lot of/too much work?

Appendix O: The results and notes per participant in the evaluation of the application

Participant 1

Category 1: intuition

- The participant has no trouble in directing throughout the application
- The participant finds the shortest path to the goal of the task every time and thinks the application is intuitive to navigate through
- The participant thinks that it is a better option to use a picture or video of a real baby to place the sensor and receive more explanation.
- The participant recommends placing the older stress reactions in the logbook at the bottom and the new ones on top. This is because the participant thinks that reading from top to button is generally done by the users of the application
- The buttons to navigate through the different periods in the statistics application were not found very quickly

Category 2: the correct number of features and giving the right amount of feedback

- The participant thinks the application does the right thing by giving the user an option which amount of feedback to receive from the sensors. However, the visualisations could be more visually appealing
- The participant chose the option of getting the most feedback possible from the sensors
- The participant likes the ease of contacting a professional and the different options to reach the specialist. However, the telephone options are being questioned regarding the availability of the specialist.
- The participant likes the idea of being able to share the data within the application with a professional.
- Filling in the additional notes is not being considered to be too much work for the parents.

Category 3: general design of the application

- The participant does like the use of different colours in the application to indicate the importance of the various subjects
- The general colours in the application were considered to be neutral and therefore good.
- The participant suggests making the not filled in stress response of the baby be another colour to mark the parent that it has not been filled in yet.

Category 4: General impression of the application

- The participant seems to think that the application, in general, serves its purpose but needs to be further developed.
- The participant seems to have no problem making an account
- The application is now built to be used by one of the parents. The participant suggests making the application suitable to be used for both parents. This means that the logbook is shared with both parents, and other functionalities can be shared.

In conclusion,

The met requirements are: A1, A2, A3, A4, A5, A8, A9, A10, A12, A19

The requirements which are not met are:

Participant 2

Category 1: intuition

- The participant found the application in general intuitive to use. Most of the tasks were easy to execute and did not cause any trouble.
- The icons used were intuitive for the participant.
- The participant had a few problems with the second scenario. Here the participant was not able to directly go to statistics. The participant would have found it more logical to go directly to the statistics page from a message in the logbook. Also, the participant missed the option to go back sometimes.
- The option to navigate through different periods on the statistics page was not clear at first.
- The participant clicked mostly before thinking about what the reason was for clicking on something.
- I wanted to say that it was very nice to have feedback on the placement and connection of the sensors.
- The messages on the logbook should go from old to new, down to up (so the opposite of now).

Category 2: the right number of features and giving the right amount of feedback

- The participant does think the application gives enough feedback to the parent about the sensors.
- The participant liked the idea of the option to choose the amount of feedback to receive.
- The graphs were easy to read by could have been designed more appealing
- In general, the application does reach its goal.
- The participant thinks it would be better to use clickable options instead of having to type when adding a note into the logbook.
- The participant thinks that it depends on the baby's situation if the user is going to fill in the additional notes every time. The parent will be more motivated to fill the notes when the baby's problem is bigger.

Category 3: general design of the application

- The general design of colours and icons are sufficient.
- The use of different colours to indicate something important is being considered to be a good thing and not distracting

Category 4: General impression of the application

- Adding a QR-code to the sensors would be an easy method to make sure the neighbours will not accidentally connect with your sensor.
- The participant did not think it was a problem to register for the application
- The participant would like to see the application be developed to be used not by just one parent but by both parents. Both parents should have their own accounts but have the same logbook and data available.

- The participant misses a "tips" page. The participant thinks that it is good that the user easily may have contact with a professional. However, the participants think it is better to implement a tips page within the application, which helps them solve the problem first themselves before contacting a professional.

The met requirements are: A1, A2, A3, A4, A5, A10, A12

The requirements which are not met: A9, A19

Participant 3

Category 1: intuition

- The participant found the application in general intuitive to use but had problems finding the "share with a professional" option. The participant expected this option to be on the statistics page
- The participant would like to see an option where both the sensors could be connected simultaneously
- The participant liked the explanation about placing the sensor. However, the participant would like to see a different visualisation of the baby. The participant brought up the idea of having a small video on how to place the sensor instead of the picture
- It was clear for the participants what the notifications mean
-

Category 2: the right number of features and giving the right amount of feedback

- The participant chose to get as much feedback from the devices.
  The participant liked having a waiting screen and confirmation about the placement and connection of the sensors.
- Except for the sharing data functionality, the participant had no problem navigating through the application. The participant was able always to find the shortest route.
- The participant liked having a different visualisation of the application. The amount of information visualised in the graphs is being considered to be sufficient. However, the graphs could be designed more appealing in the future.
- Filling in the additional notes is not considered too much work for the parents in a situation where there is a clear view that the baby is potentially having a problem. For regular use, the notes could be too much of an effort to parents.
- The participant liked having a different kinds of options to communicate with the professionals. However, the participant thinks that it would be better to have the specialist state which communication methods can reach him.
- The participant questioned if contact with email and messages can not be considered as the same. When this is the case, the participant would like to have the message method instead of the email method. This is because of the better approachability of sending a message in the application over sending an email.
- The participant likes having the option of being able to call the specialist very quickly. This is preferred for situations where the question is very urgent.

Category 3: general design of the application

- Colour and icon use are implemented correctly. The participant did not find these not distracting or strange. Having different colours to highlight certain parts are being considered to be a good thing.
- The participant would like to see a filter option in the logbook to better view the specific kind of notification. Now to look through your additional notes could be a lot of effort.

Category 4: General impression of the application

- The participant would like to see an option where both parents can use the application instead of one (of with both an own account)
- The participants state that it could be for the parents a big thing to download and use an application that measures and displays the stress reaction of the baby. The participant suggests having an introduction text at the beginning of the application to comfort these parents.
- The participant had no problem making an account for the application.

The met requirements are: A1, A2, A3, A4, A5, A9, A10, A12, A19

The requirements which are not met are: /