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Smart Sleep

Project report

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Table of Contents

Introduction

Each day people discover new functions of the human brain and relate these to how we behave ourselves in society. In times where great discoveries are made like the ticking of a clock, one of our primal behaviours is still surrounded with mystery. As you can see in the literature research chapters, plenty of research has been dedicated to sleep. This research taught us what happens when we sleep, and what happens to us when we do not sleep for some time. But it did not clearly show why we sleep. Because of this, researchers have developed theories about why we are sleeping in the first place. Putting all these theories together, I can only conclude that sleep is an extremely complex process, essential for humans to function optimally.

Then why did I choose to design for such a complicated phenomenon as sleep? First of all, for personal reasons. I have been interested in sleep for quite some years, because I have been living with a sleep disorder for quite some time myself. When I was twelve years old, I started noticing I fell asleep more and more during the day. After visiting specialists, it got diagnosed with Excessive Daytime Sleepiness, which is one of the symptoms of narcolepsy. The product I have designed attempts to help people suffering from narcolepsy, enabling these persons to participate in social activities just like everyone else.

The second reason I chose to work on this project is the highly social approach of this project. Sleep is an essential process in human beings, but people will only notice this when it is not there. Therefore, designing for sleep will always result in a socially relevant design, with the potential to change people's lives. This is the first project that showed me this transformative potential from the beginning and therefore motivated me throughout the project to create something interesting, something special.

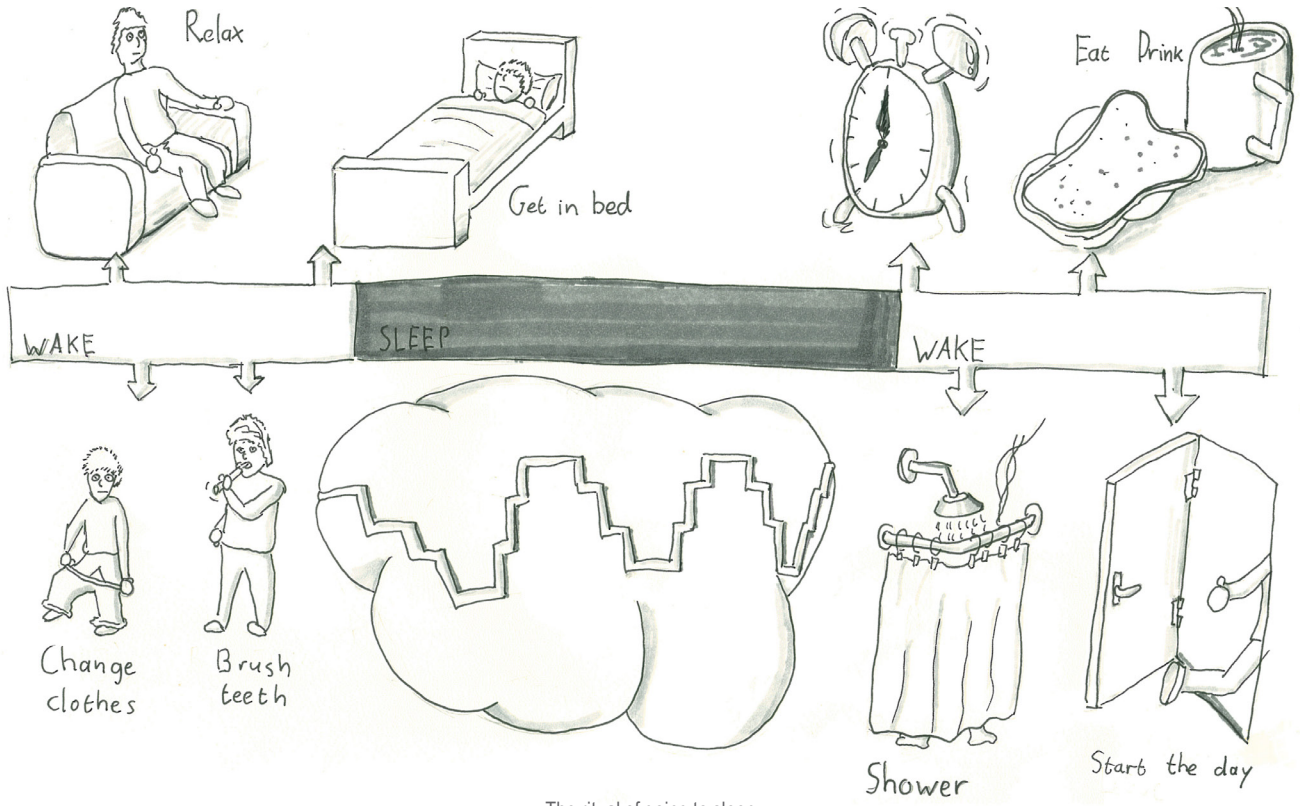
I am writing this introduction after I finished this project. This project changed me as a designer because it showed me the importance of a socially relevant design case. All aspects about such a design case are interesting: the research is more intriguing, the experts have more specific knowledge and the target group is more willing to help you with the design. Taking all these aspects together, you get the perfect conditions to create a socially transformative design. What can be achieved under these circumstances, can be read in this report.

What is sleep?

The focus of this project is on the process of sleep and the possibilities to enhance or adapt this process, in order to improve sleep in humans. To design for such a complex process, literature research after sleep is necessary. With this knowledge, it is possible to design a product that fits within the project's focus.

We know sleep as the phenomenon of closing your eyes and "refreshing" for the next day. Is it possible to decompose sleep in more specific activities? In 'why we sleep'(Horne, 1988) Horne observes the following common features amongst sleeping mammals:

- A typical body posture
- A specific site or nest for this behaviour.
- Physical Inactivity
- A regular daily occurrence influenced by a circadian clock.
- More stimulation is required to rouse the animal than during wakefulness.



The ritual of going to sleep

Stages of sleep

While sleep feels like a single activity (or a lack of activity) to us, it actually consists of multiple stages. According to stages of sleep (Dale Purves, 2001), Nathaniel Kleitman and Eugene Aserinksy first distinguished these different stages using electroencephalographic (EEG) recordings of sleeping humans. The different stages occur in a very characteristic sequence. J. Horne describes the four different stages in “Why we Sleep” (1988), each with their own function.

REM sleep

REM sleep is the most-discussed stage in sleep research. During this stage brain, activity comes close to that of a person that is awake, and measurements from a person in a REM sleep show that sleepers also have lots of eye activity during REM sleep. Therefore, this stage is called Rapid Eye Movement (REM) sleep.

Stage 1

During this stage, the brain transits from alpha waves, standing for being awake, to theta waves, a much slower wave. This stage is also called “drowsy sleep,” since a person still has some feeling of an external environment. Twitches and hallucinations are common in this stage, since it is a transition between reality and sleep.

Stage 2

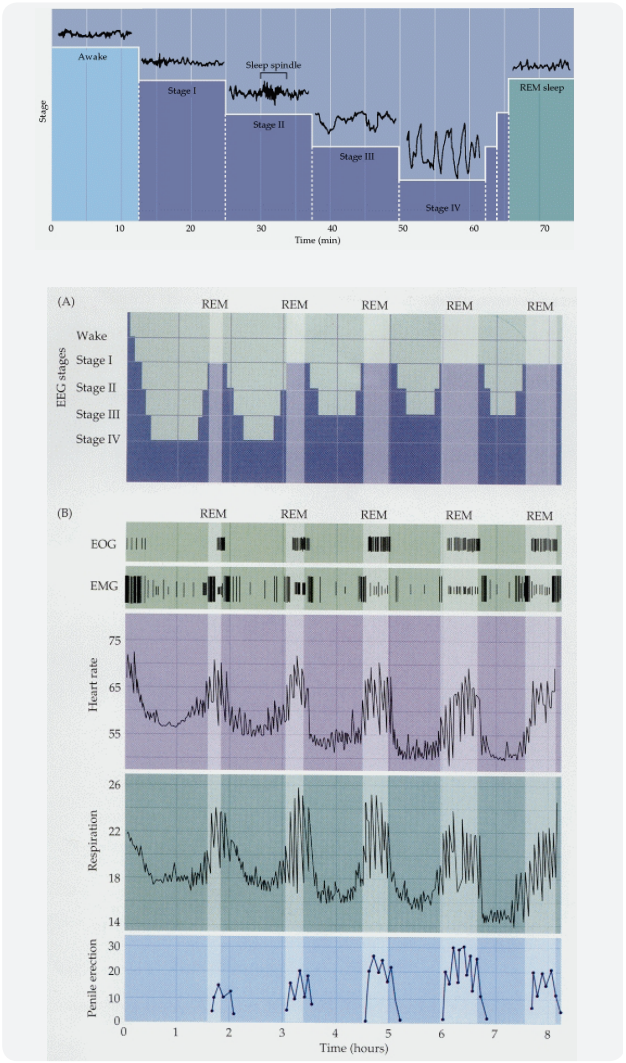
The second stage of sleep takes the sleeping person into a deeper sleep, characterized by a lowered heart rate and so-called “sleep spindles.” These sleep spindles characterize that the brain is inhibiting impulses from the outside, to let the person sleep.

Stage 3 SWS

The last stage is the deepest stage of sleep, also called Slow Wave Sleep. A sleeping person spends the most time of his sleep in this stage. At this point in sleep, the person has the lowest respiration and heart rate, and EEG measurements only show activity in the slower brain waves. It is the most difficult to wake up a person from this stage, and typically a person waking up from this stage is confused and disoriented.

The sleep cycle

After the SWS stage, the brain will fall back to stage 3 sleep, and then back to stage 2 etcetera. After stage 1, the brain will have periods of REM sleep, and then continue back to stage 2. This loop is called the sleep cycle. During the night, a person will spend 20-25% of his sleep in REM and 45-50% in Stage 2. Time spend in Slow wave Sleep is dynamic. Total SWS in children and young adults is more than in elderly, some elderly even have no SWS during their nights.



Graphical representation of the different sleep states, retrieved from: http://www.ncbi.nlm.nih.gov/books/NBK10996/figure/A1975/?report=objectonly

Functions of sleep

Different research shows that sleep in humans does not have one specific function, but is a process that serves multiple purposes. Scientific research backs up all the theories about the different purposes of sleep. Because these different theories about sleep are all sufficiently grounded in research, it is likely that sleep has multiple functions.

Sleeping to restore

The first and (initially) most logical function of sleep is to let your body rest. A sleeping person does not move, because the brain produces a neurotransmitter that blocks the signal to the muscles. Therefore, it is safe to say that sleep has some sort of restorative function. Research also shows that lack of sleep affects the immune system, and therefore makes you more vulnerable to diseases (Zager, Andersen, Ruiz, Antunes, & Tufik, 2007).

Sleeping on the way home is normal for commuters

Sleeping to improve memory

Different studies suggest that sleep is beneficial for the memorial functions of the brain. The theory is that during sleep, the part of the brain that receives new impulses shuts down, so that the part of the brain that stores memories can focus on reorganizing the memory. These processes cannot run simultaneously and therefore, one needs to sleep.

Sleeping to improve motor skills

Like the previous theory, this theory focuses on improving the neural connections in the brain. During sleep, the part in the brain that focuses on controlling the muscles shuts down, so it can be reorganized. This makes sense, because research shows that people were able to learn a motor skill when they slept sufficiently (Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002)

Research suggests that lions sleep to preserve energy

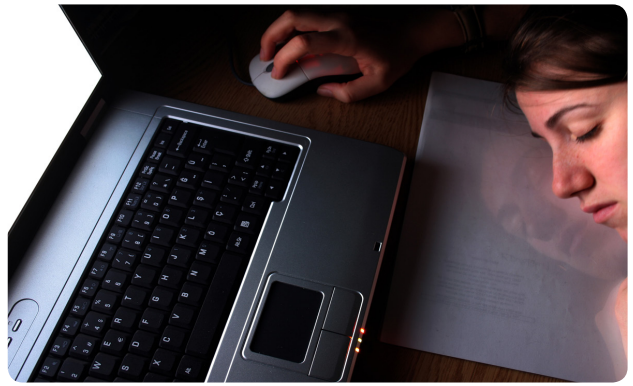
Sleeping to preserve energy

This theory is based on animals and suggests that we sleep to preserve energy. A day has 24 hours, and animals do not need all the hours of a day to hunt for food, while hunting for food is a risky and intensive activity. Therefore, when the animal has enough food, it will retreat and sleep to preserve the energy from the gathered food, and lower the risk of being caught by another animal. According to this theory, sleep in humans is an evolutionary side-product of this preserving sleep. (Allison & Cicchetti, 1976)

Sleeping disorders

A sleeping disorder is the disruption of regular sleeping patterns in humans. There are many causes for sleeping disorders, and there are around 90 distinct sleep disorders (Harvey R Colten, 2006).One of the following symptoms mostly marks these disorders:

- Excessive daytime sleepiness
- Difficulty initiating or maintaining sleep
- Abnormal movements behaviors and sensations during sleep



Sleeping in front of your laptop, a sleep attack or just tired?

Narcolepsy

This disorder causes the person to fall asleep at any given time on the day. Narcolepsy arises during teenage years, and can come together with one of the following symptoms: Excessive Daytime sleepiness, sudden muscle weakness (Cataplexy), Sleep paralysis, Hallucinations and Insomnia.

Parasomnias

Parasomnias are undesirable and uncontrollable events arising during sleep. Different parasomnias manifest themselves during different stages of sleep, typically during transition periods from one state of sleep to another. Examples of parasomnias are Sleepwalking, Sleep terrors and Confusional arousals.

Restless Legs Syndrome

This syndrome, as the name suggests, is characterized by an “irresistible urge to move the legs” or other limbs. It can also come with itchy and burning feelings.

Limb movements during sleep can really keep you awake at night.

Periodic Limb Movement Disorder

Sleep disruptions, caused by limb movements characterize PLMD. Persons with this disorder also have difficulty with sleep onset and maintenance.

Obstructive Sleep Apnea

Collapses of the airway occur during sleep, leading to abrupt reduction of oxygen uptake in the blood. The most important symptom of OSA is Excessive Daytime Sleepiness. The heavily fragmented sleep at night probably causes this sleepiness. Obesity is an important marker for OSA, but also snoring and neck size.

Measuring sleep

It is possible to use human properties as a measure of sleep. For example, environmental temperature can have a regulating effect on sleep, but it is also possible to deduct sleep depth from skin temperature. In this section, I will discuss the different known ways to measure sleep depth, and technologies to do this.

Temperature

Body temperature is one of the most significant sources of information of human body. Even a small change in body temperature can already indicate a big change in a person's medical condition. Therefore, doctors use expensive measuring devices to obtain accurate measurements of human body temperature. Body temperature can be divided in three important categories, namely Proximal, Distal and Core temperature.

Proximal temperature is the temperature measured on the skin, at chest height. This part of the body is covered with isolating clothing most of the time; therefore it doesn't lose much heat during the day.

- Distal temperature is the temperature measured at the places where maximum heat loss occurs. These places are both feet and hands. Because the blood flowing through the limbs has lost more heat than blood flowing through the chest, it cannot warm hands and feet to the same temperature as the chest. On top of this, more heat loss occurs from the limbs, because they are exposed to the air, while other body parts are covered most of the time.
- Core temperature is the actual temperature inside the human body. This temperature is the most important one to keep a human alive, since changes here change how different processes in the human body take place.

Research after thermoregulation in sleeping humans shows us that thermoregulation changes while sleeping (Horne, 1988). The table below shows temperatures that the human body regulates when awake and asleep.

	Core Body Temperature	**Proximal Temperature**	**Distal Temperature**
Awake	36.9	34.5	32.5 (dynamic)
Sleep	36.1-36.5	33.5-34.5	33.5-34.5

From the table above can be seen that Core Body Temperature drops during sleep, but both proximal and distal skin temperature rise slightly during sleep, compared to being wake (**Quote**).

Measuring temperature

Previous paragraphs state that temperature is a measure for sleep depth. There are different solutions to measuring skin and body temperature. Each of these methods has pros and cons.

NTC and PTC

The Negative Temperature Coefficient (NTC) is a resistor that responds to higher temperatures by lowering resistance. The PTC does the opposite; it increases resistance. Measuring this resistance can therefore be used to measure temperature. NTC's are cheap components, and are available in different varieties. Measuring body temperature with an NTC requires extra components to filter and amplify the signal in the temperature range between 30 and 40 degrees. A drawback of the NTC is its logarithmic Temperature / Resistance Curve. This means it is not possible to linearly map values of resistance to temperatures; it requires linearization, which costs processing-power.

RTD's

Resistance Temperature Detectors or RTD's also work with resistance and temperature, just like an NTC. RTD's can be more accurate and stable than Thermocouples. The ideal RTD is made out of platinum; this material has a linear temperature resistance relationship, and is therefore very suitable to use in this type of sensor. A very broad used RTD is the pt100, which is calibrated to have a resistance of 100 ohms at a temperature of 0 degrees. From this point on the resistance and temperature curve is linear, and therefore it is easy to deduct the temperature from the measured resistance.

Thermocouples

Thermocouples consist of two different metals welded together. When the temperature rises, a voltage difference is measurable at the welding point. This small difference can be filtered and amplified with extra components, and then be used as a measure for temperature. Thermocouples have a huge range (typically from -500 to 1000 degrees Celsius), but can also be used to measure temperatures in the range of body temperature.

Digital Thermometer IC's

A number of companies, such as MicroChip and Texas Instruments, provide Integrated Circuits (IC's) to measure temperature in a number of fields (medical, industrial). These IC's are small, cheap and pre-calibrated, and therefore the easiest way to accurately measure temperature. The only disadvantage is that they're relatively inaccurate, with a maximum accuracy of 0.5 degrees Celsius.

Brain activity

Brainwaves can be captured from a person using an EEG device. Researchers have related different patterns in brainwaves to different stages of sleep by using an EEG during a person's sleep. The quality of sleep can therefore be derived from the captured EEG graphs. EEG devices have become available for the consumer market in the last few years.

This means consumers can measure the quality of their sleep using one of the commercially available EEG devices.

Neurosky Mindwave

The NeuroSky Mindwave is one of the available solutions for sensing brainwaves. It uses one single dry sensor and an ear clip. Subjects do not need to add extra conductive fluid on their skin to amplify the signal. This makes it really easy to mount the headset. (Neurosky, n.d.)

OpenEEG

An open source alternative for reading brainwaves is the OpenEEG project. The project goal is to create an EEG device, and provide developers and users to create their own EEG device from scratch. (OpenEEG, 2011)

Emotiv EPOC

The Emotiv EPOC is also a headset with EEG sensors integrated, but instead of only one sensor this headset has 14 channels, which makes it much more suitable for academic research or professional EEG capturing. (Emotiv, 2011)

Activity

A sleeping person cannot move, because his brains block muscle activity while sleeping in particular sleep stages. Therefore, physical activity can be used as a measure of sleep. Smartphone applications, such as ‘Sleep as android‘ use this observation to measure if you have had a good night sleep. These apps also function as a microphone, so the user is able to monitor sounds during the night. This can be used to discover if you snore or talk in your sleep.

The Sleep as Android application measures physical activity during the night, using the built-in accelerometer.

How to influence sleep

The process of sleeping is flexible; humans are able to influence their sleeping rhythm and each individual has his or her own optimal sleep length. Simply staying awake longer than the usual bedtime will result in a tired feeling, and the feeling that the eyes are getting heavier. This is caused by the human circadian clock, which will start the production of melatonin (the sleep hormone) a few hours before bedtime (Cajochen, Kräuchi, & Wirz-Justice, 2003). It is possible to actually influence your personal bedtime, and therefore influence your circadian clock. The following factors have influence on sleeping patterns.

Light

Light influences the daily cycle of people and animals. The pineal gland in the brain produces melatonin at different levels during the day, with a peak just several hours before bedtime. How is the pineal gland able to produce melatonin according to a 24-hour-a-day rhythm? Darkness stimulates the production of melatonin, but light inhibits this process. This causes most people to start feeling sleepy when the night falls, but it is also easy to influence this system, and therefore influence sleep. People use artificial light to postpone their melatonin production and therefore shift their biological clock (Alfred J. Lewy, Wehr, Goodwin, Newsome, & Markey, 1980). People suffering from a jetlag or people working in night shifts can use melatonin to regulate their biological clock. Taking melatonin just before sleep can shift the circadian clock of these people forward (Buscemi et al., 2004).

Temperature

Eus van Someren suggests in his “Mechanisms and functions of coupling between sleep and temperature rhythms” (2006) that subtle changes in skin temperature influence thermo sensitive neurons in brain areas involved in sleep regulation.” The research suggests that temperature is able to trigger and enhance sleep through regulating skin temperature. It is still on which parts of the body this heating and cooling works best. The research group used a thermo suit that was able to cool and heat the whole body. It is interesting to look at the possibilities to scale down the used thermo suit, and still maintain the effect.

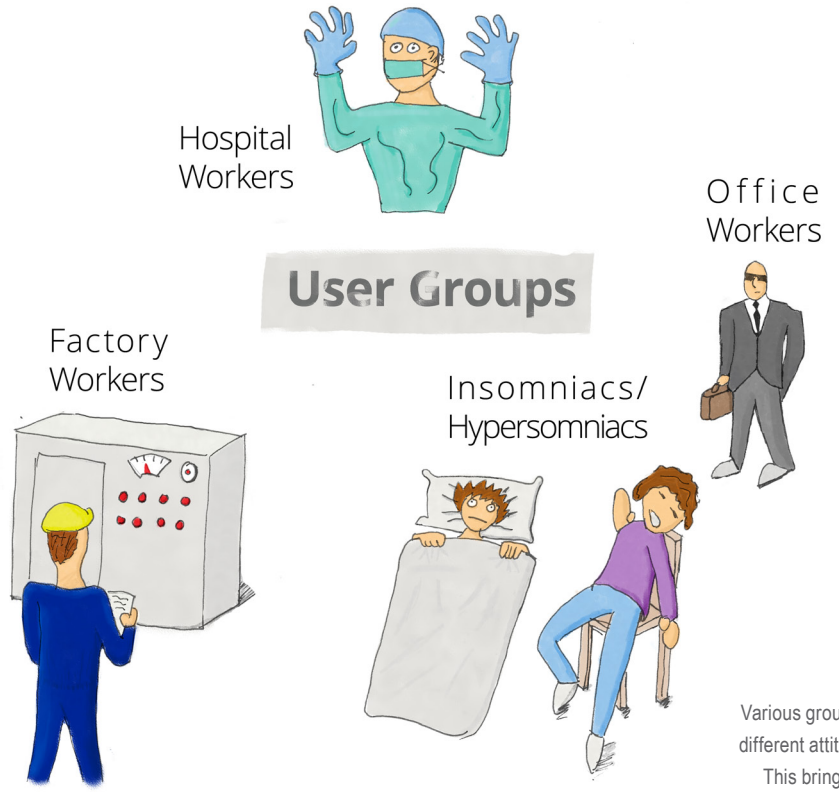
Drugs

Apart from external stimuli, different substances can also alter bodily functions, and thus influence the sleep-wake cycle. Examples of these drugs are:

- Caffeine is known for having a stimulating effect, and restoring alertness. Effectiveness of caffeine has been proved using the Multiple Sleep Latency Test (MSLT) with a group of healthy young men (Zwyghuizen-Doorenbos, Roehrs, Lipschutz, Timms, & Roth, 1990)
- THC, the main effective substance of the cannabis plant induces sleep in humans, but decreases the percentage of time spend in REM state during sleep (Freemon, 1974). Alcohol has a same effect on sleep as THC; it induces sleep, but decreases the percentage of REM sleep during sleep.
- The psychoactive drug LSD induces REM sleep in humans (Muzio, Roffwarg, & Kaufman, 1966). There has not been any research about side effects of additional REM sleep after taking LSD.
- GHB, is a drug, but is also used as a sleep medicine (Xyrem) for insomniacs. GHB is known to promote the Slow Wave Sleep. Other studies show that GHB users release more Growth Hormone during their sleep. (Van Cauter et al., 1997)

Opportunities in sleep improvement

Literature research shows that researchers know the multiple functions and processes of sleep, but the bigger picture is still missing. Therefore, I will not focus on trying to improve sleep in general, but try to influence or improve the factors that contribute to a better sleep. Here is a list with different opportunities in sleep or wakefulness improvement.



Various groups of users have a different attitude towards sleep. This brings opportunities.

Maintaining wakefulness in patients with narcolepsy

A specific group of people with a sleep disorder, namely narcoleptics, can also benefit from recent research from the van Someren research group. This new research suggests people suffering from narcolepsy can improve their vigilance and maintain their wakefulness by cooling their skin (Rolf Fronczek et al., 2008). The research did not mention specific applications, although the observations from the research open up possibilities for narcoleptics to improve their vigilance. Another possibility to improve wakefulness is by using EEG technology to detect sleep attacks, and respond to this by an external stimulus, such as light or sound.

Circadian rhythm reinforcement

Recent Research suggests possibilities for sleep improvement. For example, research from the van Someren research group (Eus J.W., 2006) found a correlation between skin temperature and the quality of sleep. This means there is an opportunity to influence sleeping behaviour in humans. This can be beneficial for people not suffering from any particular disorder, who want to increase their quality of sleep. The reinforcement can take place shortly before the person goes to sleep, and shortly afterwards, since it is possible to influence the circadian clock during these times. (A.J. Lewy, Wehr, & Goodwin, 1980)

Reinforcement can happen in the form of light, sound and temperature. This way, the sleeping environment actually becomes a smart environment with sensors and actuators. The measured body temperature is logged and the data is sent wirelessly to a processing station, which sends instructions to the components of the smart environment (e.g. smart lights, speakers etc.).

Flexible sleep solutions for demanding jobs

These days, many people have jobs that demand flexible working hours, and break with the original human circadian rhythm. For these people it is interesting to regulate their sleeping pattern to ensure maximum sleep efficiency, breaking with the original circadian sleep wake cycle. It is possible to design a product that helps the user to take a power-nap efficiently. Multiple researchers have tested for the optimal time to take a nap. They found that different nap times correlate with different improvements in the brain. For example, 10-minute naps improve alertness for 2-3 hours, while 60-minute naps can actually improve the procedural memory (Ficca, Axelsson, Mollicone, Muto, & Vitiello, 2010).

With this data, it is possible to design a product that is able to let you sleep optimally within a given period. The product is able to monitor the different sleep states a person goes through, and can therefore wake the user when it will not cause any negative effects, such as sleep inertia. The user should also be able to vary the length of his naps to improve alertness or his procedural memory.

Comparing opportunities

To determine the possibilities of each of these different opportunities, the opportunities are scored according to a set of requirements. These requirements reflect the possibilities to create a realistic product within the set time frame. The following requirements are used:

Demand

Are the people mentioned in this direction actually waiting for a product can help them?

Evidence based

Is scientific evidence available to validate this opportunity?

Non-Intrusive

The product should not be an obstacle in the daily life of the user, and should also not be used in any ways the user would feel uncomfortable with, as with some medical products.

Realistic

Is it possible to create a concept and a prototype, demonstrating the interaction and added value?

	Maintaining wakefulness in patients with narcolepsy	Circadian rhythm reinforcement	Flexible sleep solutions for demanding jobs
Demand	+	-	+/-
Non-Intrusive	+/-	+	+/-
Realistic	+	-	+/-
Enriching/Improving	Improving	Enriching	Improving
Form	A wearable, since it relies on biological parameters	An intelligent system, consisting of different modules working together	A separate product, portable and should be able to monitor wake a person
Opportunity value	This opportunity is challenging, since a positive outcome could improve lives a group of people	This opportunity can enrich the sleeping experience of many, but there may not be much demand for this.	Opinions are divided about the effects of polyphasic sleep.(Wozniak, 2005)

Enriching or Improving

Is the direction aimed at enriching a healthy person's life, or improving the quality of life in a person suffering from a particular disease or disorder?

Form

Which form will this direction take? Will it be a product, a system or just a service?

Conclusion

I decide to continue in the direction of maintaining wakefulness in patients with narcolepsy. From the table above can be seen that this direction scores high in most of the requirements. Moreover, this direction offers a challenge and can actually improve quality of life for a group of people. This fits in my vision of societal impact trough design.

Narcolepsy and sleep

Narcolepsy has a prevalence of 40-60 / 100.000. This means in The Netherlands alone 7000 people suffer from this disease (van Breukelen, C. W., 2011). There are currently only 1000 people diagnosed with this disease in the Netherlands. This underdiagnosis can be caused by the symptoms, which tend to get worse over time.

Narcoleptics and sleep have an interesting relationship. On one hand, people suffering from narcolepsy have sleep attacks during daytime, and therefore have trouble staying awake. On the other hand, these people also have trouble with sleeping during the night. Next to these well-known symptoms, most narcolepsy patients also suffer from other lesser-known symptoms. In “Narcolepsy: Clinical Features, New pathophysiologic Insights, and Future Perspectives” (S.Overeem et al., 2001) all of these symptoms are discussed:

Excessive Daytime Sleepiness

EDS is the most common and recognizable symptom of narcolepsy. It is described in two different ways, namely the constant feeling of sleepiness and the frequent occurring sleep attacks during the day. In a patient, one of these versions of EDS is more dominant.

Disturbed nocturnal sleep

Patients with narcolepsy fall asleep quickly, but have multiple awakenings during the night. These awakenings can prevent that the person is getting sufficient deep sleep during the night.

Cataplexy

Cataplexy is the phenomenon of sudden loss of muscle power. These attacks start abruptly and take several seconds. The amount of attacks and the amount of loss in muscle power differs per patient. Attacks are mostly provoked by the patient’s own emotions, such as laughter, or nervousness. Cataplexy mostly coincides with a sleep attack; this explains the literal “falling asleep” observation in some narcoleptic patients.

Sleep Paralysis

Paralysis is being unable to move. This seems normal, but in Sleep Paralysis the person is unable to move during the onset and awakening of sleep. Sleep Paralysis is related to cataplexy, because they both give the patient the same feeling; being unable to move. Sleep Paralysis attacks can take up to 10 minutes, in which the patient is in a sleeping position, but is already conscious of his surroundings. Most patients feel frightened during these attacks.

Hypnagogic hallucinations

Hypnagogic hallucinations are dreamlike experiences that occur during the transition of wakefulness and sleep. During these periods, the hallucinations can be experienced as “real,” and have to be double-checked by the person before they believe it was actually a dream.

Conclusion

Narcolepsy is a disorder that can affect people in multiple ways. Most common is the **constant feeling of sleepiness** and the **abrupt sleep attacks**. It seems that the sleep attacks during daytime also further disturb the sleep rhythm during the night. After admitting to this sleep, patients are often confronted with **hallucinations and paralysis,** which negatively influences their experience of sleep.

Sleeping and waking up with narcolepsy

Last chapter ended with the notion that is not easy to live with narcolepsy, because of the diverse and numerous symptoms. But how exactly does sleep and wake interfere with each other in a sleep-wake disorder like this? The same document as used in last chapter (S.Overeem et al., 2001) sheds light on this using the theory of state boundary control. This theory is based on two principles:

> ***"the impossibility to sustain any given sleep/ wake state for a length of time: When awake, patients fall asleep quickly, and when asleep, they awaken quickly"***
>
> *(S.overeem et al. , 2010)*

> ***"various phenomena that normally occur together in a sleep stage can occur dissociated (i.e., on their own and out of their context). "***
>
> *(S.overeem et al. , 2010)*

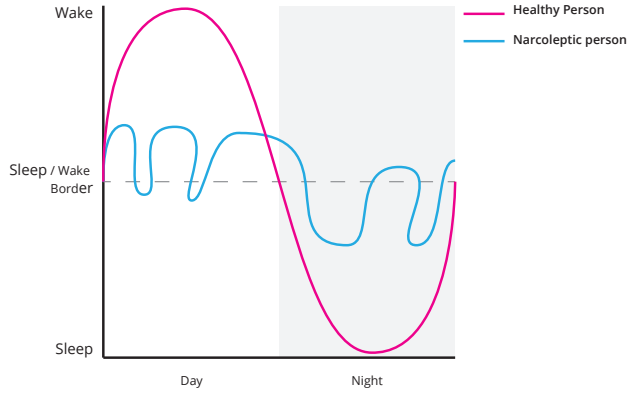
The two principles suggest a narcolepsy patient is never 100% awake and never 100% asleep. Furthermore, this hypothesis is confirmed trough research:

> ***"... narcoleptics may also have a continuously depressed level of wakefulness."*** *(Fronczek, R. e.a., 2006)*

Symptoms that suggest sleep can arise when a person is awake and the other way around. Not being able to sleep for 100% can have it's consequences on wakefulness daytime, but there is no evidence for such a relationship. (Broughton et al., 1994)

Taking this information into account, it is possible to visualise the relationship between sleep and wake in a person with narcolepsy. Using such a visualisation, it is possible to pinpoint the moments of opportunity to help a person with narcolepsy. The visualisation can be seen on the right.

The problem of staying in one state (sleep / wake) can be used as a possibility to sleep and wake up at any given point in time, since the treshold to fall asleep or wake up is smaller compared to a healthy person. A person with narcolepsy should therefore be easy to wake up, because of the lowered treshold towards being awake.



The pink graph shows how the average wakefulness in healthy people changes during the day. The graph is different for narcoleptics. They have trouble staying in one state. Vigilance occasionally swings around the sleep wake treshold, resulting in Excessive Day Time sleepiness and short confusing sleeps.

This visualisation is a representation of the state boundary control theory, not an exact representation of how vigilance progresses during the day.

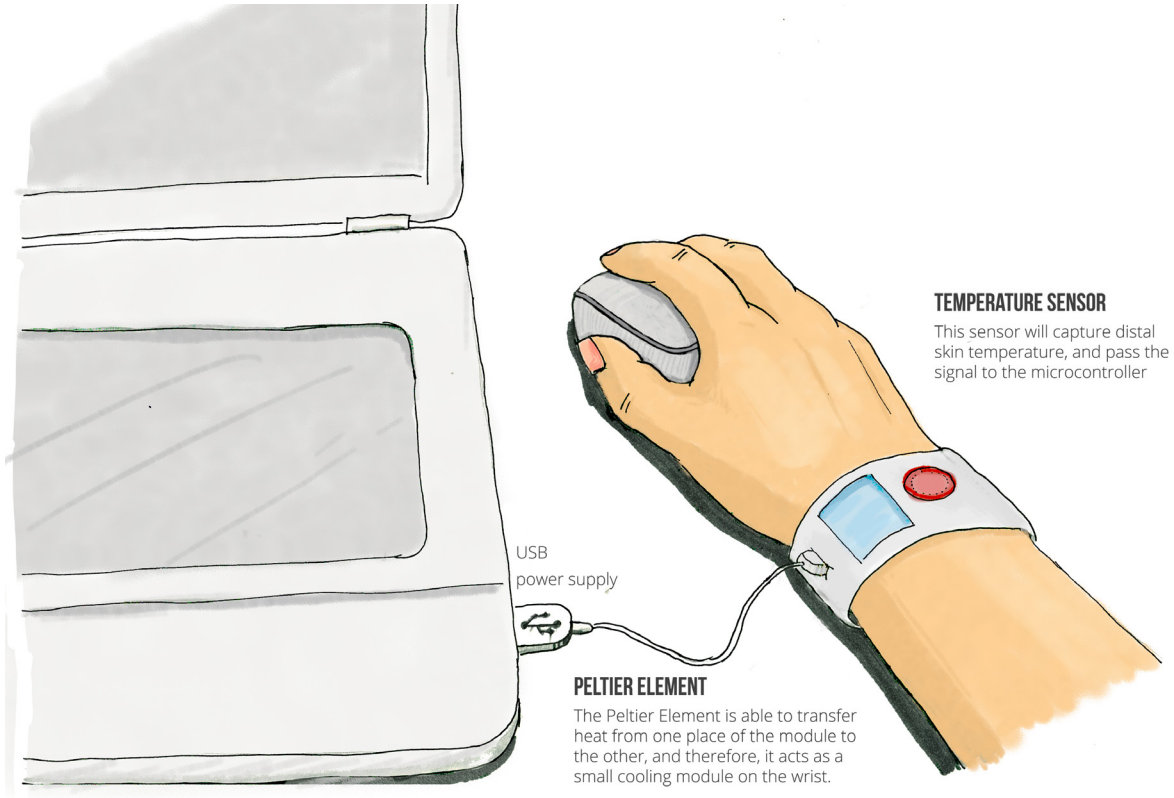
Maintaining wakefulness in narcoleptics

Research Summary

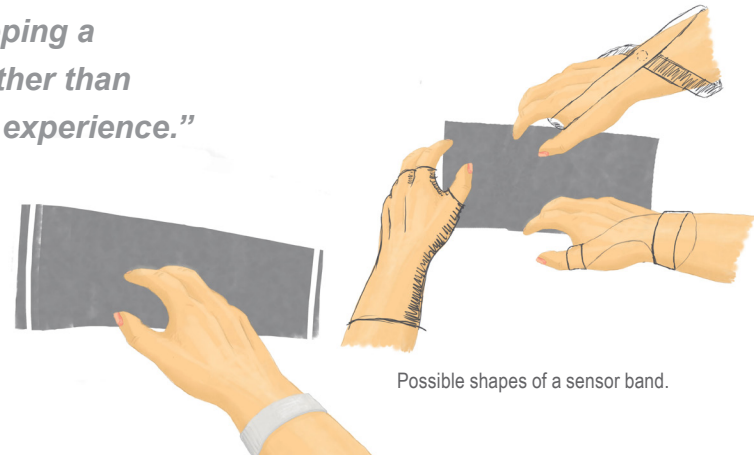
Research shows temperature regulation in narcoleptics is different from temperature regulation in non-narcoleptic people (R. Fronczek et al., 2006). People suffering from narcolepsy have bigger variations in skin temperature; distal skin temperatures are lower and higher during the day. Next to this, skin temperature slowly rises during the day. This could mean sleepiness builds up during the day or wakefulness decreases during the day.

Design opportunity

Based on the research it is possible to deduct and influence wakefulness in narcoleptics using distal skin temperature. A design that integrates this finding consists of a wireless temperature sensor, attached to one of the hands or feet. This module measures distal skin temperature, and is able to alert the user when skin temperature rises significantly. Rise in distal skin temperature is an indicator for an upcoming sleep attack and trough an alert we create an opportunity for the user to act against it, for example through a cup of coffee, a small exercise or a cold beverage. Trough integrating a cooling module, we can also achieve the desired distal skin cooling. These cooling and measuring elements can form a sensor-actuator system, in which the cooling element keeps the distal skin at a specified temperature.



"This project is aimed towards keeping a patient awake during the day, rather than providing an improved sleeping experience."

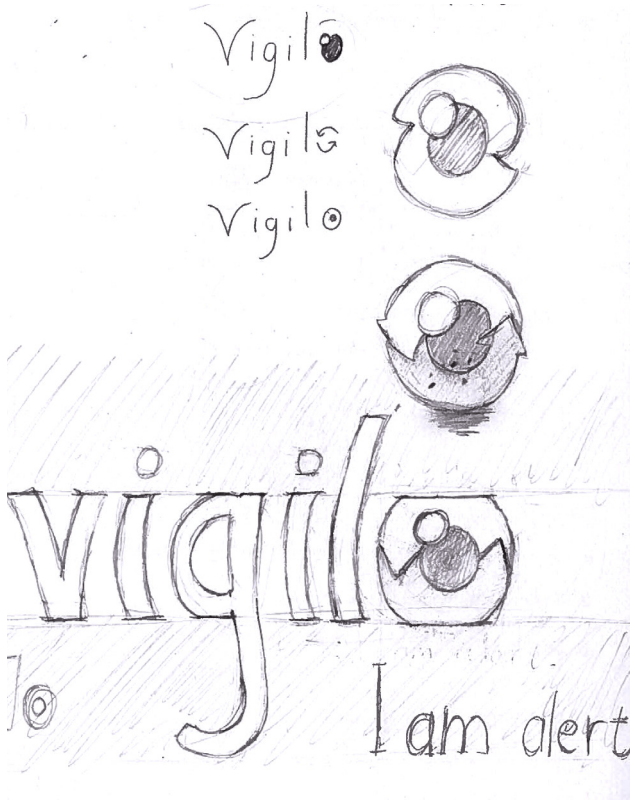


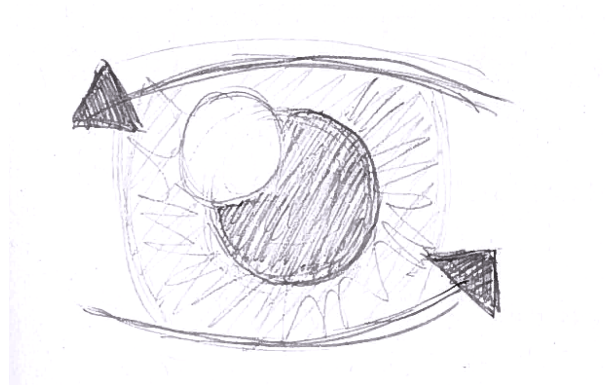
Possible shapes of a sensor band.

Product Proposition Vigilo

vĭgĭlo - *to watch, i. e. to be or keep awake at night, not to sleep, be wakeful*
(Charlton T. Lewis, & Charles Short, 1879)

Vigilo is the product that integrates the idea from the previous chapter. Vigilo is an intelligent wristband that monitors the user's skin temperature throughout the day. During a calibration period, Vigilo will learn the user's temperature cycle: when does the user have his highest skin temperature, and when is it at its lowest? After getting to know the user, Vigilo can easily spot differences from your normal temperature cycle, caused by bad night sleep, or sleep attacks. Vigilo can make the user aware of these dips in vigilance, and can help getting over this by applying mild cooling to your hand via the integrated cooling module. This way the user can be more productive during the day and more aware of his temperature cycle.

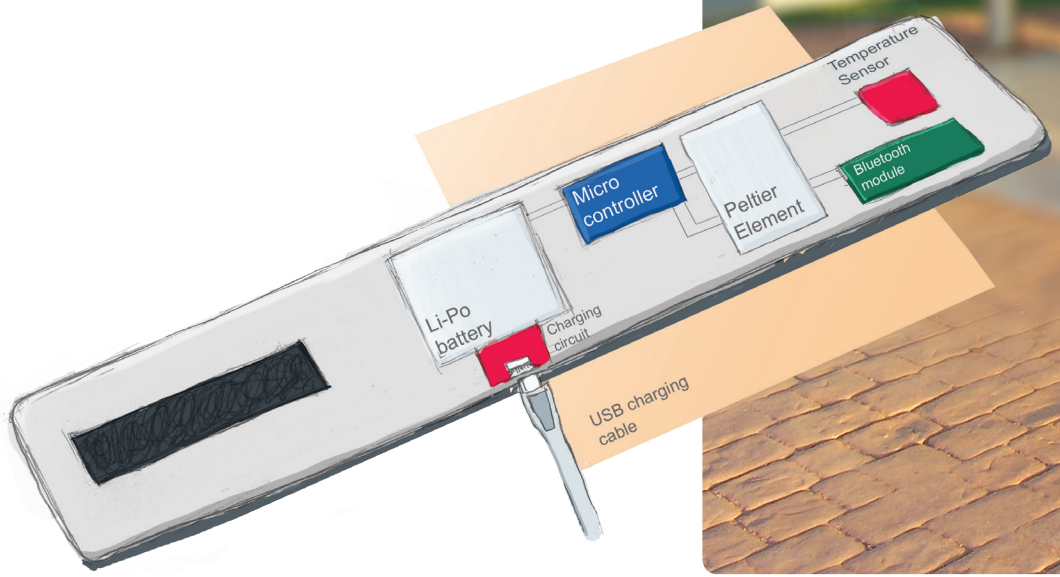




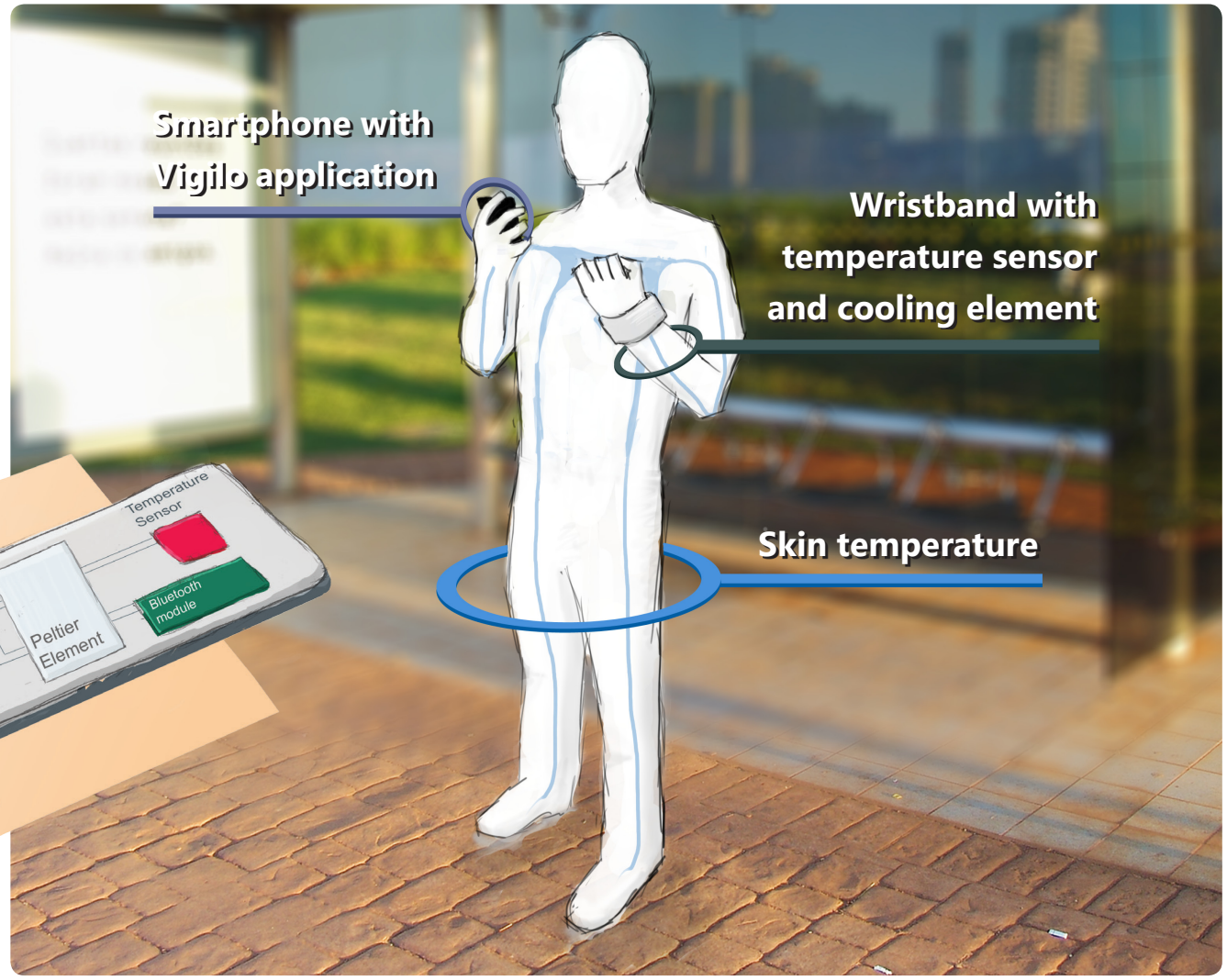
Vigilo product logo design process. The eye is symbolic for being awake and, as the Latin translation suggests, being wakeful.

Product visualisation

The user wears the product troughout the day in the form of a wristband. This wristband consists of several components to enable the described functionality. The user's smartphone show the gathered data, and enables the user to control the behavior of the product.



The different components, all integrated into the fabric wristband



The product only works with warm-blooded humans because they have a skin temperature that is maintained by the brain. The wristband and Vigilo application act as a touchpoint to provide this data to the user.

Value Proposition

Vigilo is designed for people suffering from narcolepsy, or other disease that result in Excessive Daytime Sleepiness. This group of people would like to have a product to keep them alert, and a product that can take away their worries about falling asleep. Research shows that distal skin cooling can improve vigilance, for people with narcolepsy as well. Therefore, the benefits of using Vigilo are about having a productive day, be alerted when reduced vigilance is detected and keeping the user awake during the day.

Target Consumer

People suffering from narcolepsy or other diseases that cause them to fall asleep during daytime

Consumer Insight

Consumers want..

..a product to keep them alert.

..to participate in social activities without worrying about unexpected sleep attacks.

..to be more aware of their sleep rhythm.

Reasons to Believe

Research shows skin cooling improves vigilance.

Benefits

Alert the user when reduced Vigilance is detected.

Keep the user awake during daytime.

Beneficial for productivity and confidence of user.

Competitive Environment

Medisana, health care products

Philips, health care products

“The Sleep Watch”

Lark.com

Drugs / Cafeïne

Discriminator

Improve productiy during daytime.

Makes you feel more confident.

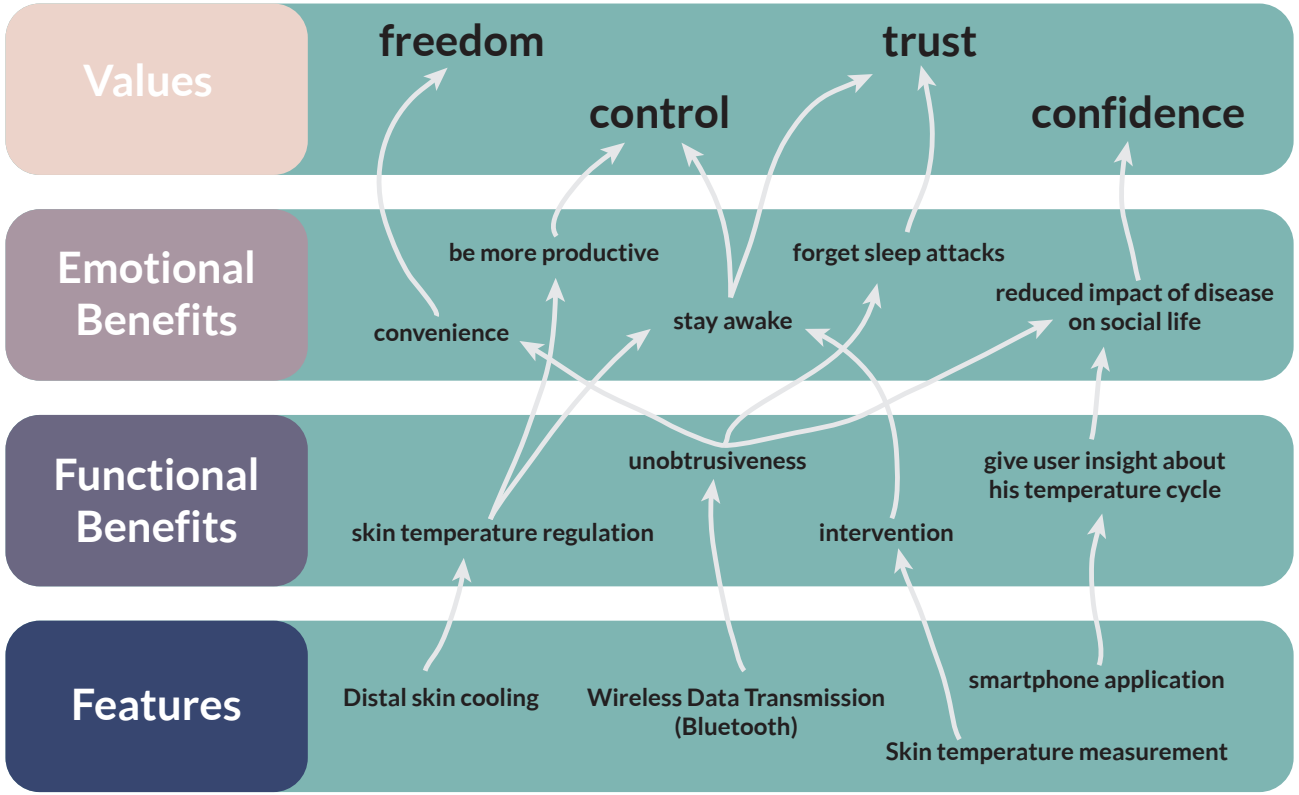
Value Ladder

From the value proposition, the following values can be derived:

- Freedom to do whatever you want
- Having control over life, the user decides what he will do
- Having trust in the product to help the user
- Feel confident about your behaviour, instead being afraid for a sleep attack

The product's features all reflect the values, translated via functional en emotional benefits for the user.

Stepping even further down the value ladder, we encounter the technology side of the product. The functionality of the product has been implemented in a prototype. The next chapter will provide a more detailed look into the functionality of the prototype.



Technology Description

The product features described in the previous chapter work together intelligently to monitor and respond to the user's skin temperature.

Measurements

ΔT_{skin} change in skin temperature in °

$\Delta T_{environment}$ change in environment temperature in °

When ΔTenvironment changes at the same time as the skin temperature changes, then it is likely the change has been caused by changing environmental temperature rather than changing skin temperature.

Calibration

During the calibration period, vigilo will monitor the users skin temperature in order to get a clear picture of their thermoregulation.

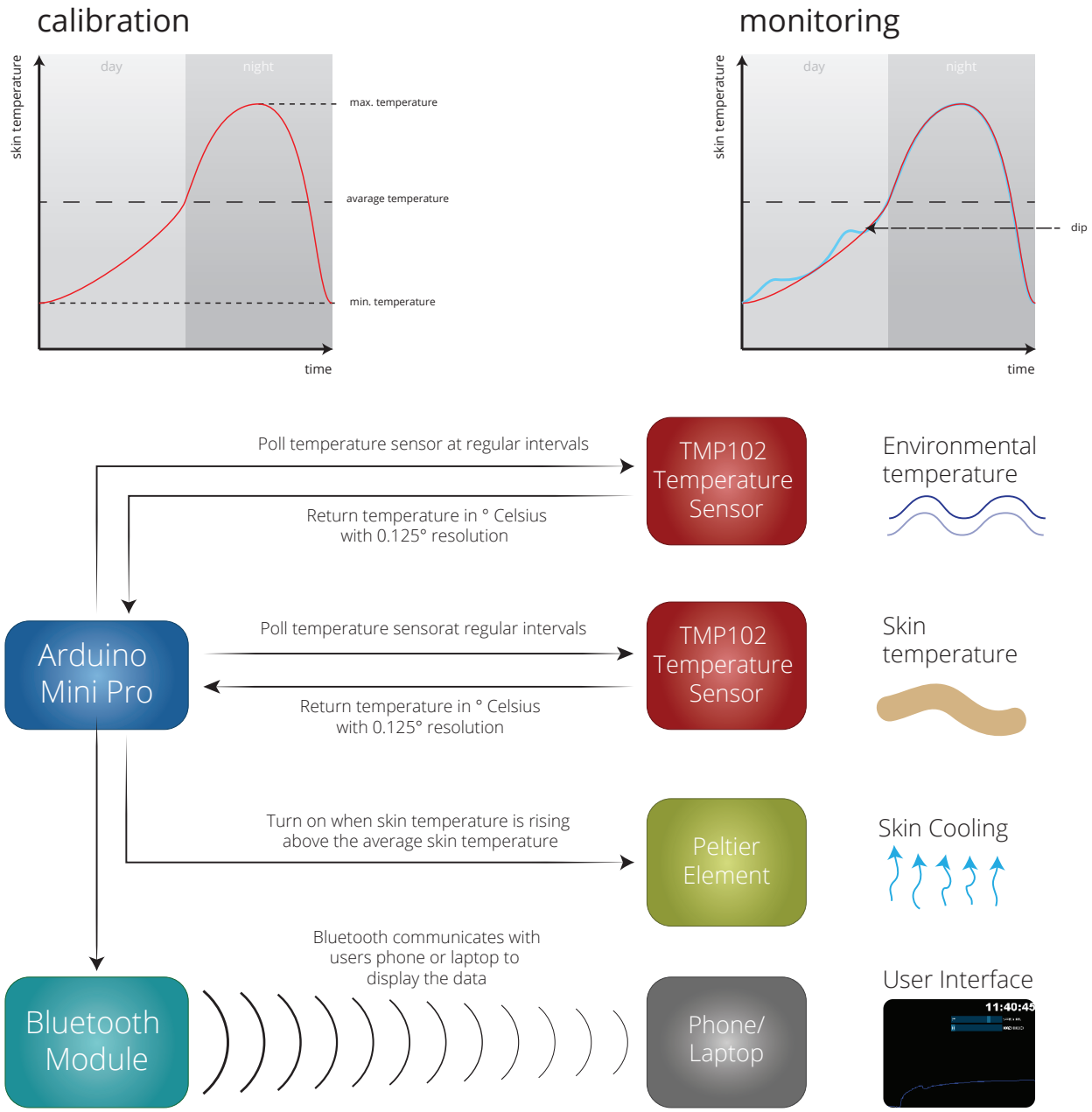
To function optimally the system has to find the following variables:

- Average skin temperature
- Maximum skin temperature (during sleep)
- Minimum skin temperature (in the morning)

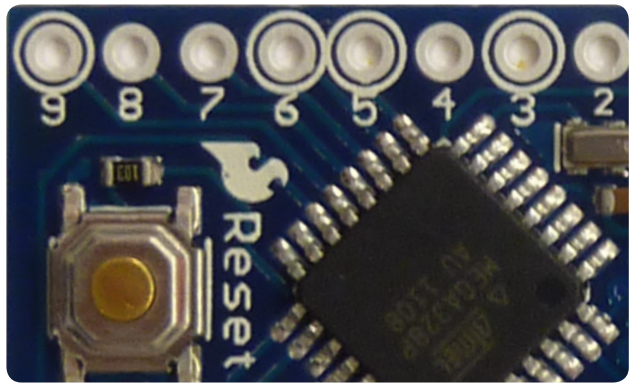
Next, the system will be able to map the current temperature to a level of wakefulness.

Monitoring

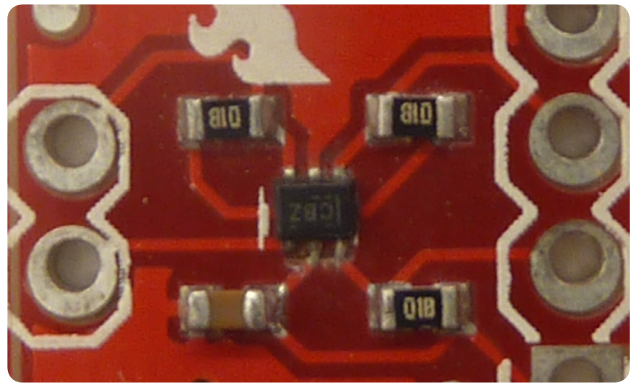
When a peak is detected in distal skin temperature, Vigilo will unobtrusively alert the user.



A visualisation of how the device would behave. The top two graphs do not represent actual measurements, but provide an example graph to demonstrate the device's workings. Real sensory data is used in the "Data Analysis" chapter.



An Arduino Pro Mini micro controller


TMP102 Digital temperature sensor

Bill of Materials

The Bill of Materials (BOM) specifies what components are used in the Vigilo system. The components listed in the table on the right are components that are used in the current prototype.

Summing these costs gives an impression of the costs of a prototype. However, different cost reduction methods are available for producing the final product. Bulk purchase of components can reduce the price per component. Custom PCB design and production can further reduce the costs per product, by leaving out components that aren't interesting for the product, and removing "the middle man". In this case the middle man is Sparkfun.com, which is the supplier for most of the components that are used in the prototype.

To reduce costs, components can be purchased in bulk from suppliers such as Farnell and Digikey. Most of the components listed here can also be bought as SMD component. This means costs per component can be as low as €1,50. This method requires extra preparation, but can significantly reduce the total costs when producing this product in bulk, for example.

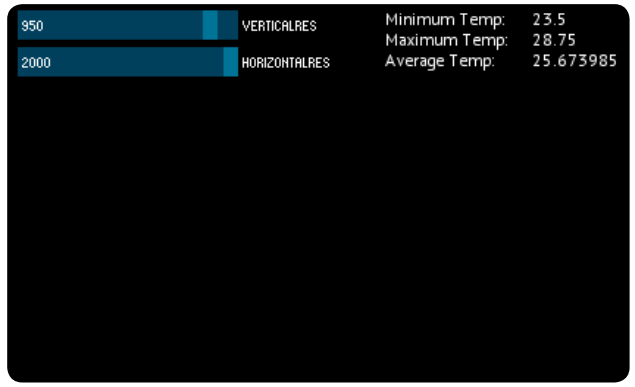
Parts	Type	Supplier	Quantity	Subtotal per part (EUR)	Price Total (EUR)
Arduino Mini Pro 3.3v/16 Mhz	Micro controller	Sparkfun.com	1	14,17	14,17
Serial Bluetooth Transceiver Module	Communication Module	DealExtreme.com	1	5,43	5,43
Texas Instruments TMP102 digital temperature sensor	Sensor	Sparkfun.com	2	4,45	8,90
9V snap connector	Power supply connector	Sparkfun.com	1	0,96	0,96
9 Volt Alkaline Battery	Power supply	Sparkfun.com	1	1,49	1,49
Ribbon cable (3ft)	Raw Material for wiring	Sparkfun.com	1	0,56	0,56
Jogging Fabric á 10€ / m^2	Raw Material (fabric)	Personal (Market)	0,03 m^2	10,00	0,30
			Total (EUR)	€	31,80

Prototype

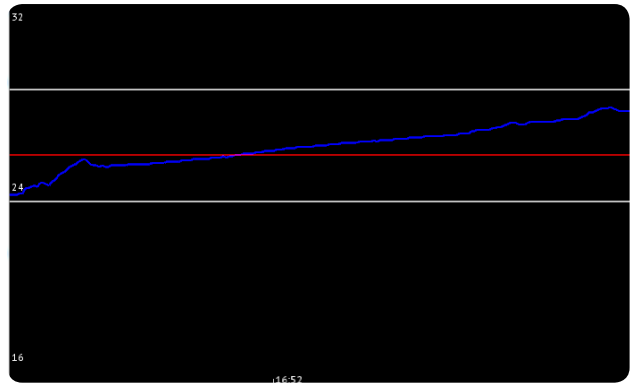
To verify the statements in practice, I have created a prototype that measures distal skin temperature. The prototype consists of a bracelet, containing a TMP102 temperature sensor. Using an of the shelf sensor unit (TMP102) it is possible to measure variations in distal skin temperature. These variations can be visualised by plotting the temperature data into a graph. A screenshot of such a graph can be seen on the right

Variations in distal skin temperature over time are clearly visible. With a specific algorithm it would be possible to recognize and predict these variations, and signal the user.

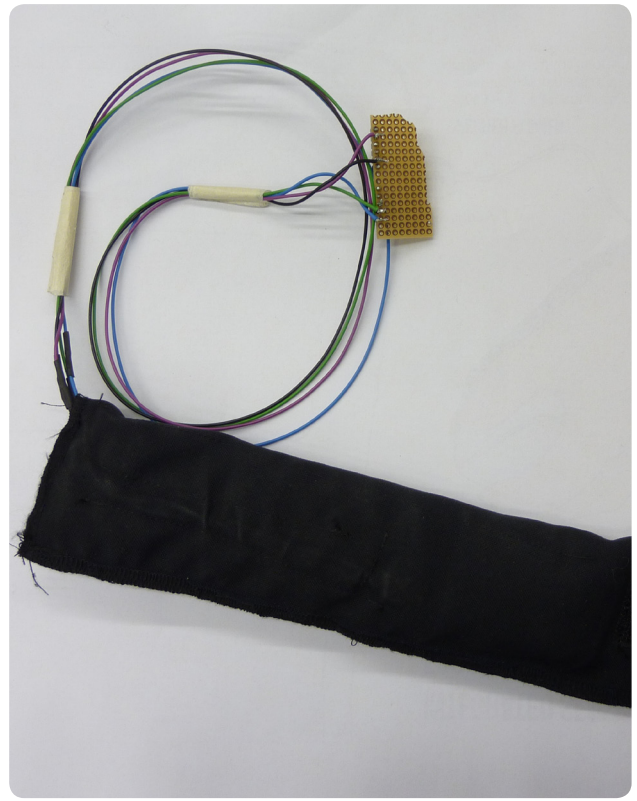
Therefore, the sensor should be integrated into a higher-fidelity prototype: an intelligent wearable for maintaining wakefulness.



Processing Graph



Temperature over time graph

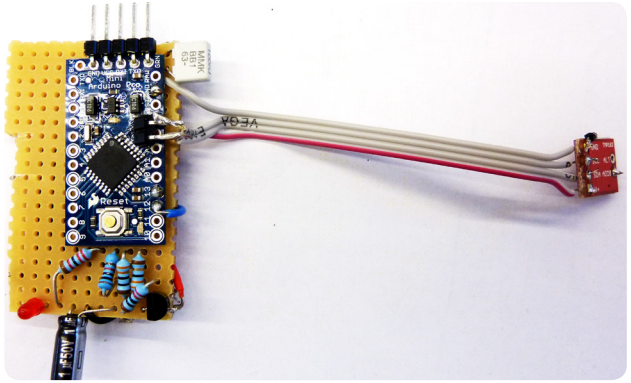


The first prototype; a wristband

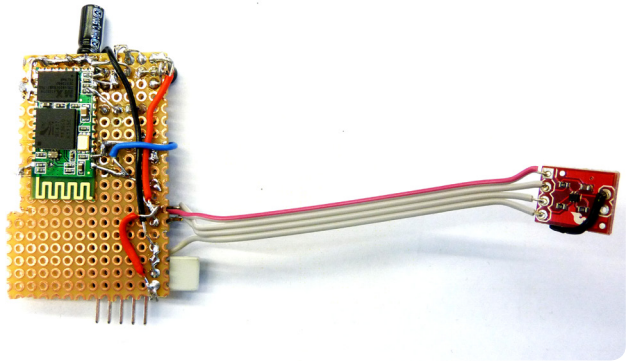
Further Development

The prototype presented last chapter was capable of performing one of the essential functions of Vigilo; monitoring ones temperature. However, the prototype does not demonstrate the final product: an integrated solution for monitoring vigilance and taking measures to improve this.

Further development of the prototype enable me to measure distal skin temperature variations unobtrusively. The data from these measurements are used to underpin one aspect of Vigilo: Being able to measure and detect temperature variations.



Arduino Pro Mini

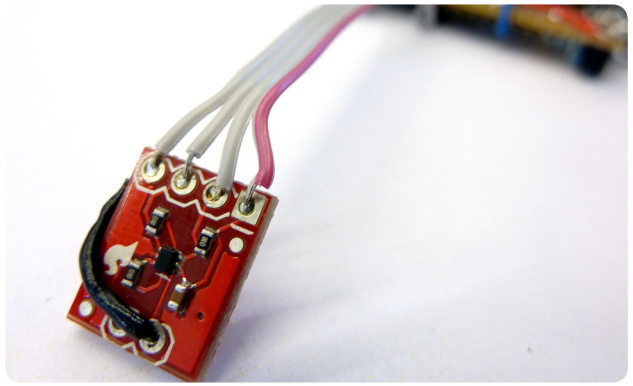


Sensor module with temperature sensor connected

Connectivity

I have explored possibilities for wireless communication between sensor unit, and a display unit. A Bluetooth module enable wireless communication between sensor unit and another Bluetooth enabled device. Wireless connectivity enables the user to split the monitoring and actuating and it will make the product less intrusive. Wearing the temperature monitor, and looking at the gathered data are now two separate activities.

A smartphone also has Bluetooth capabilities and therefore is capable of reading the signals from the sensor module. A smartphone application can function as the touch point for the sensor module. In this way the user can review his temperature data via his smartphone.

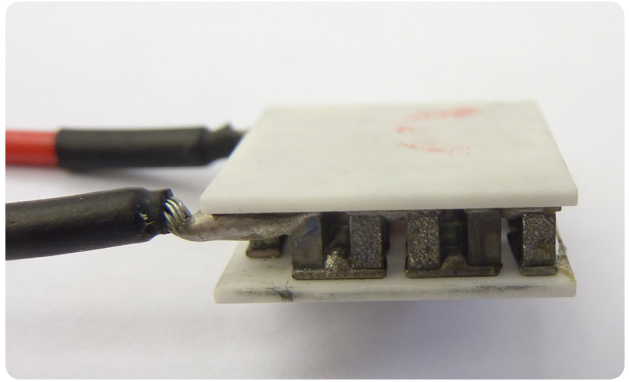


Close-Up of the TMP102 sensor temperature sensor

Temperature

The used prototype measures skin temperature and skin temperature variation using one single TMP102 temperature sensor. The signal from this sensor can be used to measure variations in skin temperature.

If the user wears the product throughout the day, then variations in environmental temperature could influence the measurements of the skin temperature sensor. This problem can be solved by implementing a second temperature sensor; a sensor to measure environmental temperature. The signal from this sensor can be used to cancel out changes from the measurements of the skin temperature sensor. In this way, skin temperature measurements are not influenced when the user changes from a hot to a cold environment, and the other way around.



A Peltier element

Cooling

The prototype did not have the ability to cool down the skin. A next iteration should incorporate a peltier element, which is also included in the technology description. This component functions like a heat pump; if powered, one side warms up, and the other side cools down. This is a useful component to perform mild skin cooling.

A disadvantage of the peltier element is it's efficiency. It has a low Voltage to Energy coefficient. On top of this, the component acts like a heat-pump and therefore, all the heat it removes from one side, heats up the other side. It is necessary to remove the heat from the warm side as quickly as possible (by using heat conducting metal), as it can also warm the wrist and therefore nullify the cooling effect from the peltier element.

Despite it's disadvantages, the peltier element is currently the only portable solution for personal cooling using electricity and solid components.

The Vigilo wristband, including a 9V battery

Form / Textile

The earlier prototype had the shape of a wristband. Black fabric was used for the outside, and for isolation purposes, some wool was included on the inside of the wristband. The wool has a high isolating value, and therefore measurements with the earlier prototype were influenced. The wool acts as a heat capacitor, consequently the measured temperature kept rising. When the user takes of the wristband, the temperature slowly falls back to environmental temperature, due to the leftover heat saved by the wool.

The next iteration will have less isolating material in the place where the sensor is positioned. This will decrease the amount of heat that will be stored in the wristband itself. This way, the sensor is able to make a reliable measurement of the user's distal skin temperature. The fabric should also be slightly elastic, and should feel soft, in order to stimulate users to wear the wristband all day.

The fabric I have chosen to use for the final prototype is jogging fabric, the fabric that is also used in training pants. It's a slightly stretchy and comfortable fabric.

A 9V battery supplies power to the wristband

Power

The current prototype is powered using a 9V Alkaline battery (6LR61). These batteries typically have 565 mAh of power available.

The sensor module uses 60mA in search mode, this is when the module is not connected to another device.

If connected, the module jumps in connected mode, and uses a steady 45mA. Using the power consumption and capacity values, it is possible to calculate how long the battery is able to power the sensor module:

565 / 45 = 12.56 hours approximately.
This is enough to power the wristband for at least one day.

The final product is powered trough an integrated Lithium Polymer battery in the wristband. These batteries can be charged many times, and have a relatively high capacitance for their size (around 1000 mAh, making the sensor module last for 2 days). Just like a phone, the user can charge the wristband during the night, via a micro USB slot and then wear it for a full day.

The vigilo application can run on any Android powered smartphone

Personal Assistant capabilities

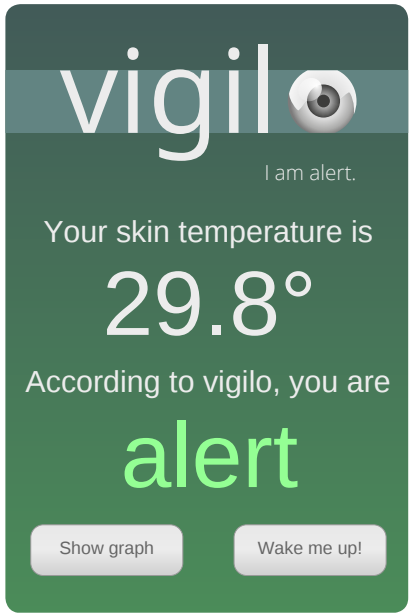
For Vigilo to act as a personal assistant, a device capable of monitoring and changing ones behaviour, a communication medium is needed. This is necessary to let the user have influence on the device's behaviour.

Because of the current rise of smartphones, this communication medium can be integrated as a smartphone application. The application should be capable of the following:

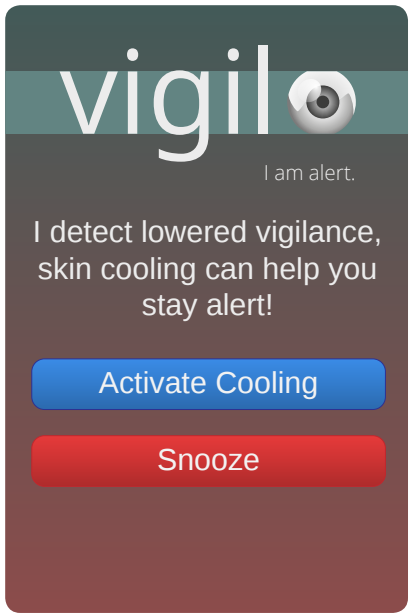
- Alert the user when vigilance drops
- Advising the user about his current vigilance state
- Show the user's personal temperature cycle
- Control the cooling system, integrated in the wristband.

Layout mock-ups on the right show how the application would look like. The core feature is the alerting system. Vigilo will alert the user when the system detects a vigilance drop (see 'Data Analysis').

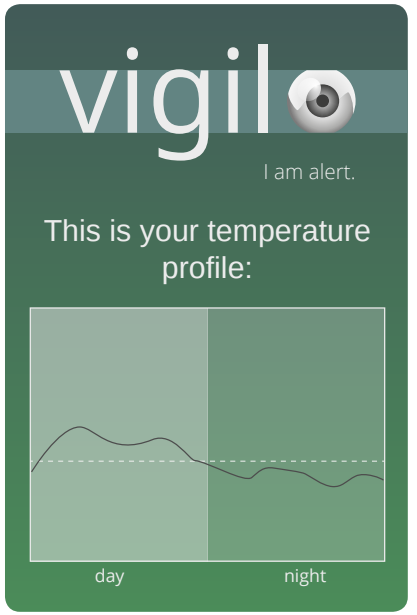
Other features can provide the user with more insight in the phenomenon of a circadian temperature cycle, which can be of informative value. They do not directly contribute to the working of the system, but give more information about the workings of the system.



This is the homescreen of the application. The user can check his temperature, and see what Vigilo thinks you are. (alert, lowered vigilance, sleeping)



This is the alert screen
The user will see this screen when vigilo detects a vigilance drop. It will start to rumble and ask the user to activate the cooling system.



Vigilo can also provide the user with interesting data about the temperature cycle. The user can view this data and check if vigilance drops occur at particular moments during the day. This way, the user is able to anticipate on sleep attacks

Validating in context

In order to validate the product, involvement of the target group is required. Involvement of the target group (people suffering from narcolepsy) will generate feedback needed for product improvements. Narcolepsy is a rare disorder; this means it is difficult to establish contact with a group of people with this disorder. Therefore, I have chosen to work with written feedback from online communities of people with narcolepsy. The two communities I have asked to participate are narcolepsyNetwork.org and narcolepsiestichting.nl. I have kindly asked people of these communities to read the research conclusions and product description. Next, I have asked them to tell me if the product would fit their lifestyle. Because of the disturbed sleep rhythm, people with narcolepsy can have different rhythms of life. Therefore, I must know if the product would also fit non-regular lifestyles.

The goal of this questionnaire is to find out if the product is perceived as beneficial by the target group (people with narcolepsy. It also helps in profiling the average user of this product, and providing a qualitative information about possible usage scenarios.

The 'Narcolepsie Stichting' helped gathering survey results

The questionnaire

- Age / Gender / Job / Social Status
- What Time do you get out of bed? And what time do you go back in bed?
- Would the product fit in your daily activities? Why or why not?
- Apart from the research, would you believe in the workings of this product?
- Do you picture yourself using this product?

Results

I have received 15 complete questionnaires from people diagnosed with narcolepsy. Their age ranges from 7 to 66 and their primary daily activities vary from running a household to having a full-time job.

Because of these variables I cannot make solid assumptions about the life of people diagnosed with narcolepsy. However, I can use the feedback to improve the likelihood that this target group will use the product. Furthermore, the answers provide me with qualitative markers that I can use to improve the product.

On the next page a visual summarizes the different opinions about the product. These can be categorized in different attitudes towards the product.

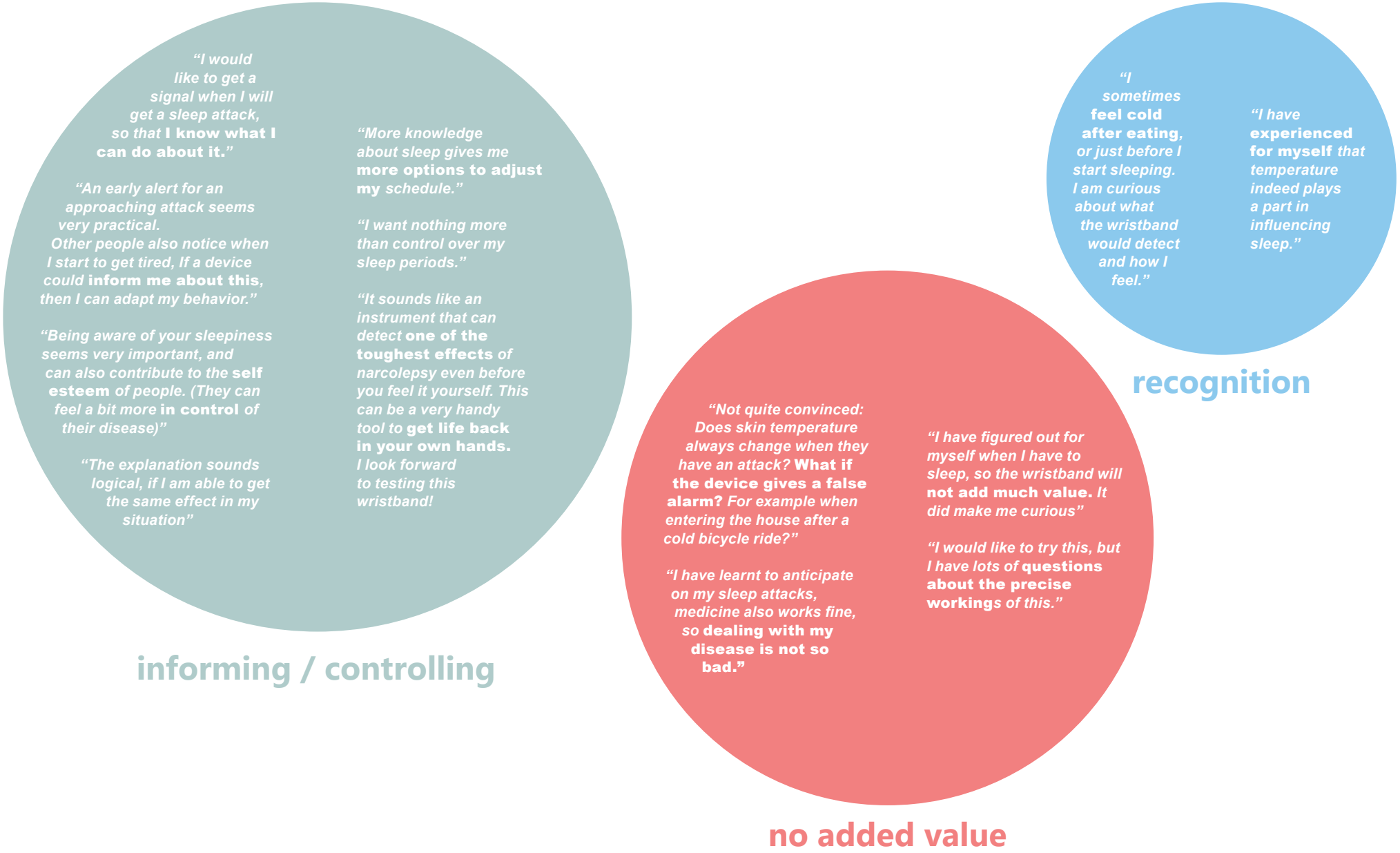
Conclusions

I notice the opinions reflect the values I have defined in the value ladder (see 'Value Ladder'). Most often participants mention the value "**awareness"** . Next to this, they also mention the ability to plan their day or **adjust their schedule**. Being able to detect a sleep attack is inextricably linked to planning the day. This allows the user to get the most out of the wake periods.

Based on this user research, the value proposition should also be updated, to reflect what the target groups actually wants.

People who are not convinced by the product proposal, mostly talk about how this device is going to measure temperature, and how it will respond in a particular situation. This can be due to the fact that the users are scared for false alarms. To accommodate these people, the design can be changed to only inform the people about their sleep attacks, without alarming them at inappropriate moments. Vigilo can have added functionality to inform the user about the temperature cycle and how monitoring this can make your lifestyle more healthy.

All in all, I can conclude that the product features mentioned in the value ladder connect to the target group's values.

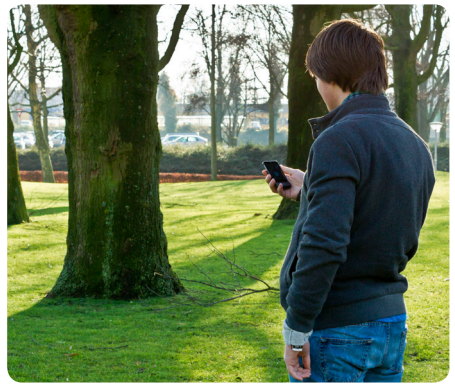

"I would like to get a signal when I will get a sleep attack, so that I know what I can do about it."
"An early alert for an approaching attack seems very practical. Other people also notice when I start to get tired, If a device could inform me about this, then I can adapt my behavior."
"Being aware of your sleepiness seems very important, and can also contribute to the self esteem of people. (They can feel a bit more in control of their disease)"
"The explanation sounds logical, if I am able to get the same effect in my situation"
"More knowledge about sleep gives me more options to adjust my schedule."
"I want nothing more than control over my sleep periods."
"It sounds like an instrument that can detect one of the toughest effects of narcolepsy even before you feel it yourself. This can be a very handy tool to get life back in your own hands. I look forward to testing this wristband!
informing / controlling
"I sometimes feel cold after eating, or just before I start sleeping. I am curious about what the wristband would detect and how I feel."
"I have experienced for myself that temperature indeed plays a part in influencing sleep."
recognition
"Not quite convinced: Does skin temperature always change when they have an attack? What if the device gives a false alarm? For example when entering the house after a cold bicycle ride?"
"I have learnt to anticipate on my sleep attacks, medicine also works fine, so dealing with my disease is not so bad."
"I have figured out for myself when I have to sleep, so the wristband will not add much value. It did make me curious"
"I would like to try this, but I have lots of questions about the precise workings of this."
no added value

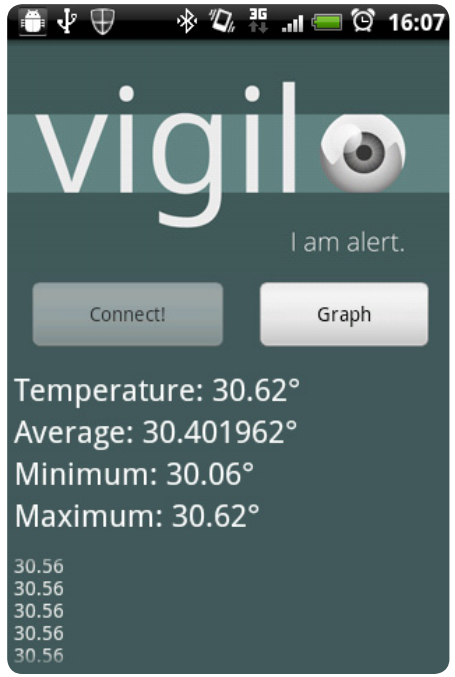
Gathering Data

The data has been gathered with the prototype discussed in the ‘further development‘ chapter. I have worn the wristband during the day while working at the TU/e. The prototype has been configured to send measurements to an Android smartphone with intervals of 2 seconds. With this interval I am able to detect even slight changes in skin temperature.

The measurements are done with a prototype of the Vigilo software, discussed in the previous chapter. The software is programmed for Android smartphones and capable of storing temperature data, calculating the average temperature and minimum and maximum. The software can also plot the temperature variations in a graphical representation. Screenshots of the used software are displayed on the right.

I have worn this prototype one day; from the moment I started working until one hour after dinner.





Screenshot of the prototype software

Checking skin temperature can be done everywhere, using the smartphone application

Because the electronics are integrated into a wristband, it is comfortable to wear.

Data Analysis

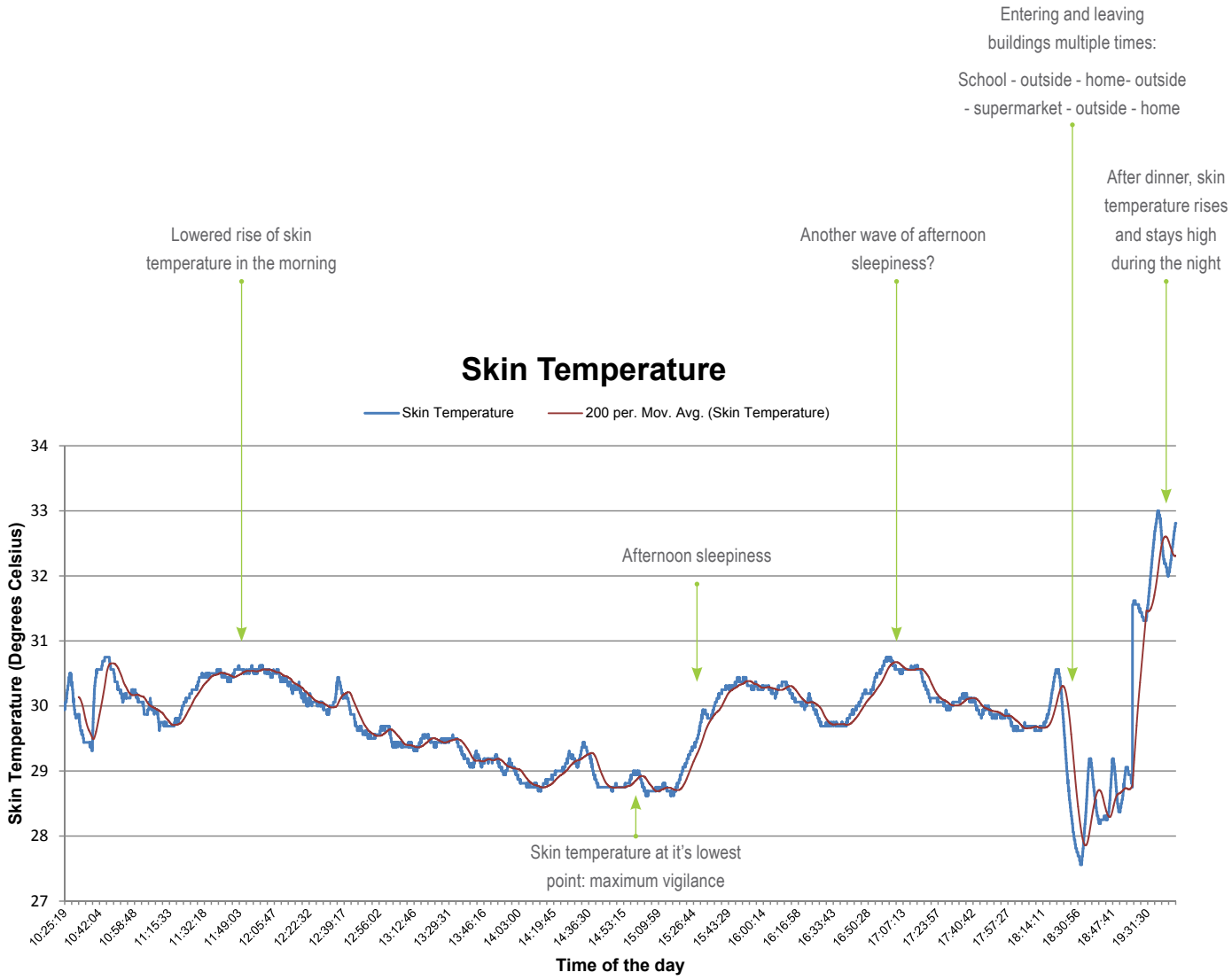
All the measurements are written into one file. This file consists of 16000 measurements; these are all used for the data analysis. A graphical representation of these measurements can be seen in the graph on the right.

The relationship between skin temperature and sleep is an interesting area of research. This is even more true for narcoleptics, since research shows significant differences in temperature regulation between healthy people and people with narcolepsy:

> ***"throughout the day, distal skin temperature was elevated in narcoleptics. ... narcoleptic patients maintained a DPG that control subjects did not even reach asleep in a supine posture."*** *(Fronczek, R. e.a., 2006)*

Skin temperature decreases during the day and changes to a heightened state around half past three This is the moment I normally start noticing afternoon sleepiness. The graph on the left side reflects this feeling with a steep rise in skin temperature.

The graph also shows other peaks, but I am not able to relate all of them to a personal experience. Based on this data I can conclude it is difficult to develop an algorithm that is able to detect sleepiness.



This graph shows measurements done with the prototype during a whole day. The blue line shows the measurements, while the red line shows the average based on 200 samples. It shows temperature fluctuations with different amplitudes during different times of the day. Some of these can be accounted to external influences, others can be a sign of vigilance drops.

Discussion

In this chapter I would like to discuss future scenarios of this product and the technology behind this. I have researched the possibilities to create a useful product for people suffering from narcolepsy. After reviewing the data, I noticed this technology can also provide opportunities in other areas.

Data and signal processing

The data that is collected from the prototype provides new insights about thermoregulation in humans. It shows situations in which an automatic sleep detection algorithm would have difficulties detecting a ‘true’ sleep attack. For example when entering a building from outside. These fluctuations look exactly like the patterns I would like to detect: ‘lowered vigilance‘ patterns.

Hardware improvements and advanced signal processing could help me make the signal more useful for detecting these dips in wakefulness. It is possible to add another temperature sensor that measures fluctuations in environmental temperature. This data can be used to cancel out fluctuations that are caused by changes in the environment rather than the skin temperature. The resulting temperature graph should only reflect changes in skin temperature, even when the environmental temperature changes from +/- 20° Celsius to 1° Celsius.

Smoothing the signal could be helpful to distinguish the noise from the useful fluctuations. Before it is possible to do this, I should determine which fluctuations should be detected. Peaks with varying amplitude arise during the day, which leave me wondering: what exactly do these fluctuations represent, and are they useful for my design?

As can be seen in the graph on the previous chapter, I was not able to relate each variation to a specific activity. This can mean two things. Firstly, the sensor could be sensing noisy data, so the valuable data is scrambled trough measurements that are slightly off. This can be due to the quality of the sensor itself, or due to the position of the sensor in my design. Secondly, the measurements aren’t noise and the variations represent small metabolical changes, that are reflected in skin temperature.

The second option is obviously the most interesting one, but also means that filtering away these fluctuations, means filtering away valuable (and possibly relevant) information. So on one side, a filter should filter away irrelevant information leaving only interesting variations. But on the other hand, it is important to keep information in the signal, because the signal could be useless after filtering.

Furthermore, signal processing techniques could help in making ‘predictions‘ about the signal. Using so-called autoregressive models (Pavon, Jackzhp, & Zvika,2011) it should even be possible to predict values in time based on previous values. I can’t estimate how effective applying such an algorithm would be in detecting sleep attacks, but the added value of predicting values based on earlier values is evident.

Technology

Looking at the product from a technology-perspective, There are still some questions left to answer. Can monitoring skin temperature also provide useful information to other groups of people?

The human body is an incredible source of information, and distal skin temperature, if interpreted correctly, can possibly provide more information than suggested in this document. For example, skin temperature can serve as abstract information about the activities of two people.

Skin temperature can be used to distil other medical information from. For example, research showed people with narcolepsy always have an elevated distal skin temperature (Fronczek, R. e.a., 2006). Therefore, a temperature graph of a person with narcolepsy shows characteristics a temperature graph of a healthy person does not show. The product I proposed can therefore also be useful during diagnosis. A specialist can analyse the temperature graphs and use these in his diagnosis, together with results from sleep research.

Perhaps even other disorders can be diagnosed by specific skin-temperature characteristics. Measuring skin temperature can be incorporated in the diagnostics routine. This gives specialists more insight in the daily lives of patients and can therefore help specialists to prescribe more effective medication or therapy.

These cases go beyond the scope of this project, but basically the technology behind the prototype provides possibilities for the development of these kind of products.

Conclusively, the technology behind the described prototype is improvable. Nevertheless, the skin temperature sensor system can be used in lots of other situations rather than for detecting sleep attacks in people with narcolepsy.

Present versus Future

The product described in this report has been designed to be a specific tool for people with narcolepsy. This differs from the prototype I have created. In the current stage, the current prototype can be used as a data-collection tool for healthy people as well as people with narcolepsy. This makes the project interesting for a broader target group, even without the improvements and future plans that are described here. Based on what this project has to offer at this moment, it is possible to start looking at future for improvements, but without this current functionality, there will be no room for improvements.

Therefore, it is important to market this product as a temperature monitoring tool for everyone. This would strategically be a better option then marketing the prototype as a solution for people with narcolepsy. The latter claim would require more research and supporting evidence, and therefore postpone the date the product would be on the market.

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Reflection

About vision

This was my first project in the Comfort & Bonding theme. The medical domain, and sleep in particular was new to me. The kind of products that are designed in this theme are characterized by their added value to the user's quality of life. Projects that are run here appeal to people in the most fundamental way; trough their sense of comfort and bonding.

Being able to work on such a project was exciting and motivated me throughout the semester. Looking back at the project's result I believe I have designed a product that fits within this theme. Working in the comfort & bonding theme made me aware of more responsible duties as a designer. Products should prove their existence in this world, by actually adding value to the life of the user. This can only happen when a product connects with the user in one way or the other. Not only the vision on design was different within this theme, also the design process differed from typical design processes in other themes.

Processes

The design process differs each time I work on a project. At first I thought this was because of my vision being in development; a designer with a clear vision would also have a clear and structured design process. I found out this is not true; creating a vision is not about creating a static design process that works for you, but more about understanding the underlying aspects of a design process. Within our education, these underlying aspects are the four activities within the reflective transformative design process.

After all these years I am starting to get a grip on the design process model that is pictured in the "Eindhoven Designs - Volume 2" booklet. I can categorize what I have done according to the four different activities (envisioning, making, synthesizing and exploring). It is not that I didn't want to do this at first, but only after working on multiple projects I recognize the terms that are used and I am able to relate these terms to work I had done in the past. The model can actually be a helpful tool in guiding the design process, rather than a fancy marketing tool to describe what we do at this faculty.

Competency Areas

Competencies I have developed during this project should be representative for my whole development, since this is my Final Bachelor Project. Therefore, I have aimed at showing my development trough the activities in my project. For example, I have set the following goals:

Academic level literature research into the subject. If I want to change society with design, I should be able to quickly gather knowledge about a subject, and determine what is useful information for design. This project I gathered lots of information regarding sleep. Not all the information I have gathered was relevant for the product I have designed, but all the information contributed to getting there.

A working prototype demonstrating the purpose in real-time. In my opinion, a prototype should always serve a purpose. I try to integrate as much functionality aspects in the prototype as possible. This way, it can be used to test the product in context, and users can get a good sense of how the final product will be. The prototype I have developed is a functional prototype, it can be used by different persons, and it can gather data from these user tests. This way I am able to improve the design based on the results of user-test sessions.

Designing a product using roadmapping techniques. I have created a value ladder and a product proposition. With these tools I have delimited the area in which I want to design the product. These tools are useful, because they help me in answering the question: What exactly is my product? From that point, I can create a full-fledged roadmap to define how this product should be developed in the future. Determining how the future of a product should look is also based on actual sales and developments in technology and fabrication. This is beyond the scope of the project, since it is not even a proper product yet.

Concept validation in context. I have contacted my user group directly via a community forum. This allowed me to communicate with the target group over a timespan of multiple weeks. This gave me enough time to prepare a structured survey. Reactions I received were anonymous, but because of the nature of these fora (for people with a disease) I can say the reactions are authentic and honest and represent the target group. Once again, I found out it is difficult to gain quantitative evidence to prove my claims and once again I decided to do a qualitative analysis of the results, rather than a quantitative one. The results of this analysis were surprisingly positive, and reflected the values I set up in the value ladder. This showed me how qualitative analysis enables me to validate design decisions in context. A way to significantly improve the result of my project, is to provide the prototype to an actual narcolepsy patient. Comparing the temperature data of this patient with the data of a healthy person could give me insight in the exact differences between these two groups of people.

This is the first semester in which data-analysis is addressed during my project. Creating a prototype with a sensor is one, but creating a sensor and logging the data is another thing. Just assembling this prototype is a pointless activity, but being able to analyse the data and reflect on the results is an important activity during the design process. Only when I have gathered data for some time I can decide how to improve the design, based on this data.

I have prototyped in iterations: first make a prototype, then try it, reflect on it and create something totally new, based on the conclusions from your last design. This can be a painful process, but each iteration the design grows significantly. Before starting a new iteration, I should decide what I would like to gain from a particular iteration, so I will not work too long on an iteration from which the result I will throw away later.

Choosing direction

Even though my vision grows over the years, it remains difficult to choose a direction in the early stages of the design process. With the information gathered from extensive literature research, it is possible to see all kinds of possibilities fitting within the boundaries of the project description. This semester I have listed the ideas and tried to define what I would like to gain from this project. Next, I scored these ideas according to my goals. This was a pragmatic way to decide which idea should be continued, saving me lots of valuable time.

My vision also played part in making this decision. I recognized the problems narcoleptics have, since I also encounter some of these problems myself. I was able to use this experience while doing research about the disorder, leaving me more time for other aspects of the design process.

Design Process