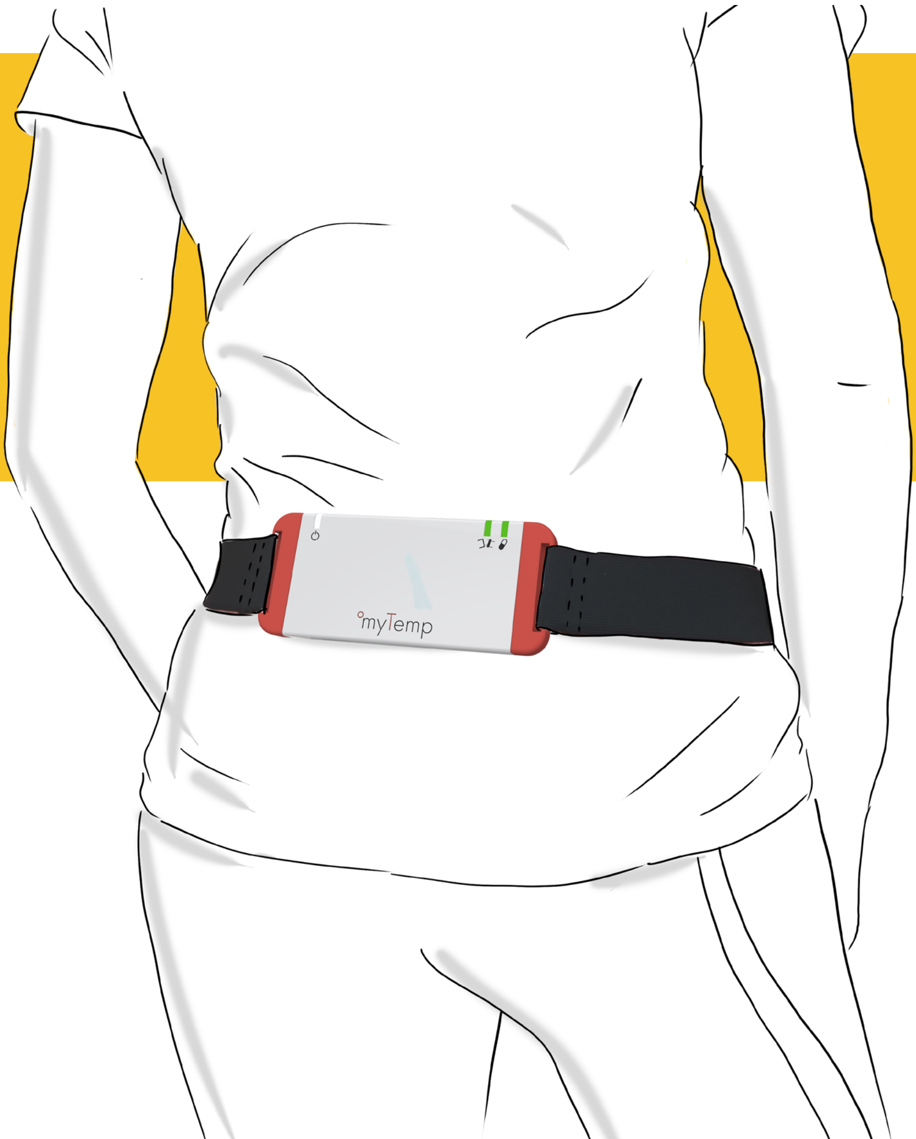
Graduation report
Creating an antenna band for the myTemp system



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Summary

This graduation report describes the design process of the antenna band of the myTemp system. The myTemp system is a high accuracy core temperature measuring device, that uses an indigestible measuring pill and an antenna band to measure the temperature inside the intestines. It is mainly used in thermo-physiological or exercise-related research, often to research how the core temperature changes in athletes when exercising in hot, humid environments. By researching this, heat-related illnesses or exertional heat strokes can be avoided that are caused by a too high core temperature.

The main benefit of the myTemp system lies in the fact that the indigestible measuring pill does not contain a battery and can therefore be manufactured at a lower price than competitive products. This also means that there is no risk of battery leakage in the body.

This requires that the system uses an antenna belt. This belt consists of a case containing electronics and a wire that goes around the torso of the user. This wire creates a magnetic field that is able to both charge and well as communicate with the indigestible measuring pill.

In this project the main objective was to improve the comfort of the antenna belt, fit the belt to people with different body sizes, increase the reliability of the antenna-pill connection and increase the user experience.

The project consists of three phases: the research phase and two ideation phases. In the research phase, relevant information is gathered about the context, user experience and the technology used. In the first ideation phase, multiple antenna configurations have been tested and compared to find an alternative antenna. In the second ideation phase, a user test has been conducted to improve the user experience of the device.

At the end of the report, the design is presented and recommendations are given for future development.

Gratitude

I would like to thank my supervisory team, Kaspar and Iemkje, for their guidance during this project. Their suggestions and feedback have helped me to improve the various aspects of the project. When I was unsure about the process, their support helped me to get more direction.

I would like to thank the people at myTemp, especially Hans and Rutger. They provided me with the opportunity to improve a product they had spent years to develop. Hans, Rutger, Kjille, Clemens and Joost, thank you for your trust.

A special thanks to Adrie Kooijman from the Applied labs, who has helped me countless times with his knowledge and materials to help me figure out a lot of the practical details of the project.

I would like to thank my friends and family, to whom I could always turn for feedback and who were always willing to help me test ideas. Thank you so much for your time and support.

And finally, I would like to thank Simon. He has helped me in creating structure in this project when I lost overview, given me feedback, pushing me to improve and most importantly, just being there and listening when I wanted to talk.

And thank you for taking the time to read this report!

Nathalie Meijnders

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1. Introduction

Exertional heat stroke is a medical condition in which the body experiences life threatening hyperthermia (body core temperature higher than 40.5°C) (Navarro, 2017). This is caused by doing physical activity in hot conditions or when wearing restricted clothes that prevent sweating (Epstein, 2019).

Exertional heat stroke can be deadly. For example, in 2004, a 24-year-old student died after participating in the Dam to Dam Run, a running competition in the Netherlands. His core temperature was determined at 42,6°C when he was committed to the hospital (AD, 2014a, AD, 2014b). Another example is the International Four Days Marches Nijmegen in 2006. The event coincided with a heat wave. Temperatures in the shade measured 34°C. Two people died and three others required CPR (Havermans, 2006).

There are two main ways to prevent a heat stroke during exercise: cooling and acclimatising. Cooling focusses on keeping the core temperature low during the exercise, for example by drinking enough water. In the case of acclimatising, the body is being carefully trained to perform in hot climates.

To protect the athletes as well as aid their performances whilst exercising, myTemp has developed an ingestible core temperature sensor pill without a battery. This pill allows for live readings of the core temperature with the help of an antenna belt around the hips. These measurements helps athletes and coaches to gain insight into their current core temperature during performances and take preventive measures to stop overheating, like acclimatising.

The problem presented by myTemp was that their current prototype cannot be adapted to different body types, is not always comfortable to wear, has an unreliabile connection between the antenna band and the sensor pill and the user experience with the product is frustrating.

In this project the main objective was to improve comfort of the antenna belt, fit the belt to people with different body sizes, increase the reliability of the antenna-pill connection and increase the user experience.

Approach

In this product, the double diamond model was used to give structure to the process (Design Council, 2004; Image 1).

The process begins with the given problem. In this case, the current prototype is not comfortable to wear, does not adapt to different body types and is frustrating to use.

Then, the process enters the research phase. In this phase, the context is explored through interviews and observations, research is carried out concerning the technology used and other relevant areas. At the end of this phase conclusions are drawn and specific problems are defined.

In the second phase (ideation), ideas are generated that could solve the specific problems. These ideas are tested and evaluated, and these evaluated ideas are translated into a concept. This phase can be repeated multiple times for different problems. In this thesis it has been done twice: one for antenna research and the other for user experience.

The project will conclude with a concept with all the previous insights included and a set of recommendations about how to proceed after the project.

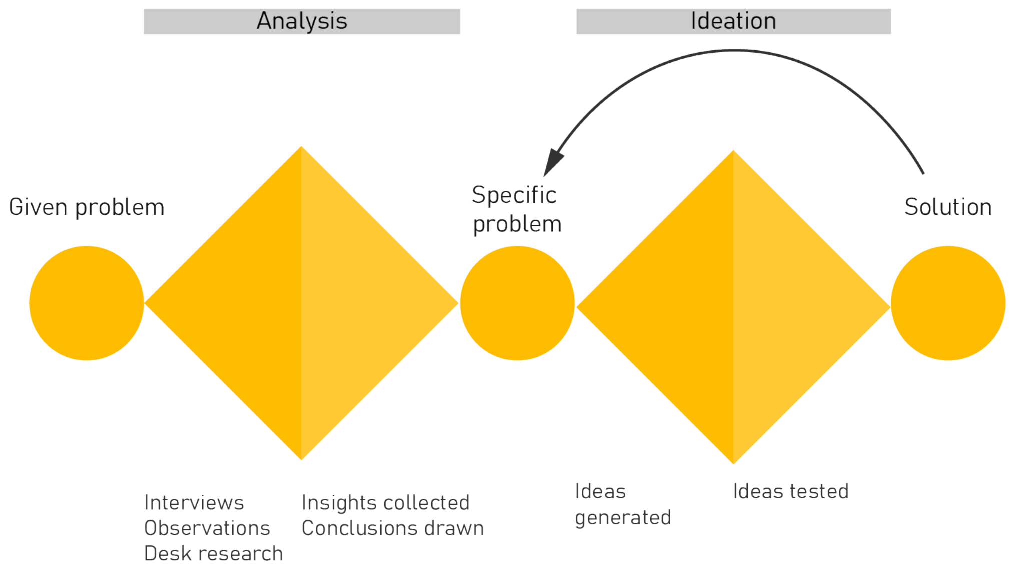


Image 1, Double diamond model

Research

2. Context

First the context of the myTemp system needs to be explored. This context gives insight in how, where and why the system is being used.

Heatstroke

Heatstroke is the most serious form of heat illness, and is clinically characterised by central nervous system dysfunction, multiorgan failure and extreme hyperthermia (usually an core temperature of above 40,5 °C). It can lead to coma or even death (Epstein, 2019).

Heatstroke occurs when the body cannot lose its heat, causing the body to overheat. Heatstrokes are divided in two categories based on their origin: classical and exertional.

Classical heatstrokes occur when the body is physiologically unable to deal with heat stress. This usually affects the elderly and chronically ill, but can also affect children and infants.

Exertinal heatstrokes are directly related to physical activity, often in combination with hot environmental conditions. Here the body generates heat due to the physical activity and is unable to lose it. In this thesis the focus will be on exertional heatstrokes.

People suffering from severe heat illness can be recognised by a high core temperature (usually higher than 40°C), high heart rate, dry skin, alternered behaviour like confusion, irritability or slurred speech, nausea, headache, flushed skin and rapid breathing (Mayo Clinic, n.d.). They need to be cooled and medical help needs to be requested immediately.

Heat and performance

With increased heat, the body experiences an increased physiological strain. This increased strain leads to a decreased physical performance. The rate in which heat impacts the body is dependent on the individual person. Factors that influence this are amongst others level of fitness, age, gender and experience with heat (Westwood, 2020).

In Veltmeijers (2014) they found that 15% of participants of a 15K run in a cool environment passed the finish line with a core temperature higher than 40.0°C. None of the participants had experienced any heat-related complaints, and in this race the temperature had no influence on their performance. What this shows is that some people experience a higher core temperature rise than others in the same conditions. It also suggests that some people are able to perform well, even with a high core temperature. This makes it hard to determine an overall temperature at which performance drops or one that is no longer safe. This threshold temperature needs to be determined for each and every individual.

By doing heat training, the individual can be trained to better adapt to the heat, and thus to better perform in the heat and have less heat-related complaints. This is often done with professional athletes who are training to perform in races in hotter climates.

MyTemp

MyTemp is a startup founded by Clemens Neervoort, which focusses on developing a gastrointestinal (ingestible) temperature sensor. This sensor can be used to monitor core temperature during sports, and can help prevent heat related injury or performance loss.

The system consists of two parts; the gastrointestinal sensor, which is embedded in a pill (Image 2), and an antenna band (Image 3). The system works via RFID technology: the pill receives energy from the magnetic field generated by the antenna band, uses it to read the temperature sensor, and sends this information back to the band. The electronics attached to the band sends this information to either a smartphone or a computer via a bluetooth connection.

While the myTemp product is still in development, the system has already been used in different types of research.

myTemp's aim is to bring the product to market in the form of a kit: a set containing 20 pills, an antenna band and software.

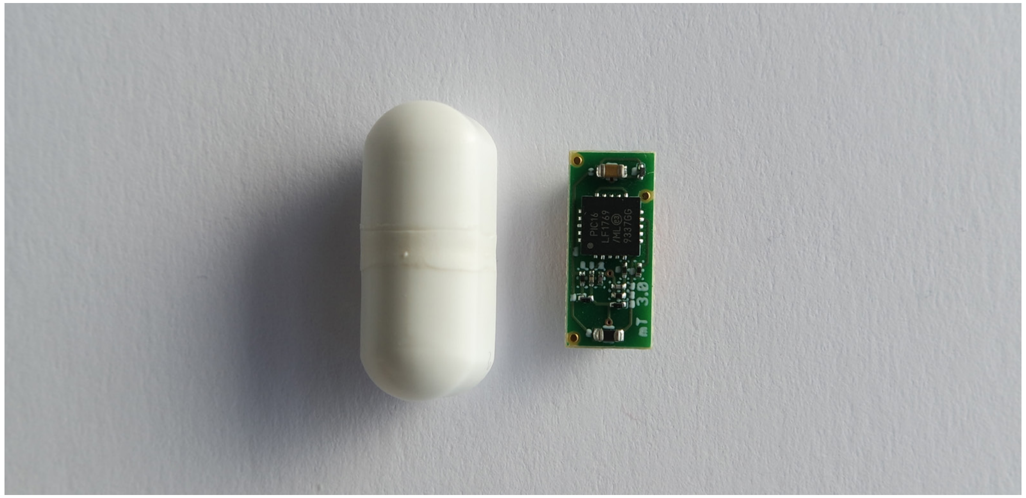


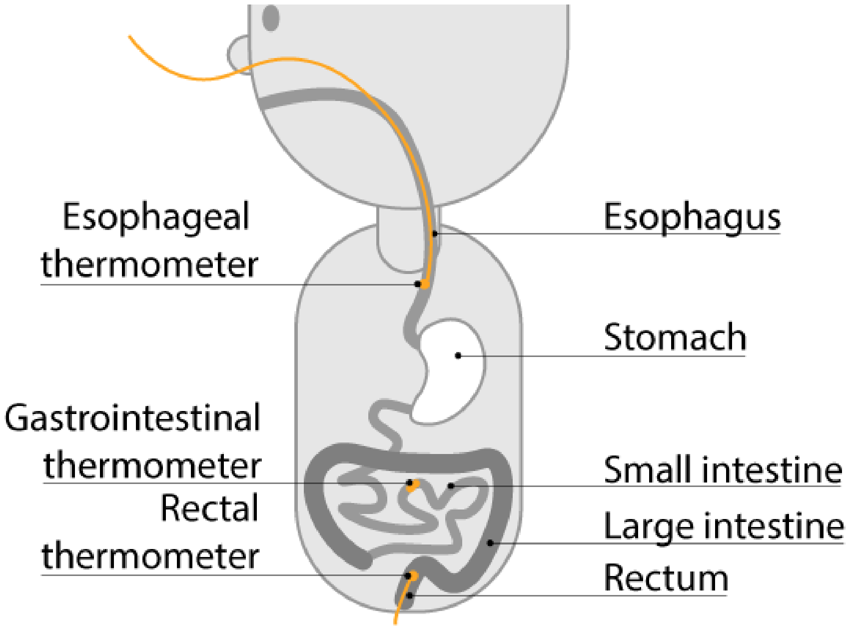
Image 2, Temperature sensor pill on the left, electronics of the pill on the right

Image 3, Current antenna belt prototype

3. Current solutions

Measuring one's core temperature accurately is difficult. In-ear and skin temperature measurements are among the most common ways to measure temperature, but can only be used as an indication of core temperature. These parts of the body are cooler than the core, and experience a delay in heating (Roossien et al., 2020). To accurately measure the core temperature you have to measure inside the body.

Image 4, Thermometry in the human body



Core temperature measurements

To accurately measure core temperatures, three options are available: esophageal thermotery, rectal thermometry and gastrointestinal thermometry (Image 4).

With esophageal thermometry, a temperature probe is inserted through the nostril in the esophageal. This is a medical procedure that requires training to insert, and is limited to laboratory-based studies. There is also a notable discomfort, the readings may fluctuate continuously and the readings can be influenced by fluid intake (Sekiguchi, 2019).

Rectal thermometry is currently the standard for body core measurements. It is a more practical method than esophageal thermometry, since it can be self-administered. It is mainly used in lab settings, where the subjects either have to run or cycle. The rectal probe can have a long, flexible probe, that allows the subjects more freedom in movement without the probe getting disconnected. It is possible to attach a data logger to the probe, to use in a field study. However, there is some minor discomfort in using this thermometer.

Gastrointestinal thermometry uses a wireless pill that contains a thermistor. The subject swallows the pill, and the pill will transmit the core temperature to a receiver. The pill needs to be swallowed at least 3 hours prior to the measuring, to prevent temperature fluctuation due to food ingestion. The gastrointestinal would allow for testing in the field, which can be valuable for researchers, coaches and athletes (Sekiguchi, 2019).

Thus using gastrointestinal thermometry is easier to use than esophageal thermometry, and gives more freedom in how and where to measure when compared to rectal thermometry.

Competitors

There are currently two main competitors of the myTemp gastrointestinal sensor: CorTemp and e-Celcius. A table with the main differences can be found on the right (Bongers et al., 2018).

Battery lifetime is about how long the battery in the pill lasts. When a battery is integrated into the pill, it has to be activated before use. This often is done by researcher, and then the activated pill is send to the participant (a timeline of this process can be found in Appendix E). The e-Celcius pills have to be activated in a special activator to turn the pill on. The CorTemp's pill comes in with a magnet attached; once the magnet is removed, the pill is activated (HQI CorTemp, 2020). A longer battery lifetime allows for more flexibility in the reserach preperation.

The myTemp pill requires an antenna belt to work. The pill itself does not have to be activated. The antenna creates an electromagnetic field that powers and reads the pill sensor. This data is then sent directly to either a phone or computer.

Capsule characteristics	e-Celcius	CorTemp	myTemp
Length (mm)	17.7	22.4	20
Diameter (mm)	8.9	10.9	8
Weight (g)	1.7	2.8	1.3
Operating range (°C)	0 - 50	30 - 45	30 - 45
Accuracy (°C)	0.23	0.27	0.001
Battery lifetime in pill	20 d	7 - 10 d	-
Power supply	Zinc-silver oxide battery	Silver-oxide battery	Self-induction
Maximum sample rate (datapoints per minute)	4	6	10
Price pill (€)	40-60 (Medgadget, 2017; Linders, 2021)	49 (ProCare, 2021)	20 (Fonville, 2021)
Price set (€)	2000 (monitor + activator + 10 pillen) (BodyCap Medical, n.d.)	2495 (data logger, pills seperately) (ProCare, 2021)	1200 (target price for monitor + 20 pills) (Fonville, 2021)

Table 1, Comparison between compatitors

Conclusion

The main benefit of the myTemp sensor is its accuracy, lack of battery and its (target) price. The pills themselves are cheaper per pill than e-Celsius, due to its use of the antenna band as both power supply as wireless communication. Onces further developed, it could become a strong competitor of the other gastrointestinal sensors.

4. Stakeholder analysis

By organising who are involved in the project and what criteria they might have for the product, a stakeholder analysis was carried out. Mindmapping was used to identify the stakeholders. Once the stakeholders were identified, the questions “Who are they”, “What do they want” and “How will they get it” were asked to determine their goals, interests and influence on the project.

These stakeholders were then placed in a graph based on their interest and influence (Image 5). The lines show which parties interact with each other.

The most interesting stakeholders are discussed below, the others can be found in Appendix A on page 98.

Athletes

Who are they?	People that do endurance sports on a professional level.
What do they want?	They want to perform to the best of their ability.
How will they get it?	Using their core temperature as base measurement to increase their performance in hot and humid weather conditions. All this with the help of researchers and/or coaches.

Academic researchers

Who are they?	They are university-based researchers, who use core temperature as one of the parameters in their research. Their research can be performance-related or medical. Sometimes they collaborate with partners outside the university.
What do they want?	They want reliable and accurate live measurements of the core temperature. The method of measuring should not influence the performance of the participants and should be able to be used in field tests. They want to gain a general, better understanding of how core temperature effects or affects other parameters.
How will they get it?	By choosing and buying the equipment for their research.

Sport researchers

Who are they?	They are researchers aiming at increasing the performance of individual, professional athletes in high temperature and high humidity conditions.
What do they want?	They want a system that can be set up quickly and gives reliable and accurate live measurements of the core temperature, to determine for each individual the best strategy to deal with heat and humidity.
How will they get it?	By choosing and buying the equipment for their research.

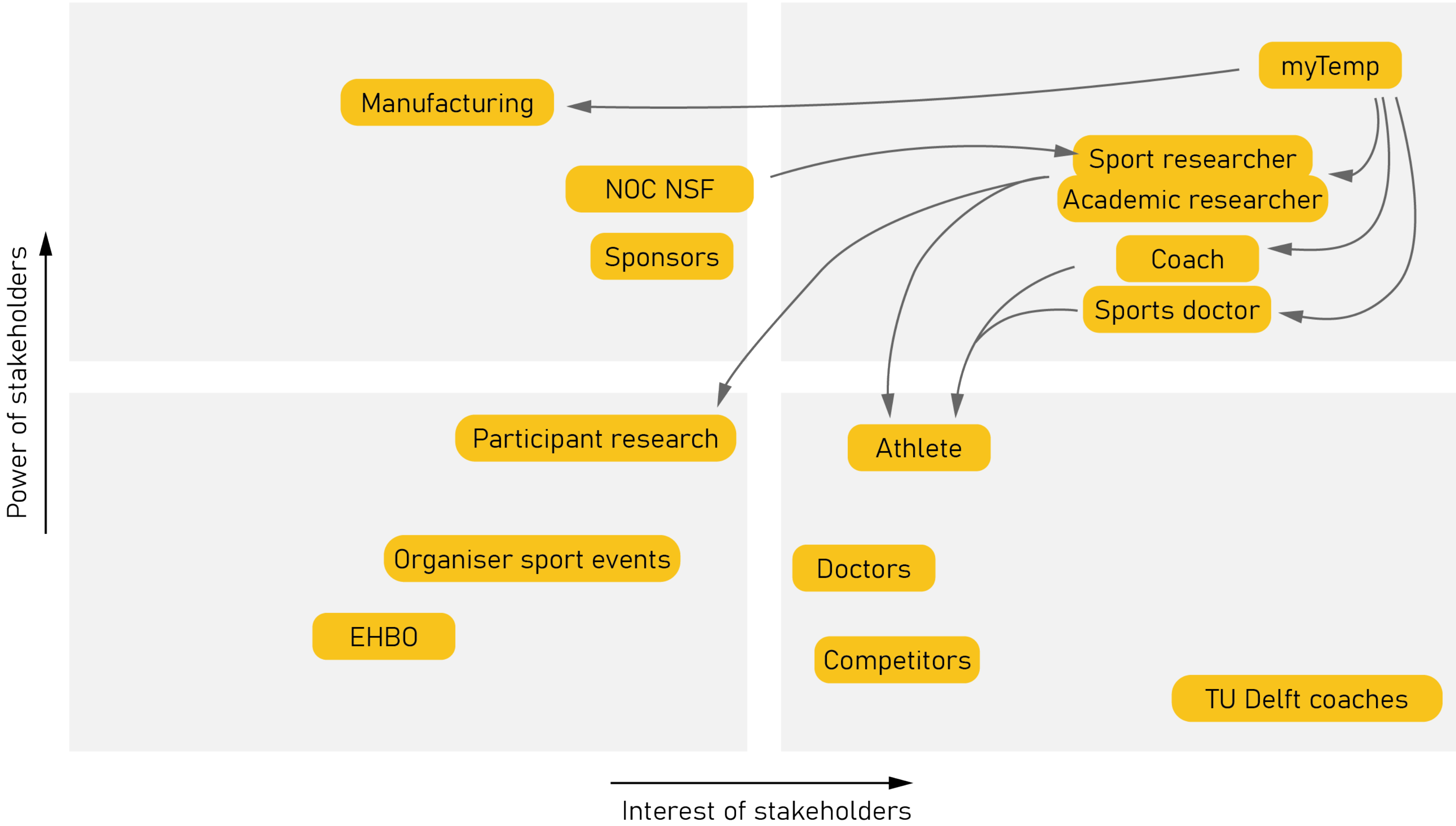


Image 5, Stakeholder analysis

Coaches

Who are they? They aid athletes in their training and monitor their performance.

What do they want? They want the athletes to consistently perform better in hot climates, and to prevent potential injury.

How will they get it? They want an easy to use tool that shows potential risks in the professional athletes core temperature that might influence their performance.

Conclusion

Sport researchers and academic researchers are the most important stakeholders. They are interested in either using it for academic research purposes, or for individual coaching. They have knowledge on how to interpret and use the data retrieved from the product. Thus, in this project for the myTemp system, it might be wise to first focus on these research-focused target groups.

5. Interviews

To gain a better understanding of the context in which the myTemp system is used and to find the current flaws in the systems interviews have been conducted.

A semi-structured interview was used. The main research questions for the interviews were:

- In what context is the myTemp system currently used?
- What has been the user experience using the myTemp system?

The semi structured format allowed me to ask more follow up questions and explore previously unknown topics. The full list of questions can be found in appendix B.

In total there were seven participants. Six of them were researchers, and had used the system as part of their research: Four of these were academic researchers and two were sport researchers. The last one was a sports doctor and coach, and had used the system on himself.

These interviews were all noted down (Appendix C), and findings were written on Post-it notes. MyTemp had also provided me with notes of interviews they had previously done. Findings from these interviews were also included.

All the Post-it notes were clustered to find themes between interviews, and how often these themes were mentioned (Image 6).

Image 6, Clusters of interview findings

Results

The clustering revealed multiple themes about the myTemp system.
The ones that were mentioned the most were:

- Connectivity
- Hygiene
- Comfort of the band
- Interaction product

Other themes include:

- Interaction software
- Lack of professional feel of product and software
- Lack of data storage on the belt itself
- Lack of accessible information for the wearer

On the following pages these themes will be explained in more depth.

Image 7, Hierarchy of found themes

Connectivity

All interviewees said that the connection between the band and the pill sensor was unstable. The band would have trouble finding the pill initially, and when it was connected, it would lose this connection again. This is a problem because of two reasons: the quality of data and the safety of the participant.

For researchers data is quite important; without it their entire research is worthless. So especially in research where the core temperature is one of the most important data, the quality needs to be high. Currently, there are data gaps that range from a minute to a few hours. Small data gaps of a minute can be filled in by extrapolating the data, however that only works when research does not include frequent changes in performance (Folkers, 2021).

Now it is also the most frequently mentioned reason why some have switched to other core temperature measurements systems like the e-Celcius.

Another reason why the connectivity is so important is the safety of the participant. In their studies, researchers often find that high core temperatures are approached. They need to be able to pull a participant out of the research when the core temperature is too high (39.5 to 40.0 °C). If they do not, the participant could experience permanent damage.

Currently, they use the live output of the myTemp system to monitor the core temperature. If the connection breaks, they can not guarantee the safety of their participants for that period of time.

Hygiene

The interviewees talking about the hygiene of the product said that they were unsure how to properly clean the antenna band. Some said that they did not clean it all together, some tried to clean it using a cloth with disinfectant.

While the antenna band does not sit directly on the skin but instead is worn over clothes, the band still gets a bit sweaty and should be cleaned after use. With the COVID-19 pandemic, there is also more awareness of keeping equipment clean.

Usually they clean their equipment by wiping it down using a cloth and disinfectant or they submerse it in a disinfectant solution.

Comfort of band

The participants perceived little trouble with the comfort of the band when they were riding on bikes. However, when wearing the band while running or when doing team sports the band would move too much around.

In one instance the researcher had trouble fitting the band over the equipment worn by a firefighter, since the band was too small.

Interaction product

The main way the antenna band currently interacts with the user is via sounds. However, what each sound means is not always clear to the researchers. Currently there is a sound every time the temperature is succesfully measured, but also when it fails to measure. A different sound can be heard the first time the pill is found and when the belt is turned on.

This causes an overload of stimuli for both researchers and participants. When the belt is not working, it will make a sound every 15 seconds. But when it is working, it will still make a sound every 15 seconds. One researcher had at one point three people in the same room and had to disable all sounds, because it all became too much. This meant that that he was unable to hear if there was a problem with the system, as he had no control over what specific sounds he could disable.

Also, people were not able to distinguish between the sounds, and would have to keep looking in the manual until they had more experience with the product.

Interaction software
With the current software the users were not able to find settings like how to change sounds for example, or the program would simply crash or not respond. Also, the software felt outdated.

Lack of data storage on the belt itself
For field studies there was a need to store data on the belt itself, so that users are not dependent on a connection between the belt and a phone or computer.

Lack of professional feel of product and software
Both the belt and the software did not feel professional, both in how they looked and how they interacted. This had to do with the fact that the system still is a prototype, and all were aware of that. For many that was not a problem for their research, since they are willing to put some more effort in the product, if that means that they get what they want from the product.

Lack of accessible information for the wearer
This is the difference between data and information. For researchers, the data are important for their research, since they do the data processing themselves to retrieve the information they need.

For non-researchers the data itself has no meaning. They just want to know if they are too hot or not, and what they should do if they are. Since core temperatures vary from person to person, absolute data can not be used; 40.0°C might be too high for one person, but another might not experience any form of heat illness at this temperature. So there needs to be a way to process and calibrate the raw data so that the person wearing the belt gets the correct information.

6. Observations

On the 18th of May 2021, I was able to visit a research project with participants. The project was a collaboration between myTemp and Sport Data Valley. Sport Data Valley provides a platform to collect and analyse sports-related data. In this project they wanted to collect core temperature data to analyse on their platform. The method was to have three long-distance runners run for 20 minutes and then have them rest until a certain core temperature had been reached.

My goal was to observe the use of the myTemp band and to document any problems or notable things.

The event was divided into four parts: an introduction, setting up the myTemp sensors, the running, and the cleaning up.

The introduction was about how to handle the myTemp system, and came with an A4-sized paper with detailed instructions. These were about how to setup the sensor, how to connect them via bluetooth with their smartphone, and some simple troubleshooting.

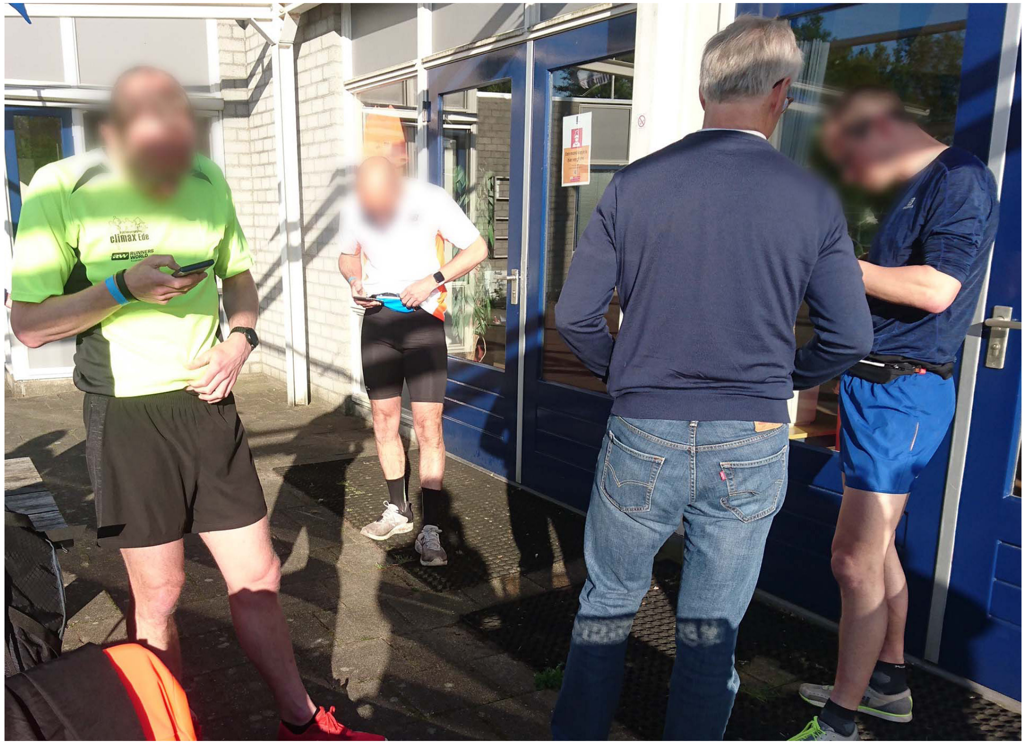


Image 8, Participants on location

After the introduction, the sensors were set up. This started with handing out the correct size band to each individual runner. This was followed by establishing the bluetooth connection and the connection between the pill and the band.

The bands were all worn under the shirt and thighted as best as they could. The myTemp sensor was always placed on the back, so that the claps were on the front of the body. This also made it more comfortable to wear. The band would only be flipped around for troubleshooting. The band would mainly be worn on the waist or just below the waist. Since the elastic band and the cable would not be of the same size after tightening it, the band would look like on Image 9.

Image 9, Belt on participant

This was the part that took over an hour. One could not get the communication via bluetooth to work with his own phone, and had to use another phone. In one case, the band was unable to detect the pill at all, even with trying different configurations of the band. It came to the point where he took another pill to see if maybe the pill was faulty, but the second pill could also not be found.

It was difficult for people to recognize the audio feedback from the band. Even though we were outside, people stood quite close together and were talking. That made it difficult to recognize whose band was making what sound. To determine what type of problem there was, you had to wait and closely listen for the bleeps. The LED indication was even less helpful, since you could not derive the specific problem from them. It was extremely hard to determine if the pill was the problem or the band.

Conclusion

The wireless connections were the main issue during the reseach. It took a full hour to get the connections working (with one that did not work at all) so that the participants could run for 20 min.

The audio feedback was difficult to hear, which made troubleshooting quite hard.

7. Sports wearable analysis

To find the ergonomic requirements for the antenna belt, products that are worn around the hips while exercising have been analysed. These products are mainly made up of running and cycling hydration packs. These packs are worn to provide storage for water, phone, keys and other items that might be useful for longer runs or cycling trips.

By analysing reviews of different products you are able to find the needs most important to the reviewer, and what design choices did or did not fulfill their needs. The products used and their names can be found in Image 10.

Quotes from reviews have been used to find the topic that the reviewers find most important. These quotes have been clustered into different main topics and then into different subcategories. This can be seen in Image 11. The colour of each Post-it notes corresponds to the product it is referring to.

Image 10, Products used for analysis

Image 11, Clusters made of quotes

The main needs can be divided into four categories: stability, breathability, comfort and storage.

Stability

Stability refers to how much the product moves around when worn. When the product moves a lot around close to the body, it can be distracting.

Here we have four subcategories: tight to the body, flat against the body, shoulder straps and dangling straps.

Tight to the body refers to the need for a product to sit tight against the body in order to prevent it from sliding around. This is often done using elastic or stretchy fabric or by having adjustable straps.

Flat against the body refers to the objects in the product to lay flat against the skin. If objects are loose, they will move separately within the bag, amplifying the movement of the product itself.

Shoulder straps are an addition to stabilizing the load. Without these straps the waist strap has to both hold the weight as well stabilize it. When shoulder straps are added, these hold the weight, and aid the stabilization, allowing the waist strap to not be pulled as tight as without shoulder straps.

Dangling straps are parts of the adjustable straps that are hanging loose. When doing sports these can move around freely and touch the body. This can be perceived as distracting. Using clips or elastic materials are used to prevent the straps of moving freely.

Breathability

Breathability is about how sweaty someone feels while wearing the product. Here we find two subcategories: material and skin contact.

The material touching the body has an influence on how sweaty someone feels. In case of a thick material the user might feel more sweaty, or in case of lighter synthetic material the sweat is immediately wicked away from the skin.

With skin contact the amount of material touching the user is meant. With less skin contact the user will feel less sweaty than with a more skin contact. This also includes the use of foam and perforated materials, which allows for more air flow between the product and the user.

Comfort
With comfort the attributes of the products are described. These are divided into four subcategories: weight, weight distribution, fit and material.

Weight is the objective weight of the product. A heavier product will feel less stable and comfortable than a light product.

Weight distribution is about the way in which the weight is distributed around the body. The more the weight wraps around the body, the better the distribution feels. This is often done in the way of having more than one place to put objects, or to add flaps next to the weight. This also helps with stability.

Fit is how the product fits to the body. A fit that is too tight might impact the way you move or breath, and fit that is too loose can lead to the product moving around. It also is about how well you can move in the product. Stretchy materials and adjustable parts are often used to allow for a snug fit without being too tight. It also can be seen that the bulk is often in the back, allowing the user to bend forward without the product getting in the way.

Comfort can be seen in the softness or stretchiness of the material used. Materials with hard or scratchy edges might want to be avoided, in case of irritating the user.

Storage
Storage is about how much and how much extra objects you can carry with you.

When running there is a need to take essential objects with you, like your phone or keys. When running longer distances, water or other objects might be needed. The longer the run, the more water is required, and the more weight needs to be carried.

Conclusion

There is a lot of overlap between the different topics, and there a few dilemmas. We can see how the choice of materials influences fit and breathability. We see a dilemma between stability and comfort: in order to stabilise the weight the product has to be worn tight against the body, possibly too tight for comfort. We see a dilemma between weight distribution and breathability: a larger surface distributes the weight better, but leads to a more sweaty feel

These factors need to be considered when designing a product that has to fit around the waist or hips.

8. Technology

Introduction
Radio-frequency identification (RFID) is a wireless system that uses radio waves to capture data from a tag or identifier using a reader (AB&R, n.d.). The technology is, for example, used in electronic keys and inventory management.

It works using three components: the reader, the antenna and the tag (read: the temperature sensing pill). Via the antenna the reader sends out a radio wave (elecromagnetic), that is picked up by the antenna of the tag. The tag then sends the data back via its antenna to the reader (Image 12).

The myTemp system is an active reader passive tag (ARPT) type. This means that the tag is batteryless, meaning that its power source are the electromagnetic waves generated from the reader.

As for the workings of RFID antennas, we will go into further detail in the next part.

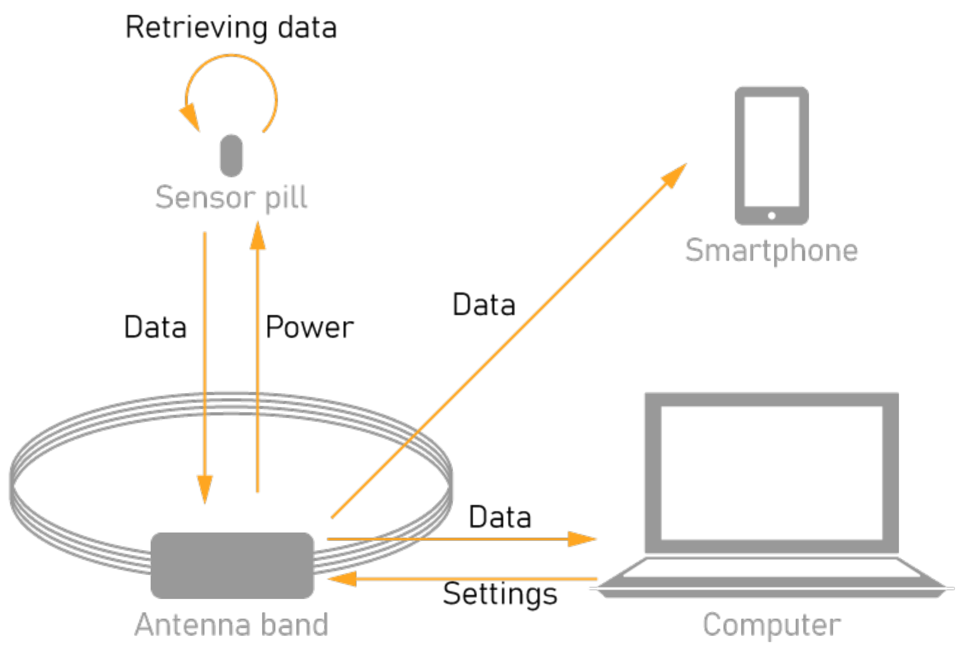


Image 12, Interaction between products

Working of the system

The main system consists of the reader, the antenna and the pill. To communicate with each other, they follow a specific protocol (myTemp manual, n.d.).

First comes the charging phase. A magnetic field is created by allowing current to go through the antenna. This creates a torus-shaped magnetic field. The pill also has a coil that is able to pick up the magnetic field. When a magnetic field goes through a coil, a current will flow in the coil. This current charges a capacitor, which acts a small battery.

When the charging is done, the pill will send a signal to the reader that the pill has enough charge to measure. Then the data phase starts. Here the reader and the pill share relevant information, like the identification number of the pill. This is used to prevent other pills from interfering with the data.

After this, the measuring phase starts. Here the pill reads out the value of its temperature sensors (NTC). In the computing phase it calculates the temperature from this value. This is because there are small differences between each temperature sensor, and each has been calibrated to calculate the correct temperature.

In the writing phase, the data is being stored in the flash memory. It means that if the connection is lost, the data is not immediately lost as well. Then in the answering phase, the data is communicated back to the reader, from where it can be transmitted via bluetooth to the phone or computer.

Theory of antenna

Before we can design an RFID antenna, we first need to know how antennas work and which parameters can be changed and which can be fixed. The focus lies more on the design of the antenna band than on the design of the antenna in the sensor pill. Most of the information is derived from Lee (2004).

An antenna can be simplified to the schematic in Image 13. There is an AC (alternating current) power source, a resistance of the coil and the inductance of the coil. The inductance value is based on the shape and size of the coil. The resistance of the coil is mainly based on the length, thickness and material used for the coil.

Inductive reactance

To be able to calculate with inductance in an AC circuit, the inductive reactance can be calculated with the following formula:

$$X_{coil} = 2\pi \cdot f \cdot L$$

Formula 1, Inductive reactance

With

X_{coil} = *inductive reactance (Ω)*
f = *frequency (Hz)*
L = *inductance (H)*

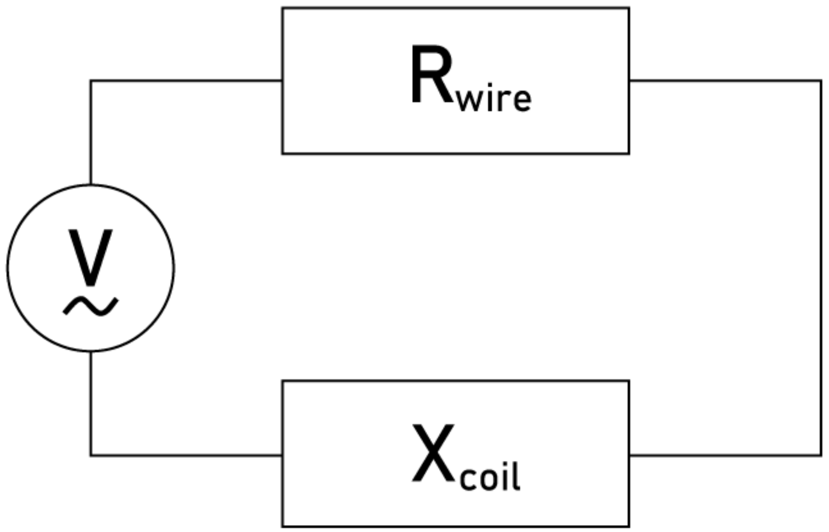


Image 13, Circuit diagram of antenna

Wire resistance

The resistance of the wire in a DC (direct current) circuit can be defined as the following:

$$R_{DC} = l / (\sigma \cdot \pi \cdot a^2)$$

Formula 2, Wire resistance

With

R_{DC} = *resistance of wire (Ω)*
l = *length of the wire (m)*
σ = *conductivity of material (Ω/m)*
a = *radius of wire (m)*

Since the wire is connected to an AC circuit, there is another factor that plays a role in the resistance of the wire. With AC power, a magnetic field is generated in the wires itself. This field pushes the charge from the centre of the wire to the edge, increasing the charge density near the edge. This is called the 'skin effect', and it creates a higher resistance in the wire. The skin depth can be calculated using the following formula:

$$\delta = 1 / \sqrt{(\pi \cdot f \cdot \mu_0 \cdot \mu_r \cdot \sigma)}$$

Formula 3, Skin depth

With

δ = *skin depth (m)*
f = *frequency (Hz)*
μo = *permeability of air = 4□ x 10-7 (H/m)*
μr = *permeability of material (H/m)*
σ = *conductivity of material (Ω/m)*

The total AC resistance of a wire can then be calculated using the following formula;

$$R_{AC}=(R_{DC}) \cdot a/(2 \cdot \delta)$$

Formula 4, AC resistance

Magnetic fields in circular loop antenna

When current goes through a coil, a magnetic field is produced. In case of a circular loop antenna, this field can be described in the following formula:

$$Bz = (\mu_0 \cdot I \cdot N \cdot a^2) / (2 \cdot (a^2 + r^2)^{3/2})$$

Formula 5, Magnetic field

With

- Bz = *Magnetic field magnitude (T)*
- μ_0 = *permeability of air = 4π x 10-7 (H/m)*
- I = *current (A)*
- N = *number of turns of coil in the loop*
- a = *radius of the loop (m)*
- r = *distance between magnetic field and centre of loop (m)*

This formula shows us the following; the magnitude of the magnetic field is directly linked with current and number of loops, and distance negatively affects the magnetic field.

Using this formula, the size of the magnetic field generated by the current prototype can be determined, which can then be used to find the ratio between the number of turns and the distance between the antenna and the pill sensor.

Angle of pill

The voltage that can be produced in the coil of the tag is dependent on the following formula:

$$V_0 = 2\pi \cdot f \cdot N \cdot S \cdot Q \cdot B_0 \cdot \cos a$$

Formula 6, Induced voltage

With

V_0 = *Induced voltage in coil (V)*
f = *frequency of signal (Hz)*
N = *number of turns of coil in the loop*
B_0 = *strength of arrival signal*
S = *area of the loop (m^2)*
Q = *quality factor of circuit*
a = *angle of arrival of the signal*

We can see here that the strength of the magnetic field, and especially the orientation of the tag coil, plays a large role in the induced voltage. If the coil is oriented 0° (perpendicular to the magnetic field), the induced voltage is maximum (cos 0 = 1) (Image 14). If the coil is oriented 90°, no voltage is induced (cos 90° = 0) (Image 15).

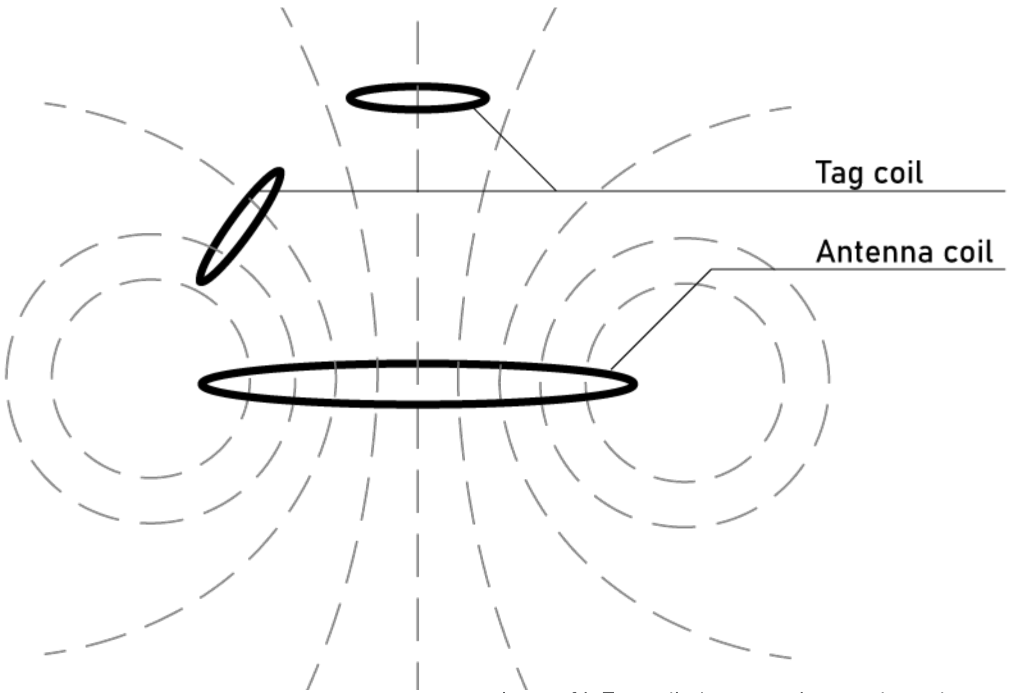


Image 14, Tag coils in max voltage orientation

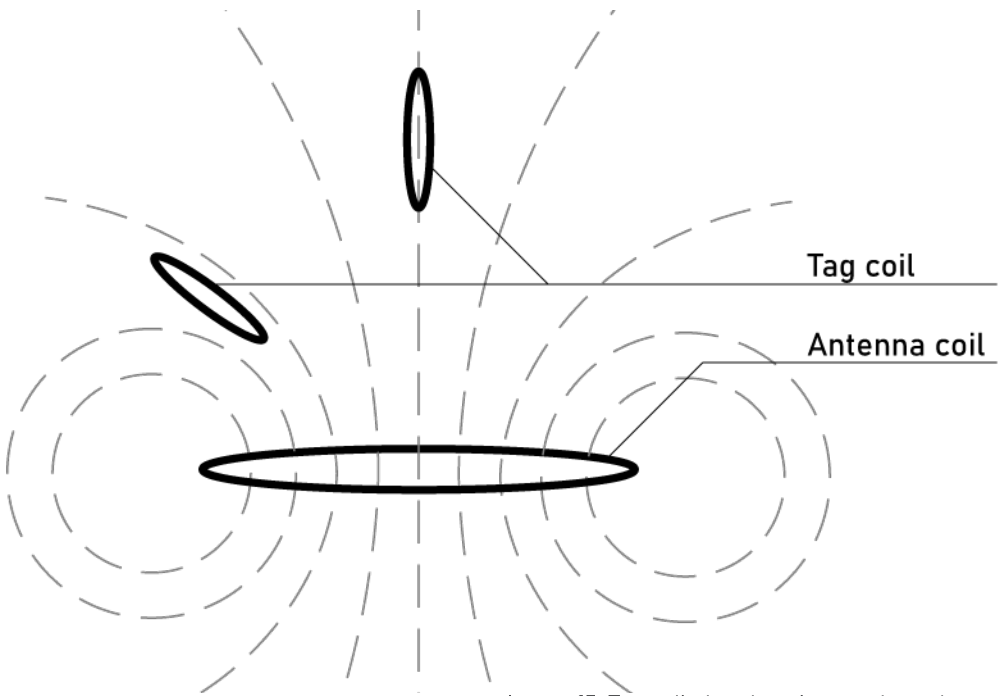


Image 15, Tag coils in min voltage orientation

Conclusion

Creating an antenna is finding a balance between creating a magnetic field vs creating heat due to resistance. The shape of the antenna influences both factors. The resistance of the wire can also be higher than expected due to skin effect with AC power.

The angle of the receiving coil (read: the angle of the pill) determines how well the pill is able to receive energy. When this coil is perpendicular to the magnetic field, the maximum energy can be transferred. When the coil is parallel to the magnetic field, there will not be any energy transfer.

With the pill moving around in the intestines this leads to connectivity problems (Image 16).

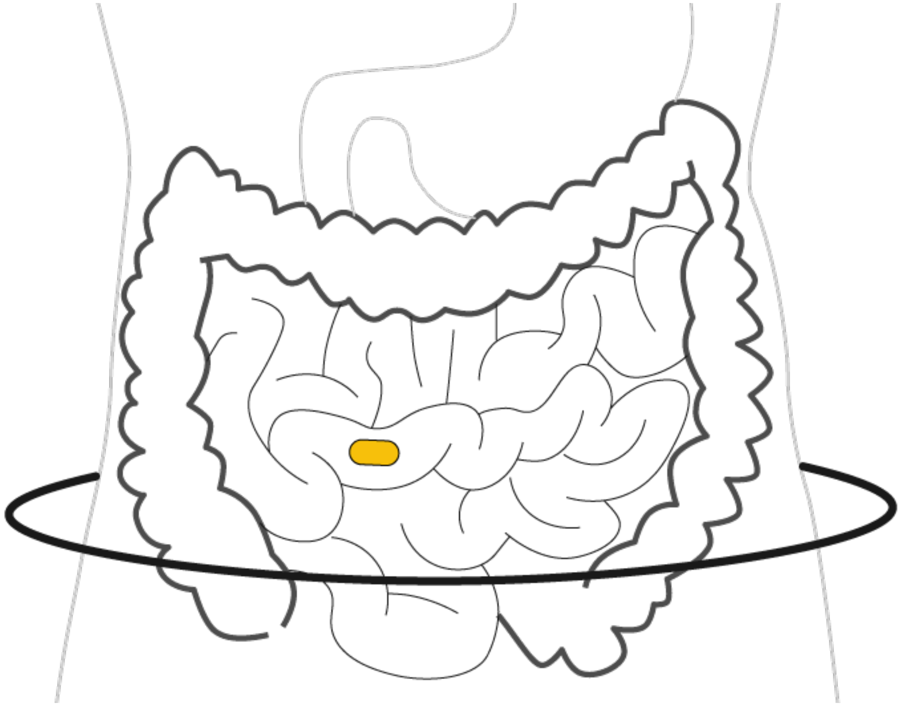
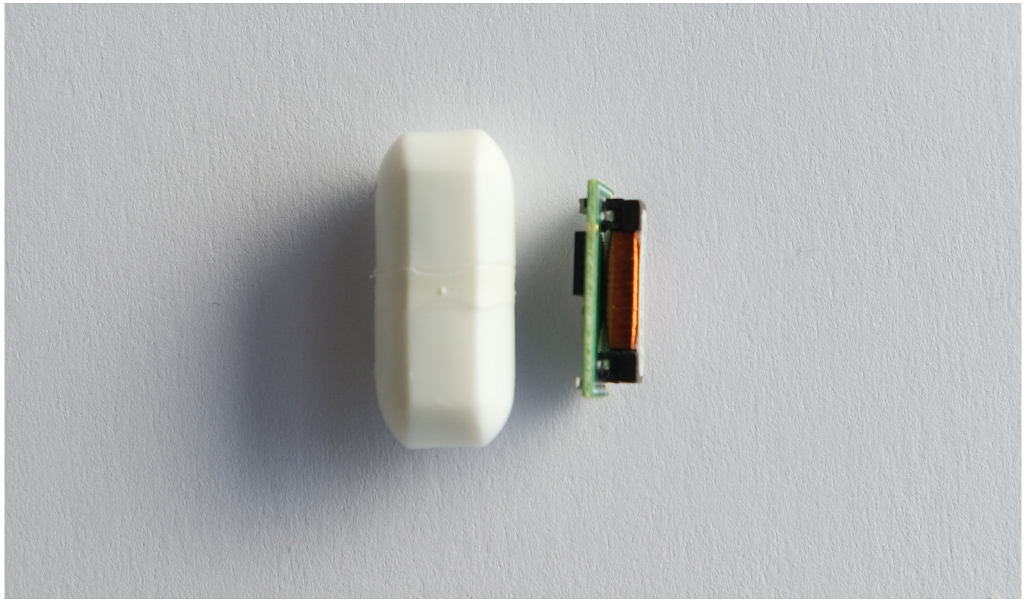


Image 16, Pill in intestines, in orientation where it cannot receive energy

Image 17, The receiving coil in the pill



9. Summary research

The main benefit of the myTemp system lies in its high level of accuracy, the fact that the pill has no battery and its low (target) price point (“3. Current solutions”). Due to these benefits, the myTemp system is currently mainly of interest to sport researchers and academic researchers, since their research requires accurate data and many test subjects (”4. Stakeholder analysis”, “5. Interviews”).

Interviews have been conducted mainly with researchers who have used the myTemp system for their research. These interviews brought to light four main problems concerning the following: unstable connection between antenna band and sensor pil (connectivity), discomfort white wearing the band (comfort), frustrating user-product interaction (product interaction) and lack of knowledge on the side of the user as to how to clean the product (hygiene).

Connectivity

Connectivity (and the lack thereof) was seen as the main downside of the system, and was often cited as the reason why the reseachers stopped using the myTemp system for their research and instead chose competitive products. The connection between the antenna band and the sensor pill was described as unstable, with the connection being lost for sometimes half an hour. Such a situation could put the participant at risk, since a too high core temperature could have been reached during the time the connection was out. The unstable connection also created data gaps, which makes the data collected less accurate (“5. Interviews”).

During the observation, most of the research was spent on trying to establish a connection between the belt and the pill.

This connectivity issue probably has to do with the orientation of the sensor pill with respect to the antenna belt (“8. Technology”). For maximum energy transfer, the coil inside the sensor pill should be perpendicular to the magnetic field created by the antenna belt. This means that when the pill is orientated horizontally in the intestines, the pill is unable to receive power from the electronics.

Comfort

The participants that wore the antenna band while riding a bike had little problems with the comfort of the belt. Participants that had to run or do team sports did find the belt uncomfortable. In this case the belt moved around too much to be comfortable (“5. Interviews”).

Because the current antenna band is made up of a cable antenna, it can flop around when the wearer is exercising. To create a comfortable product around the torso, it should be as stable as possible (“7. Sports wearable analysis”).

Product interaction

The current way in which the prototype communicates with the researcher is not ideal. It communicates with sound, in the shape of bleeps, communicating when the antenna can and cannot find the sensor pill. Especially with research where there are multiple participants at the same time in the same room or close to eachother, this can create an over-stimulus of sound. It made it hard to understand what was happening with what antenna band (“5. Interviews”, “6. Observations”).

Hygiene

When it came to hygiene, the researchers did not know how to properly clean the myTemp system. Since the interviews were conducted in spring of 2021, during the COVID-19 pandemic, hygiene and being able to disinfect products became a more important issue for these researchers (“5. Interviews”).

Conclusion

Connectivity is presently the main problem with the myTemp system.It is a problem that makes people stop using the system, because of the reliability of the data, the health of the participant and the accuracy of the retrieved data are extremely important. Thus, the specific problem becomes;

Can other configurations of the antennas (different shapes of different materials) increase the reliability of the myTemp system?

Different antenna ideas need to be explored before comfort can be addressed. This is because the comfort of the antenna belt depends on the configuration of the antenna bels. Therefore, this will be addressed after iterating the antenna. The same goes for hygiene: the materials used as antenna determine how the product can be cleaned properly.

Product interaction can be addressed simultaneously with the antenna research, since it does not rely on the outcome of this research. This creates the following specific problem;

What information needs to be communicated to the user, and what is the most effective way to communicate this to the user?

All the insights gathered in the research phase are collected in the program of requirements. This is a list of all the criteria the product should abide by. This list can be found in Appendix D.

Thus the project concludes its research phase and moves toward the ideation phase. In the next ideation phase, the exploration of new configurations of the antenna will be discussed. Improving the user-product interaction will be covered in the ideation phase after.

Ideation 1
Antenna research

10. Antenna concepts

After the analysis phase, it is time to come up with and test different ideas. These ideas were partly generated during the analysis phase and partly during a brainstorming session.

The ideas mainly focus on solving the problems of reliability and comfort. The five chosen ideas can be seen in the image below;

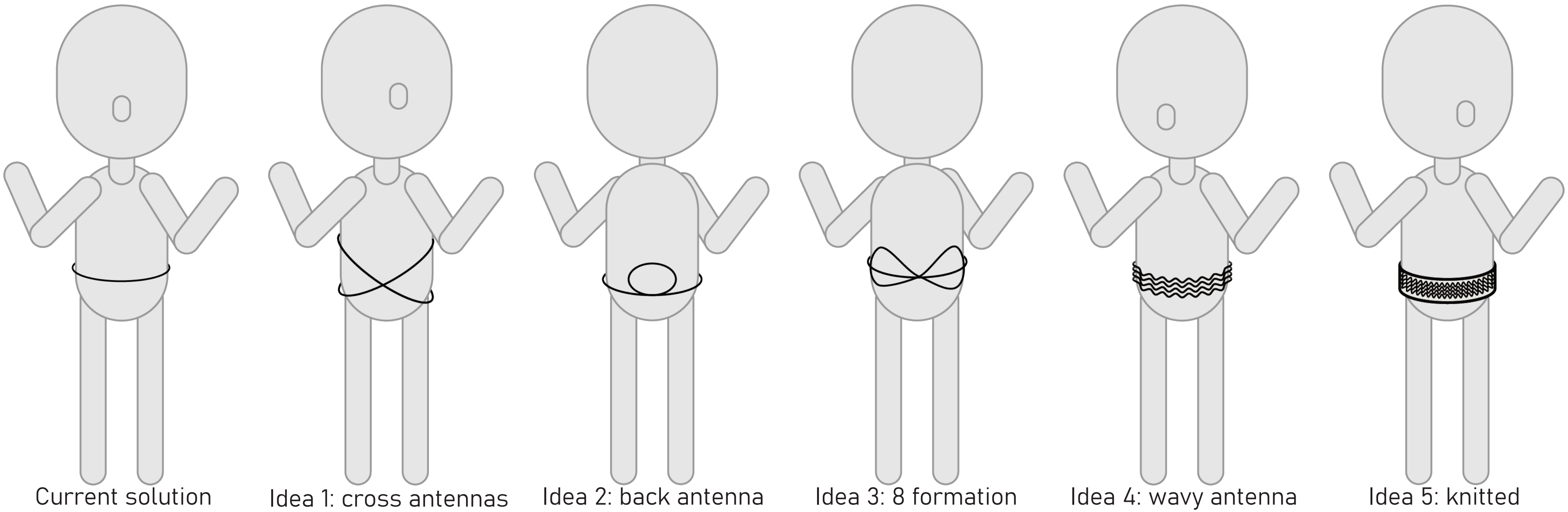
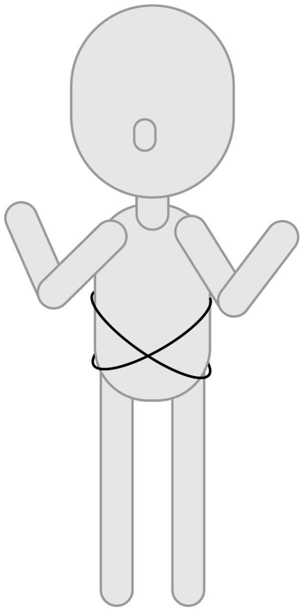


Image 18, Different ideas



Idea 1: cross antennas

For idea 1, two rigid antennas cross over the body. In theory, this idea would increase reliability because it is able to cover more angles of the pill; if the one antenna is unable to detect the pill, the other might.

This idea also might be able to cover a wider range of body sizes (see Image 19); for someone with a broader body the angle between the antennas would simply be smaller than for someone with a smaller body. This would make the idea more cost-effective, less belt sizes would have to be produced.

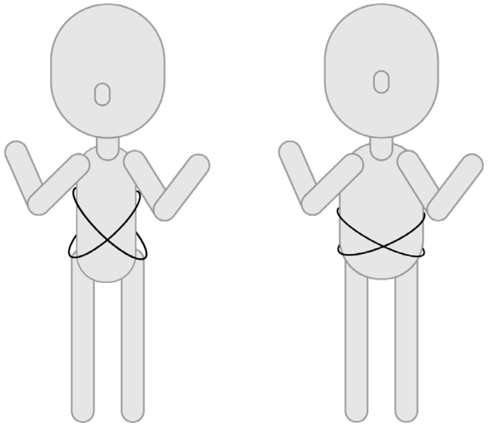
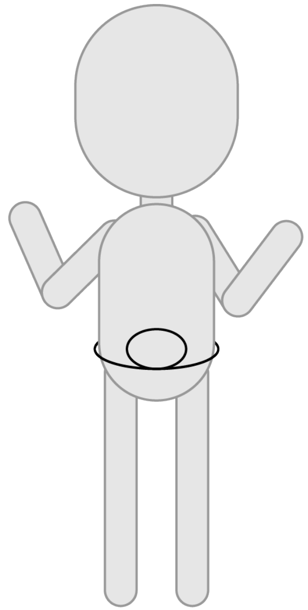


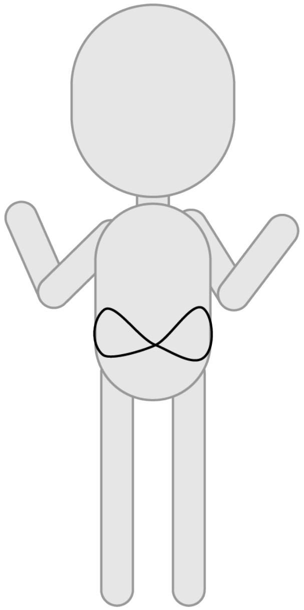
Image 19, Idea on slim person (left) or broader person

Idea 2: back antenna

In idea 2, the antenna around the body would stay the same as the current product, but a second antenna would be placed flat on the back. This idea would cover more angles of the pill compared to the current solution, just like idea 1.

A benefit of this idea would be that the back antenna would not have to be adjusted for people with different sizes.





Idea 3: 8 formation

In idea 3, an antenna would be wrapped in an 8 shape around the body. This would allow (in theory) for the magnetic field to travel further and thus more reliably detect and measure a horizontal pill (Image 20).

The antenna is not wrapped around the body like a belt, because it is only situated at the back of the body. This has the following benefits. Normal claps can be adjusted at the front of the belt. This makes it easier to put the belt on or take it off. The antenna could change shape to fit multiple sizes: being wider for smaller people or less wide and more stretched for larger people.

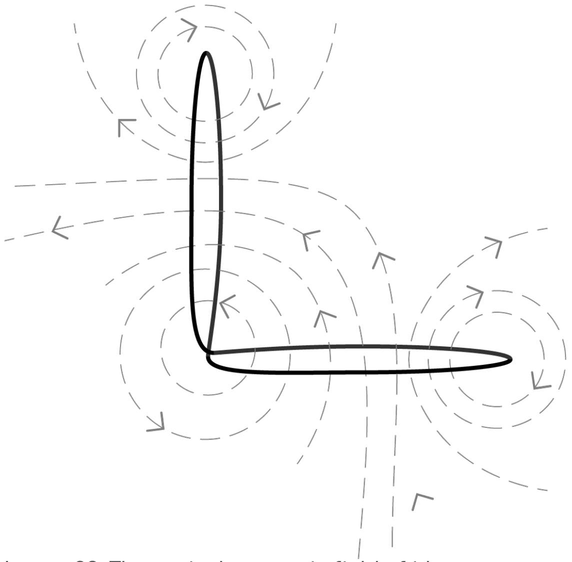
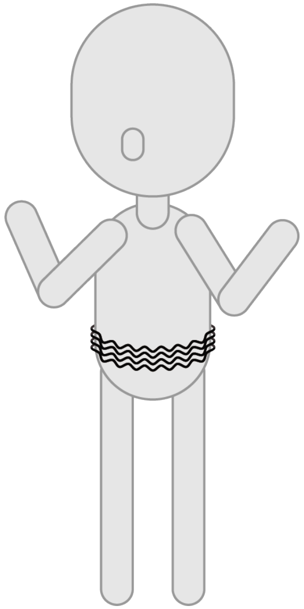


Image 20, Theoretical magnetic field of idea



Idea 4: wavy antenna

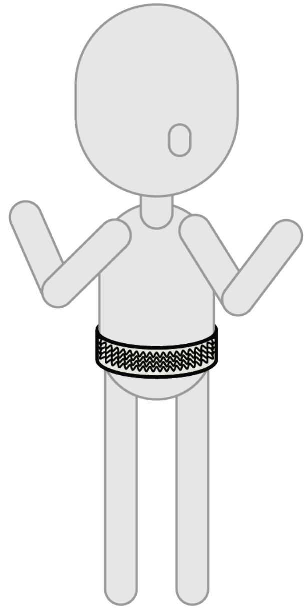
Idea 4 uses stretchable wires instead of rigid wires for the antenna. By making the wires wiggly and attaching elastic to them, the wires can be stretched quite easily. This makes the antenna fit as close to the body as possible. Idea 4 decreases the diameter of the antenna and thus increases the strength of the magnetic field. It could also compensate for different body types by stretching. Clasps might even be unnecessary if the belt is able to stretch over the hips or shoulders when putting it on or off.

Idea 5: knitted antenna

For idea 5, the antenna is knitted using conductive threads instead of using rigid wires as antenna. This has the same benefits as idea 4, but is more customisable. It would also open the possibility of integrating the antenna into clothes.

Image 21, Strechy wires (AMOHR tape)

Image 22, Knitted with conductive thread



11. Antenna research

To find the ideal antenna setup for the myTemp, a method to test different antennas had to be created. The goal of this method was to quantify the strength of the magnetic field that is generated by these different antennas, so that they can be compared based on how well they perform. Using these comparisons, an antenna design (as previously discussed in “10. Antenna concepts”) can be chosen.

First, the different research questions are discussed with their relevant theory. Then, the method of measuring will be discussed, including the setup and considerations that went into creating this method. An overview will be given of all types of antennas used, and an example of how the data that was generated was processed. The results and discussion will follow after that.

The tests had an explorative nature. Thus the tested antennas should be seen as concepts and not the final design.

The magnetic field is measured in three different ways: their strength in the plane of the antenna (Image 23), their strength from the centre going up (Image 24), and their strength with a changing angle to the plane (Image 25).

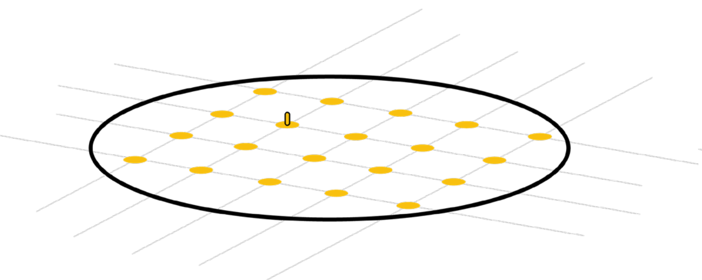


Image 23, Setup strength in plane of antenna

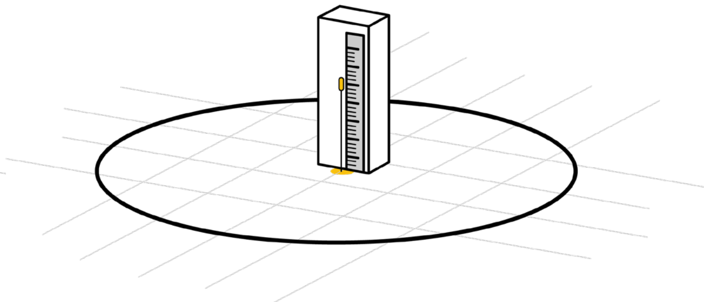


Image 24, Setup strength from centre going up

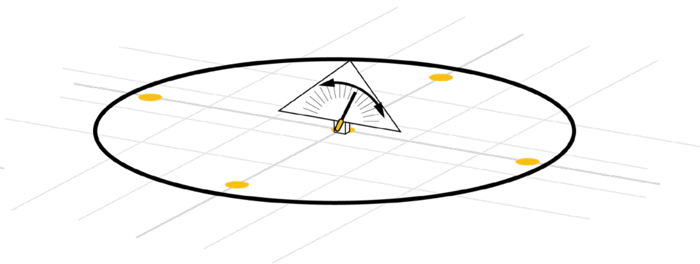


Image 25, Setup strength with changing angle

Research questions

The main research question is: “How do different antenna configurations influence the magnetic field that they generate?”.

This question can be broken down into different questions that will be discussed below.

Shape difference

1. How does the magnetic field change when comparing a circle shape to the shape when worn on the body.

The theory (“8. Technology”) often assumes a perfect round circle antenna, or symmetrical one (Lee, 2003). But when the antenna is worn on the body, the shape will be more irregular, as can be seen on the Image 26 below.

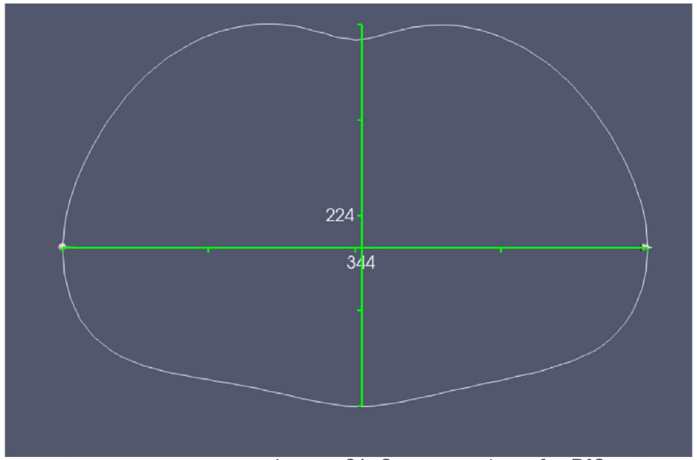


Image 26, Cross section of a P10 woman.

Size antenna

2. Do the measured values change in the same rate compared to the theory when comparing different sizes antennas?

Formula 5 on page 30 (that describes the strength of the magnetic field based on antenna and power used and location of measurement) can be rewritten to the following, when assumed that the only parameter that changes is the radius of the loop

$$Bz = (\mu_0 \cdot I \cdot N \cdot a^2) / (2 \cdot (a^2 + r^2)^{3/2})$$

$$Bz = ((\mu_0 \cdot I \cdot N) / 2) \cdot (a^2/(a^2 + r^2)^{3/2})$$

Formula 7, Rewritten magnetic field

When it is assumed that the location of measurement stays the same, it can be said that r = 0. This would allow us to plot the following formula:

$$y = a^2/(a^2)^{3/2} = 1/a$$

Formula 8, factor y

Since there are only access to two original antenna sizes (100cm and 70cm), these have been made orange on the graph. When calculating the relative change between these two values, expected would be that the 70cm antenna would perform 43% better than the 100cm antenna. This research question thus aims to validate this theory.

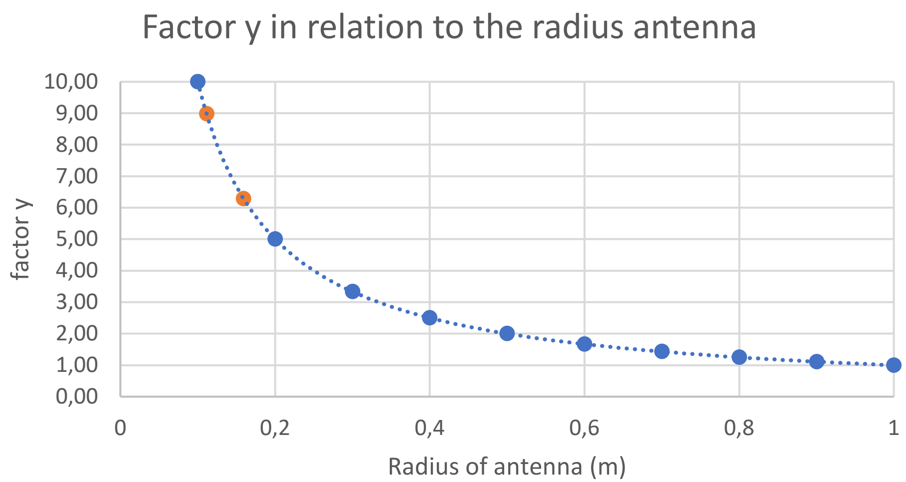


Image 27, Graph radius antenna

Wave generator

3. How does the measured magnetic field compare to the theory when using a wave generator instead of the myTemp electronics.

The wave generator generates an electronic signal with a set amplitude, frequency and wave shape. The main difference is that the wave generator operates at a lower voltage (20V) than the myTemp electronics (60V). Since voltage and current are linearly related to each other (Ohm's law) it could be expected that the current would be 3 times lower when using the wave generator when compared to the myTemp electronics, if the assumption is made that the resistance would not change.

The current has a linear relationship to the magnetic field, as can be seen in formula 5 from chapter 5. Thus, it could be expected that the magnetic field would also be around 3 times lower when using the wave generator than the myTemp electronics. The research question would test this assumption.

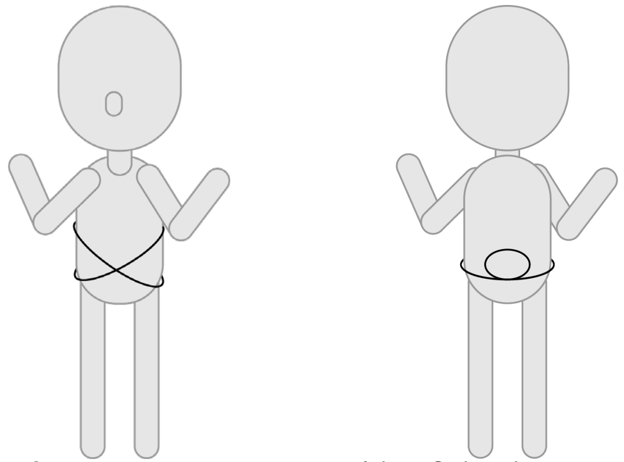
Concepts

Based on the research a few concepts were generated. These can be seen in chapter 9. To compare the concepts, the following questions were asked:

4. What is the influence of a second antenna on the magnetic field?

In theory, if a second antenna was added, it would act as a receiving antenna. This would mean that a voltage would be induced in this antenna, and thus would absorb some of the magnetic field. When referencing formula 6, the angle this antenna is placed plays a large role in how much voltage is induced, and thus how much of the magnetic field it absorbs.

In theory, when the second antenna is parallel to the generating antenna, the voltage induced in the second antenna should be maximum ($\cos 0° = 1$). When the second antenna is at a 90° angle compared to the generating antenna, the voltage induced should be 0 ($\cos 90° = 0$).
This research question aims to validate this theory for the tested



Idea 1: cross antennas Idea 2: back antenna

antenna.

5. Can stretchy or knitted antennas be used as an alternative for a cable antenna?

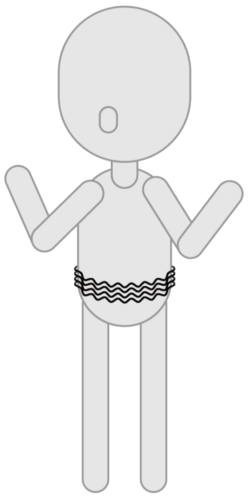
Stretchy and knitted antennas have both benefits and drawbacks. The benefit would be that the radius of the loop would always be as small as possible. This is because the antenna could stretch around the body, thus fitting as closely as possible. This is a benefit the strechy or knitted antenna has over the cable antenna.

The drawback is that the wire would need to be longer in total, since it needs to have ease to be able to stretch. This could lead to a higher wire resistance, which could lead to higher energy losses (chapter 5).

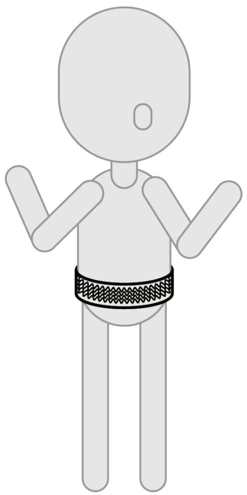
Stretchy or knitted antennas need to be tested to see what parameters have the largest influence on the magnetic field.

6. Can a bended antenna be used as an alternative for a non-bended antenna?

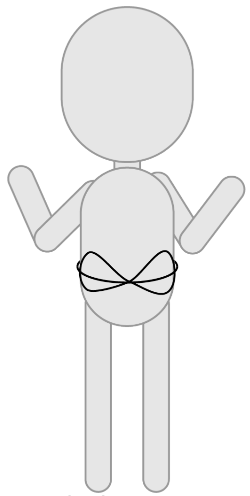
A problem that was observed from the myTemp system was that when the pill was in a horizontal position the magnetic field of the pill could not be picked up by the antenna. A bended antenna could be used as a way to detect the pill from the side, when placed on the side of the body. But the theory does not include shapes like that, thus it needs to be tested how this shape influences the strength of the magnetic field



Idea 4: wavy antenna



Idea 5: knitted



Idea 3: 8 formation

Method of measuring

Setup

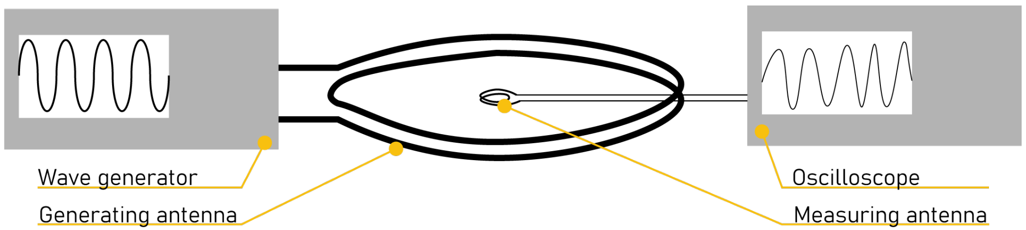
The main setup is based on two antennas: one generates the magnetic field (generating antenna), and one measures this magnetic field (measuring antenna). The generating antenna represents the myTemp antenna, and the measuring antenna represents the temperature pill.

Behind the generating antenna, either the myTemp electronics or the wave generator is placed, based on the research question. They generate the AC current needed for the magnetic field.

The voltage that is being induced in the measuring antenna, is measured using an oscilloscope.

There are three types of measurements: their signal strength in the plane of the antenna, their strength from the centre of the antenna going up, and their strength when the angle is changed.

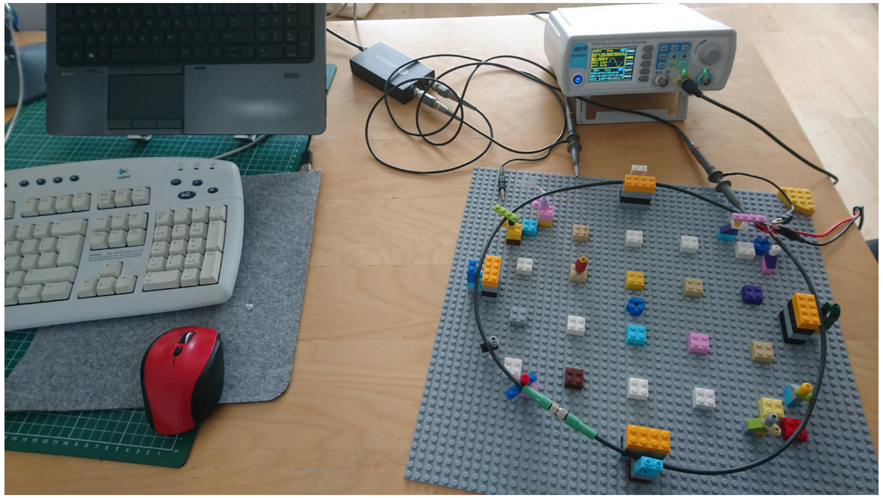
Image 28, Schematic setup



Materials

The wave generator used is the Koolertron 15MHz signal generator, the oscilloscope is the LabNation SmartScope. The measuring antenna is a self wound antenna using 0.2 mm isolated copper thread, has 90 windings and a resistance of 2,2 Ohm.

Image 29, Setup



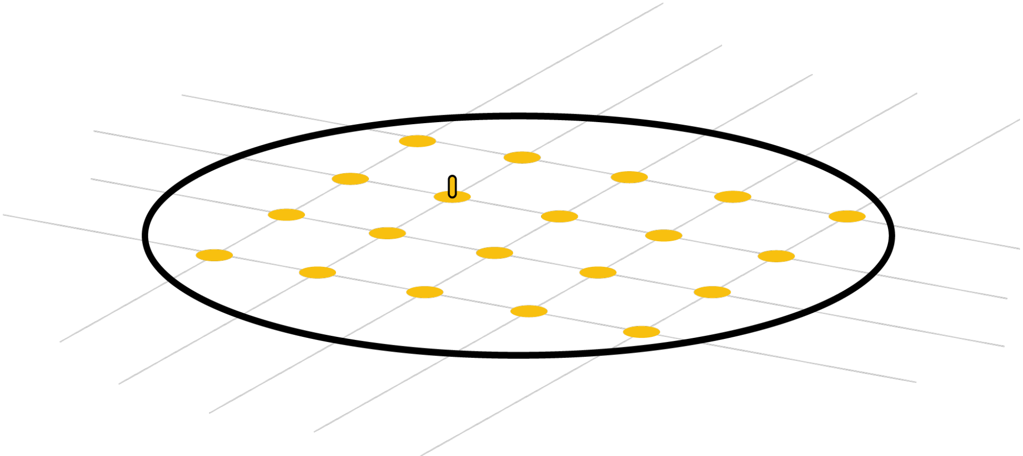


Image 30, Setup strength in plane of antenna

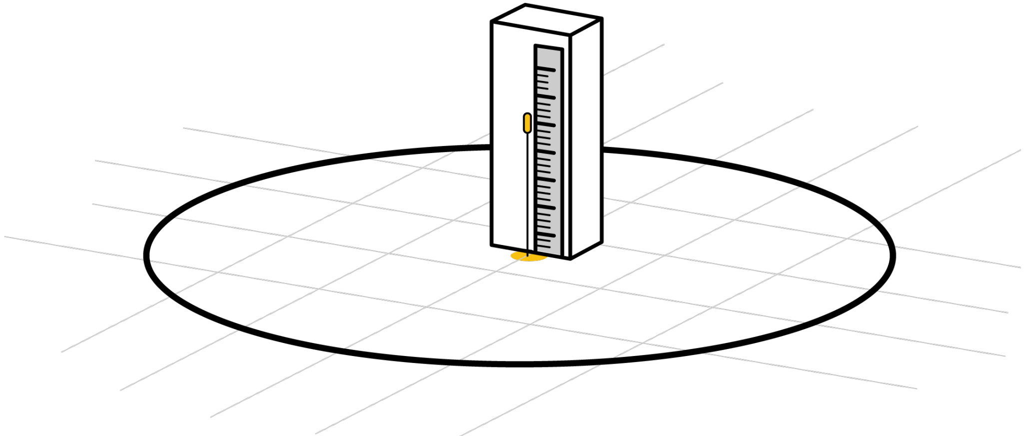


Image 31, Setup strength from centre going up

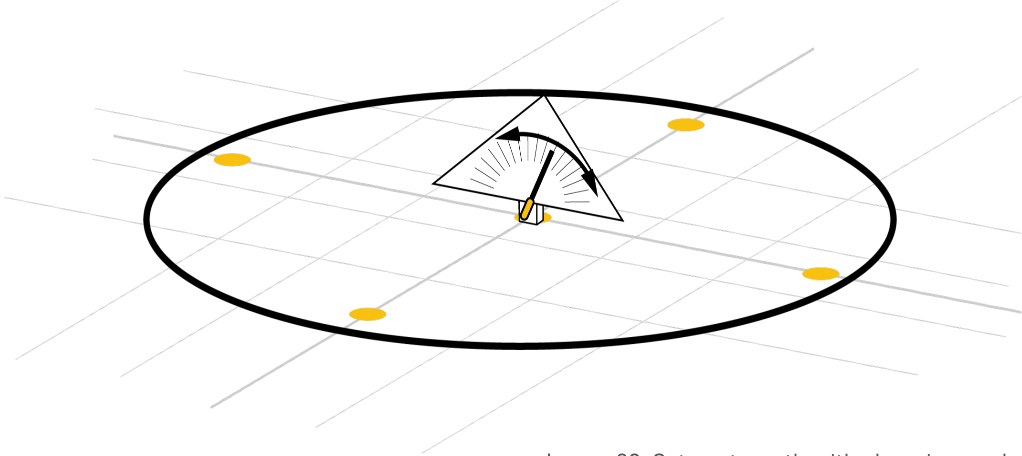


Image 32, Setup strength with changing angle

Signal strength in plane

To quantify the magnetic field, its strength is measured using a grid. This is because it varies based on location. Using a grid this strength distribution can be clearly seen.

To measure the signal strength in the plane of the antenna, a grid of LEGO bricks was made for easy reproducibility of measurement points. Each field contains 20 measuring points, in a 4 x 5 grid. The distance between them depends on the circumference size of the antenna which was either 100 cm or 70 cm.

Strength from the centre

This value shows the way the strength of the magnetic field decreases when moving further away from the antenna.

To measure the strength from the centre going up, a tower with a measuring tape was placed in the centre of the antenna. The measuring antenna was placed on LEGO bricks to give it height, and measurements were taken every 3 cm, up until 30 cm.

Angle strength

The pill will rotate in the gut, which can lead to the antenna of the pill not being able to pick up the magnetic field, thus losing connection with the pill.

To measure the strength based on the angle, a LEGO device was built that was able to turn the measuring antenna around its own centre. This device was placed on five points and the angle, direction and strength of the magnetic field were recorded.

Considerations of setup

To be able to test the new antenna design, a reliable magnetic field had to be created. Here the choice was between the myTemp electronics and a wave generator. A wave generator is a device that can output different electrical waveforms, and is able to vary them in terms of shape, frequency and amplitude.

The benefit of using the original myTemp electronics is that the results are more accurate and applicable to real life situations. However, there were connection problems and tuning problems.

First, when connecting a different antenna to the myTemp electronics, the software would often show tuning problems. Tuning problems occur when the coil is too small or too large (Stoots, 2021), and stops the working of the electronics at all. This greatly decreases the reliability of the system.

Secondly, there was no way to connect the different antennas to the myTemp PCB without a loss in reliability of the measurements or without doing damage to said PCB.

The wave generator does not have these problems, because it does not use a feedback loop (what causes tuning problems) and it uses alligator clips to connect cables to the device. It does however have some drawbacks.

One of the main differences between the wave generator and the myTemp electronics is the output voltage. The myTemp works on 60V, and the wave generator has a maximum output of 20V. Adding an amplifier to get the voltage to 60V distorted the signal too much to be able to measure them. 60V would have given a more accurate representation of the antennas in the myTemp system, however 20V had to be used for reliable results. It had to be tested though if the myTemp and the wave generator created similar results.

Another difference is the use of waveform shape. The myTemp system uses a square shape (which is better for communication), and for the wave generator the sine was used. This had to do with the consistency of the shape. The square wave the wave generator creates does not create a perfect square shape, but has a peak at the front (Image 33). This makes it harder to get an accurate average peak measurement. Thus a sine wave has been used, which was much more predictable (Image 34).

While the wave generator was not optimal, it would still provide reliable and reproducible results when compared to the myTemp system. This is why it was chosen to do each test with.

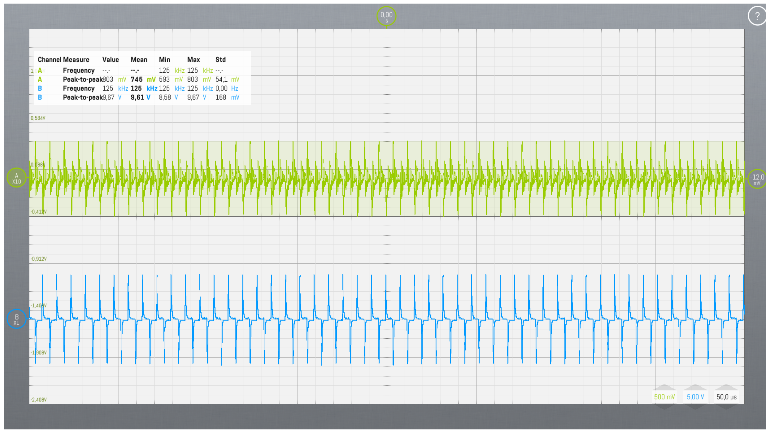


Image 33, Oscilloscope with square wave, green is the measuring antenna, blue is the generating antenna

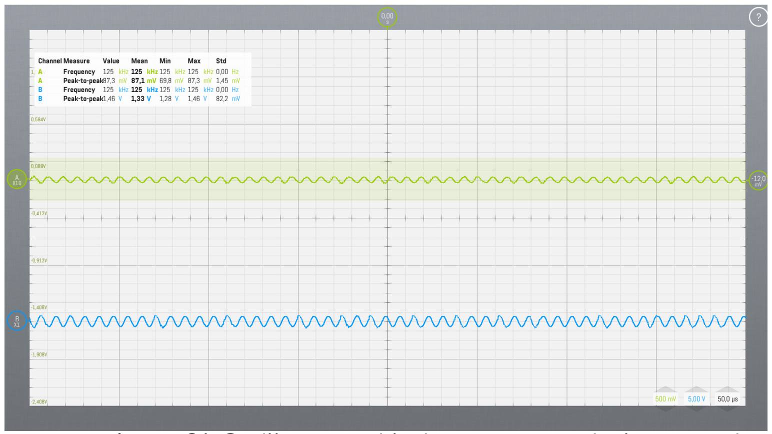


Image 34, Oscilloscope with sine wave, green is the measuring antenna, blue is the generating antenna

Procedure

Below in Table 2 are the different configurations described.

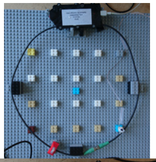
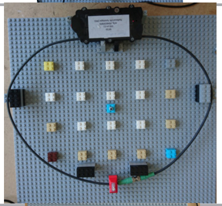
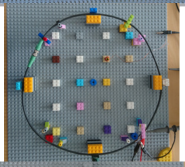
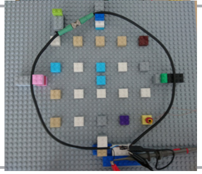
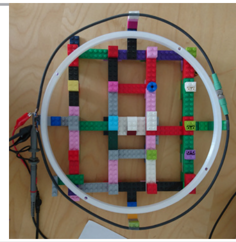
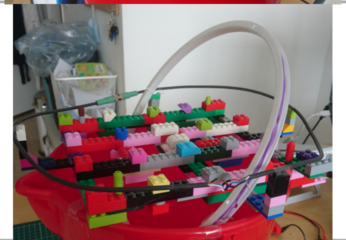
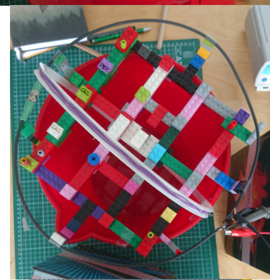
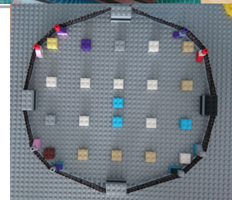
Name	Description	Antenna used	Original electronics or wave generator	Length antenna(s)	Resistance of antenna(s)	Image setup
Circle shape	Original wire antenna (100 cm) used, in a circle shape, using the original electronics	Original antenna (100 cm)	Original electronics	100 cm	2.5 Ω	
Human shape	Original wire antenna (100 cm) used, in a human cross section shape, using the original electronics	Original antenna (100 cm)	Original electronics	100 cm	2.5 Ω	
100 cm	Original wire used (100 cm), in a circle shape, using a wave generator	Original antenna (100 cm)	Wave generator	100 cm	2.5 Ω	
70 cm	Original wire used (70 cm), in a circle shape, using a wave generator	Original antenna (70 cm)	Wave generator	100 cm	1.8 Ω	

Table 2, Tested configurations

0°	Original wire used (100 cm), in a circle shape, with a second antenna at an angle of 0° (parallel) in respect to the original wire	Original antenna (100 cm) and self wound antenna using 1.5 mm copper wire	Wave generator	100 cm (both)	2.5 Ω 0.4 Ω	
30°	Original wire used (100 cm), in a circle shape, with a second antenna at an angle of 30° in respect to the original wire	Original antenna (100 cm) and self wound antenna using 1.5 mm copper wire	Wave generator	100 cm (both)	2.5 Ω 0.4 Ω	
60°	Original wire used (100 cm), in a circle shape, with a second antenna at an angle of 60° in respect to the original wire	Original antenna (100 cm) and self wound antenna using 1.5mm copper wire	Wave generator	100 cm (both)	2.5 Ω 0.4 Ω	
90°	Original wire used (100 cm), in a circle shape, with a second antenna at an angle of 90° (perpendicular) in respect to the original wire	Original antenna (100 cm) and self wound antenna using 1.5 mm copper wire	Wave generator	100 cm (both)	2.5 Ω 0.4 Ω	
Strechy	Stretchy antenna from X, in circle shape	Amotape® Conduct Nylon + Elastomer / 20 mm	Wave generator	Unstreched 100 cm	2.2 Ω	
Knitted	Knitted antenna, in circle shape	Electrisola wire, 4 wires in parallel	Wave generator	Unstreched 60 cm, stretched 100 cm	150 Ω	

Data processing

To compare the different antennas, the raw data have to be processed. This part will show how this proceeds using the circle vs human figure using original myTemp electronics as an example.

Here presented in the image below is one of the graphs of the signal strength in the plane, in this case the human figure. The graph has been overlaid on an image of the setup (Image 35).

The graph has been colour-coded, with green being the higher values, and red being the lower values. Thus, they will be referenced as heatmaps from this point on.

As can be seen, values in the centre of the antenna tend to be lower than the ones near the antenna.

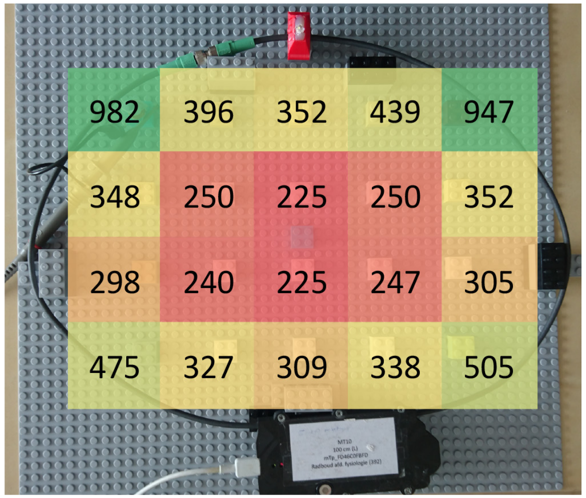


Image 35, Heatmap projected on setup

Image 36 show two heatmaps, the one on the left is the circle shape and on the right is the human figure. These examples will be used to show how the data is processed.

Circle

1038	341	276	363	613
348	214	189	211	355
320	203	185	207	338
501	254	233	283	758

Human figure

982	396	352	439.33	947
348	250	225	250.33	352
298	240	225	247	305
475	327	309	337.67	505

Image 36, Circle and human figure heatmap

The values on the heatmap are the peak-to-peak voltage, measured by the measuring antenna, and are in mV (Image 37).

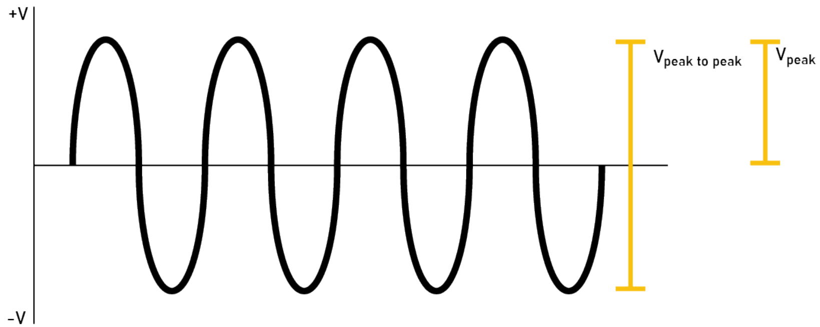


Image 37, Peak-to-peak voltage

To compare them, the absolute (Image 38) and relative (Image 39) differences between them are calculated.

Absolute difference

-56	55	76	77	333
0	36	37	40	-3
-22	36	40	40	-33
-26	73	76	55	-254

Image 38, Absolute difference

The absolute difference (mV, C_1) is calculated by subtracting the values from one heatmap (in this example human figure, x_2) to the value in the same location as the other heatmap (circle, x_1).

$$C_1 = x_1 - x_2$$

Relative difference

-5	16	28	21	54
0	17	19	19	-1
-7	18	22	19	-10
-5	29	33	19	-33

Image 39, Relative difference

The relative difference (%, C_2) is then calculated by dividing through the values of the human figure heatmap.

$$C_2 = (x_1 - x_2) / x_2 = C_1 / x_2$$

An example is that in the upper left corner of the relative difference table the value is -5. This means that that value in the human figure setup is 5% less than the value on the same location in the circle setup.

To find the difference between the human form and the circle, the average difference can be calculated. This can be done for the whole area (Image 40), or just for the middle one (Image 41). The benefit of using the whole area is that it gives a more overall picture. However, the corners tend to be of a much higher value, thus excluding them would give a more reliable picture.

Since the pill in the gut will be more in the centre of the antenna, in the results only the middle values will be used.

Relative difference

-5	16	28	21	54
0	17	19	19	-1
-7	18	22	19	-10
-5	29	33	19	-33

13 %

Image 40, Complete average

Relative difference

-5	16	28	21	54
0	17	19	19	-1
-7	18	22	19	-10
-5	29	33	19	-33

19 %

Image 41, Sectional average

Results

Shape difference

1. How does the magnetic field change when comparing a circle shape to the shape when worn on the body?

The human shape performs 19% better than the circle shape. This probably has to do with the fact that the measuring points in the human shape are closer to the antenna than in the circle shape. This creates a more concentrated magnetic field, and thus increases performance.

Size antenna

2. Do the measured values change in the same rate compared to the theory when comparing different sizes antennas?

The 70cm antenna performs 26% better than the 100cm. This is still a large difference in performance, but not the 43% difference that the theory expected. This could be caused by inaccuracies in the measurements taken, or that other parameters like the resistance and the current played a role. However, it is possible that when the antenna size is increased, the strength of the magnetic field reduces.

Wave generator

3. How does the measured magnetic field compare to the theory when using a wave generator instead of the myTemp electronics?

First was tested to see if the strength distribution of the magnetic field generated by the wave generator matches the one generated using the myTemp electronics.

Below (Image 42) the heatmaps of the antenna using the myTemp electronics is on the left, and antenna using the wave generator on the right.

Circle, myTemp electronics

1038	341	276	363	613
348	214	189	211	355
320	203	185	207	338
501	254	233	283	758

100 cm, wave generator

141	62	36	40	116
53	31	34	38	46
52	40	37	36	54
163	65	59	52	101

Image 42, Heatmaps of same antenna with different generators

To see if the scale is also similar, all the values have been divided through the lowest value measured in that heatmap (Image 43).

Circle, myTemp electronics

5,61	1,84	1,49	1,96	3,32
1,88	1,16	1,02	1,14	1,92
1,73	1,1	1	1,12	1,83
2,71	1,37	1,26	1,53	4,1

100 cm, wave generator

4,52	1,98	1,17	1,28	3,74
1,7	1	1,09	1,2	1,46
1,67	1,3	1,2	1,15	1,74
5,22	2,09	1,91	1,69	3,24

Image 43, Scaled values of same antennas with different generator

As can be seen, the values in the middle in both heatmaps (marked with the black border, Image 43) are between 1.16 (times the min value) and 1 (the min value). In both heatmaps are the four corners between 2.71 and 5.61 times the min value. It could be said that the wave generator in terms of strength distribution is similar to the myTemp electronics.

When measuring the strength of the magnetic field with a changing angle, the following graph (Image 44) shows the typical results.

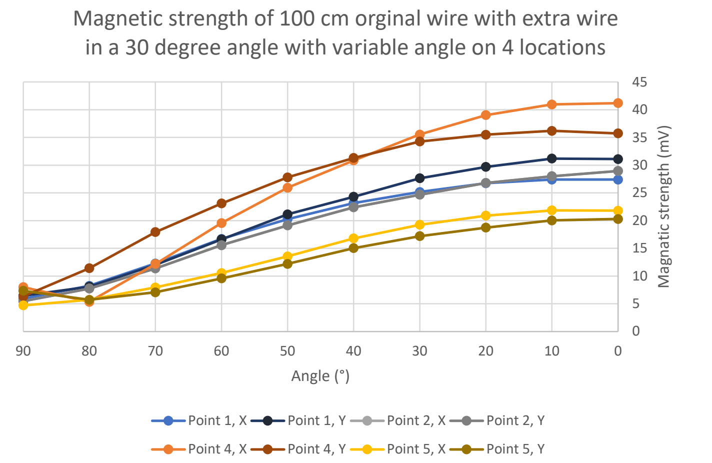


Image 44, Graph of magnetic strength of angles of one setup

As can be seen, the strength decreases with a certain curve for all measuring points. It seems that the main factor is the starting value.

To test this theory, in the following graph (Image 45) all data of all angles have been put in a graph. Each of the data series have been divided through the initial strength, so a 1 is the initial strength, 0.5 is half of the initial strength, ect.. This creates the following graph. The gray lines are all the individual measurements, the yellow line the average.

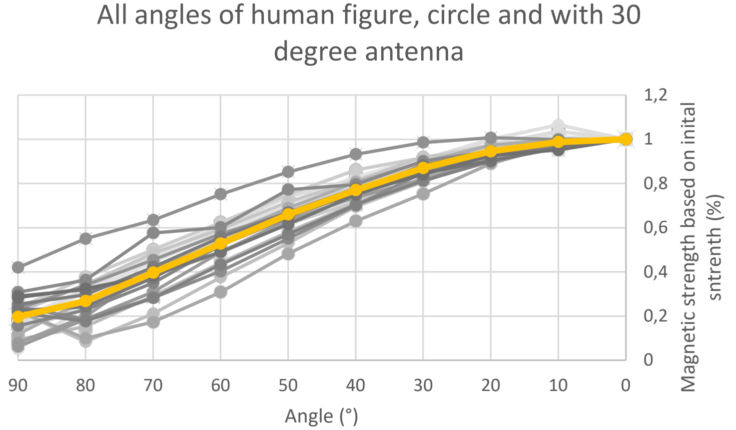


Image 45, Graph of all magnetic strength of angles

According to formula 6, the strength in theory should decrease following a cos(a). When the theoretical line is plotted on the measured value, it creates the following graph (Image 46).

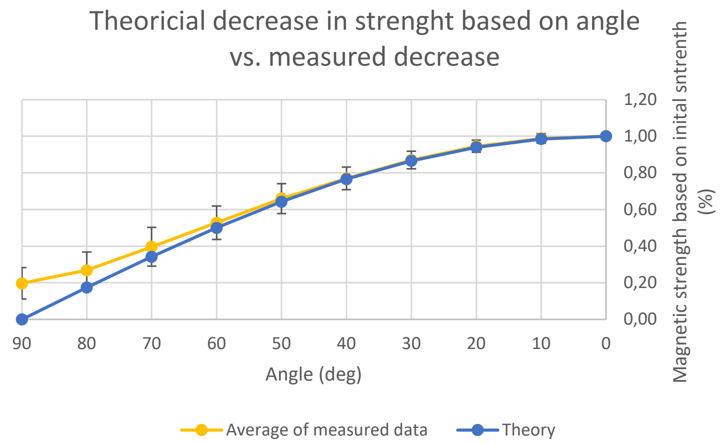


Image 46, Graph of magnetic strength of angles of one setup

The theoretical and the measured data line up until around 60deg. The difference after can be explained by the noise during the measurements. This noise made it impossible to read measurements lower than 5mV, and thus 0 could never be reached. However, this does show that the setup is accurate in terms of measurements of angles.

To see if the strechy antenna behaves differently, their values have been plotted in the graph below (Image 47). As can be seen, the strechy antenna does not behave significantly different than the wire antenna.

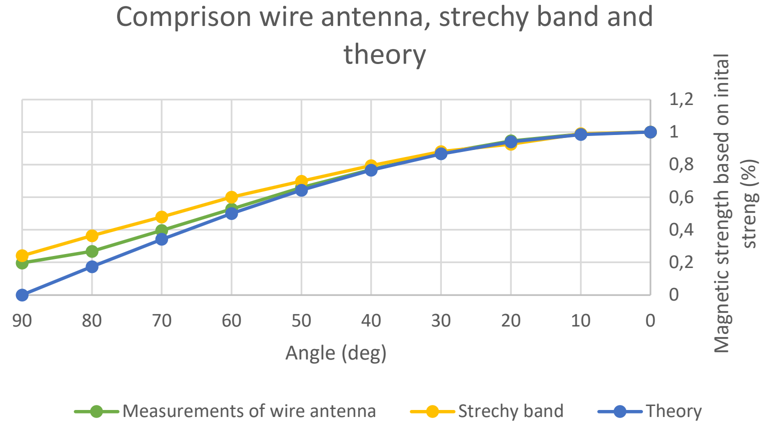


Image 47, Graph of magnatic strength changing with angles

4. What is the influence of a second antenna on the magnetic field?

As expected, the strength of the magnetic field did decrease when a second antenna was added. When the second antenna was parallel to the generating antenna, the strength of the magnetic field decreased with an average of 55%. When the second antenna was perpendicular to the generating antenna, the decrease was 10% (Image 48).

So even though the second antenna was parallel to the antenna, there was some loss in the strength of the magnetic field, even though the theory expected no loss. This could have to do with the way that the antennas were placed (it could very well be not perfect perpendicular), or with the fact that the second antenna was so big that some of the magnetic field would inevitably end up generating some voltage in that antenna.

5. Can stretchy or knitted antennas be used as an alternative for a cable antenna?

The knitted antenna is not a good substitute for a cable antenna. Its magnetic field performed 66% less when compared to the 100 cm original wire, and had no strength at 12 cm from the plane, while the other antenna belts this value was 27 cm (Image 48). This probably has to do with the high resistance, probably due to the thin wire used. This wire has to be thin to be used in the knitting machine, and the current wire used had the lowest resistance of the available wires. Adjustments could be made, like using more parallel wires to decrease resistance, but would significantly increase the size of the antenna.

The stretchy antenna only had a decrease of 7% when compared to the 100cm cable antenna (Image 48). It also performed almost the same in regard to strength measured from the centre of the antenna as the 100cm cable antenna (Image 49). Thus, in terms of performance, the stretchy antenna could be a substitute for the original cable antenna.

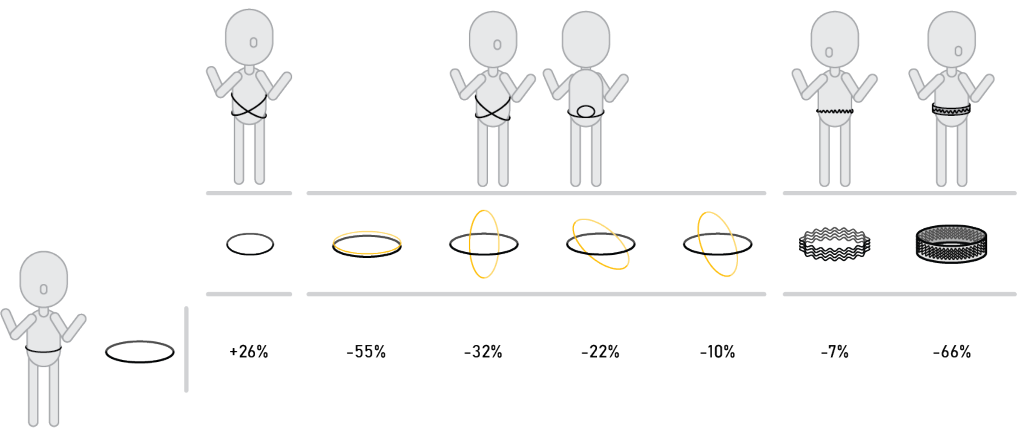


Image 48, Overview measured antennas

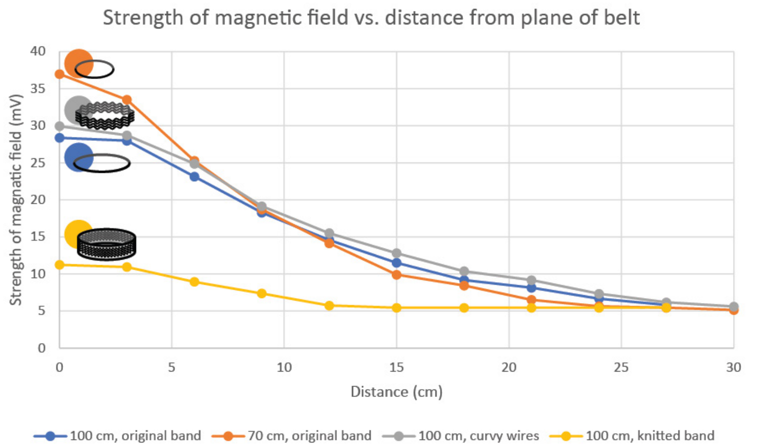


Image 49, Strength of magnetic field vs distance from the plane belt

6. Can a bended figure 8 antenna be used as an alternative for a non-bended antenna?

The bended figure 8 antenna is not a good substitute antenna. The figure 8 antenna had a lot of trouble generating a magnetic field a few centimeters from the antenna, as can be seen in the heatmaps below.

Image 50, Heatmap on setup, measurement taken horizontal from photo perspective

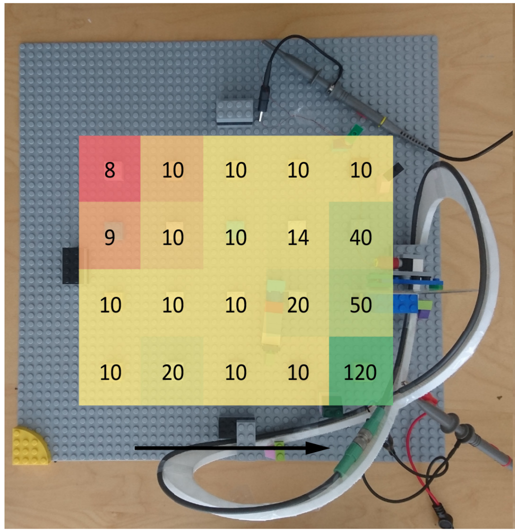
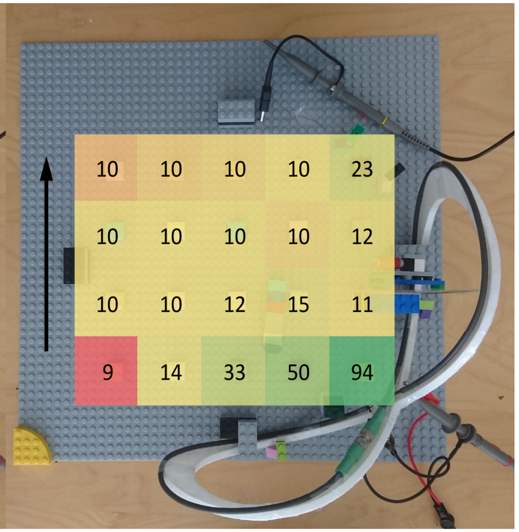


Image 51, Heatmap on setup, measurement taken vertical from photo perspective



Discussion

The shape of the antenna has an impact on the magnetic field. The human figure shape (a more oval shape) performed 19% better than the circle shape. This probably has to do with the smaller distance between the centre of the antenna and the wire. So when wearing the antenna, the performance of tested antennas would increase. This assumption did, however, assume a slim human figure. With a person that is overweight and has a belly, this benefit will be gone, as can be seen in the image below (Image 52 is a P10 woman, Image 53 is a P95 woman)

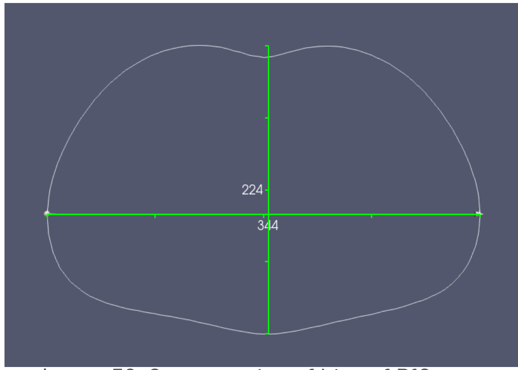


Image 52, Cross section of hips of P10 woman

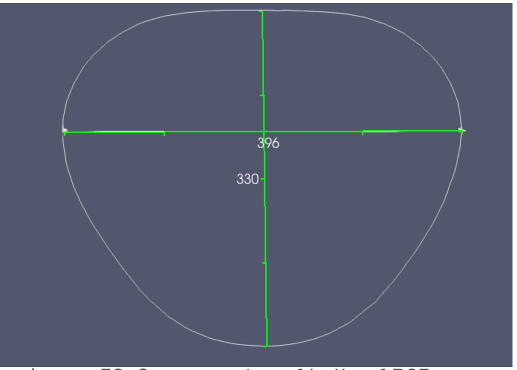


Image 53, Cross section of belly of P95 woman

Between the 100 cm and the 70 cm circumferences, an increased performance can be seen. The 70 cm circumference performed 26% better than the 100 cm. Again, this probably has to do with having a smaller diameter, which helps to concentrate the magmatic field better. So the antenna needs to be as small as possible to keep a high performance.

Adding an extra antenna does impact the strength of the magnetic field. The more parallel to the antenna, the higher the losses. This has to do with the fact that the extra antenna picks up the magnetic field, just like the coil in the myTemp pill or the measuring coil, as discussed in “8. Technology”. It is interesting to note that the extra antenna in a 90° formation in theory should not pick up any magnetic field, but that in practice there is a 10% performance loss. So, an antenna could be added, but to make the loss in magnetic field as low as possible, the second antenna should be placed as perpendicular as possible.

The knitted antenna is not a good substitute. Its magnetic field performed 66% less when compared to the 100 cm original wire, and had no strength at 12 cm from the plane, while the other antenna belts this value was 27 cm. This probably has to do with the high resistance, probably due to the thin wire used. This wire has to be thin to be used in the knitting machine, and the current wire used had the lowest resistance of the available wires. Adjustments could be made, like using more parallel wires to decrease resistance, but would significantly increase the size of the antenna.

The stretchy antenna seems like a good alternative, with only a 7% decrease in performance, compared to the original wire. It also had the same performance as the original 100 cm wire when it came to distance from its plane. As it has multiple extra benefits like fitting people with different body sizes and forming around the body, this antenna is recommended as an alternative for the cable antenna and shall be used in the belt sizing in the next chapter.

12. Belt sizing

Creating a sizing system is about fitting the product comfortably to people, using anthoperformic data. Since everyone has a different body composition, products fit differently. What one person might feel is comfortable, is uncomfortable for someone else. Offering different sizes allows people to pick and choose what they feel is comfortable.

As can be seen in “7. Sports wearable analysis”, it is important that wearables worn around the torso lay flat, and preferably fit tightly to the body. This prevents the product from moving around, which could be perceived as distracting during sport activities.

Elastic range band

Since the wavy antenna band is partly made of elastic, first of all the comfortable range needs to be determined. This is important, because when the band is too loose, it might not sit flat or might move, and when it is too tight it could be perceived as uncomfortable (“7. Sports wearable analysis”).

To determine this, the band was put on the body and pulled taut until it just laid comfortably on the skin. Then the band was pulled tight until it was just comfortable. The original length, the just comfortable and the tight lengths were measured, and then the minimum and maximum elongation rates could be calculated. This was done on two participants, and the results were averaged.

The minimum elongation rate was 1.05 and the maximum elongation rate was 1.49. The elastic itself has an elongation rate of 1.7.

Relevant body measurements
For this product, there are two relevant body measurements; hip and waist circumference. The product should preferably fit both the hip and waist, as this allows for better readjusting in case connection with the fill fails, and it would allow the user to be able to pull the band over their hips when putting the device on. However, if it is only possible to optimise for one of the two, the waist measurements would then be better. This is because the waist is closer to the intestines than the hips (Image 54).

Dataset
The used data set is the CEASAR (NL); all participants from the dataset were used (male and female, 18 - 66). This data set is available on https://dined.io.tudelft.nl/.

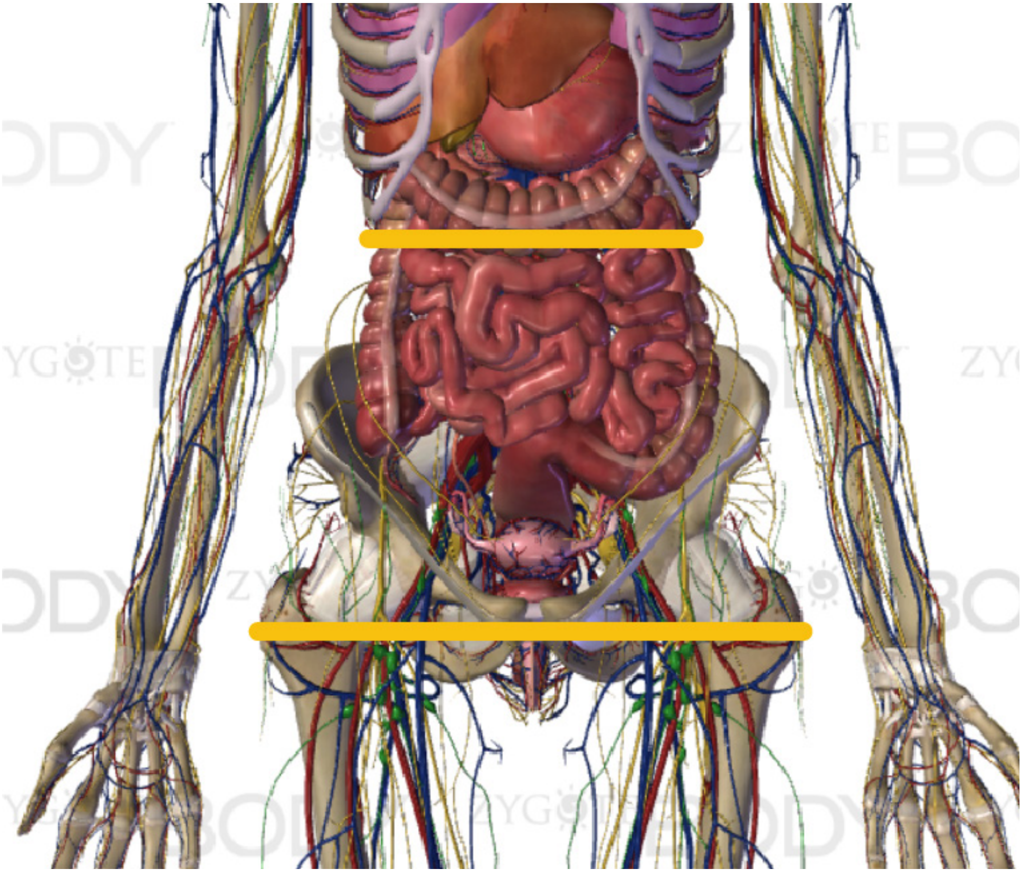


Image 54, Female skeleton with organs, yellow lines represent waist and hip measurment.
Retreived from zygotebody.com

Data

The waist and the hip measurements were plotted against each other, as can be seen in Image 55. Each dot is one person. As can be seen, there is a positive correlation between the waist and hip circumference; as the hip circumference increases, the waist circumference increases as well.

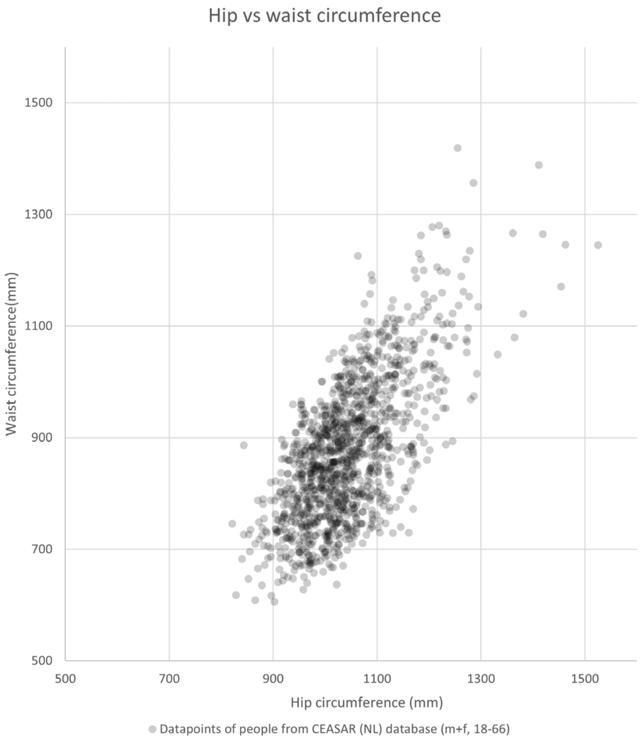


Image 55, Hip vs waist measurments

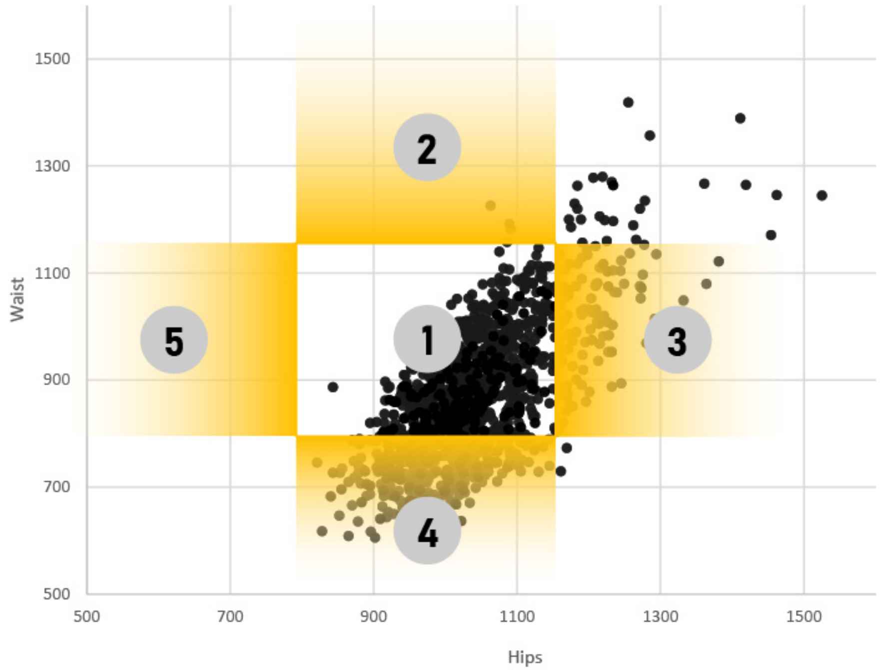


Image 56, Areas in hip vs waist measurements

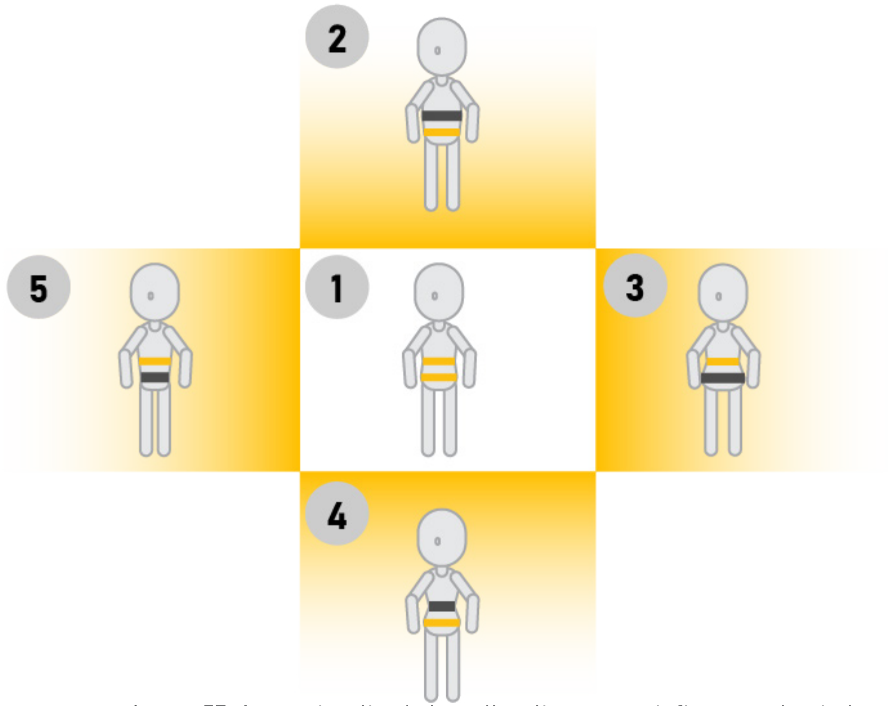


Image 57, Areas visualised, the yellow line means it fits, gray that it does not fit

Using the elongation rate of the band, the limits of each band size could be calculated. This is visualized as area 1 in Image 56, and later in the chapter as colored squares.

For the people inside area 1, the band would fit both at their hips and waist. However, it is possible that, for example, the band fits at the waist, but not at the hips. The band would then still be able to fit the person, and should be taken into consideration.

Thus, the people have been divided into five areas, as can be seen in Image 56. Image 56 shows where these areas are when looking at the graph, and Image 57 shows what these areas mean. In this image, the yellow line means that the band fits, the gray line means that it does not fit.

The people in the middle area (1) are able to fit in the band with both their hips and waist. This is the ideal situation. People in area 2, fit in the band with their hips, but their waist is too large to fit. In area 3, the band fits the waist but their hips are too large and do not fit. In 4, it fits with their hips but their waist is too small for the band. And in 5, it fits their waist but their hips are too small for a fit.

As mentioned previously in the section, 'Relevant body measurements', ideally the product would fit both the hips and waist, but the second best scenario is the one in which the band fits the waist. This means that area 1 is the most ideal and area 3 and 5 are the second best.

This means that the belt needs to be optimised for area 1, 3 and 5. To do this, a graph was created where the length of the belt is plotted against the amount of people that would be covered in each region. This graph can be seen on the right (Image 58).

Since area 5 covers not many people, the choice is not to optimise for this area. The optimised values for the length of the belt can be found in the Table 3. The P stands for percentile, and is the score where the value falls in the distribution of a population. For example, if someone has a hip circumference of P25, it means that 25% of the population have a hip circumference smaller than that person.

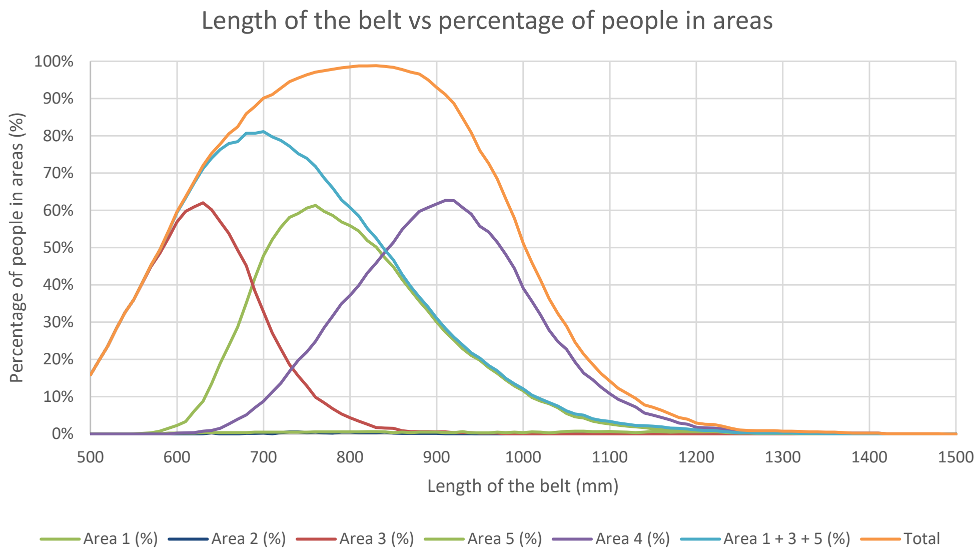


Image 58, Optimalisation graph

Table 3, Overview bands

	Band 1		Band 2		Band 3		Band 4	
Optimised for	Area 3		Area 1		All areas		Areas 1, 3 and 5	
Length belt (mm)	630		750		800		680	
Min comfortable strech length (mm)	649	P3.18 waist, <P0.01 hips	773	P19.63 waist, P0.07 hips	824	P32.87 waist, P0.51 hips	700	
Max comfortable strech length (mm)	942	P69.43 waist, P12 hips	1121	P97.45 waist, P83.25 hips	1196	P99.47 waist, P96.84	1016	
Max stretch length (mm)	1071	P64.4, hips	1275	P99.74, hips	1360		1156	

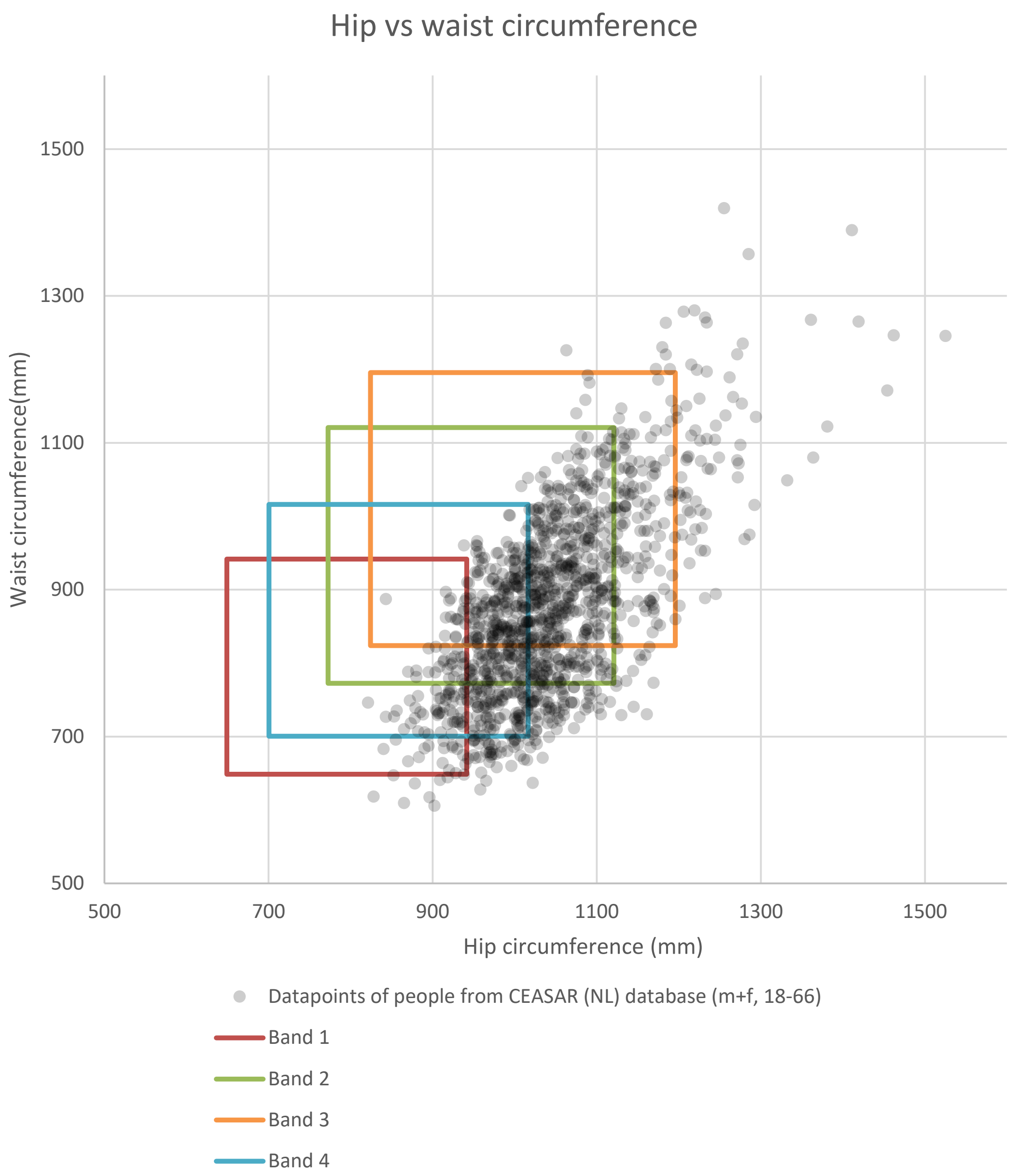


Image 59, Hip vs waist measurements, with bands visualised

The areas these belts cover can be visualised in Image 59. Only area 1 (fits both waist and hips) of each band is visualised to keep the graph more simple.

What areas each band covers in how many people in total can be seen inImage 60.

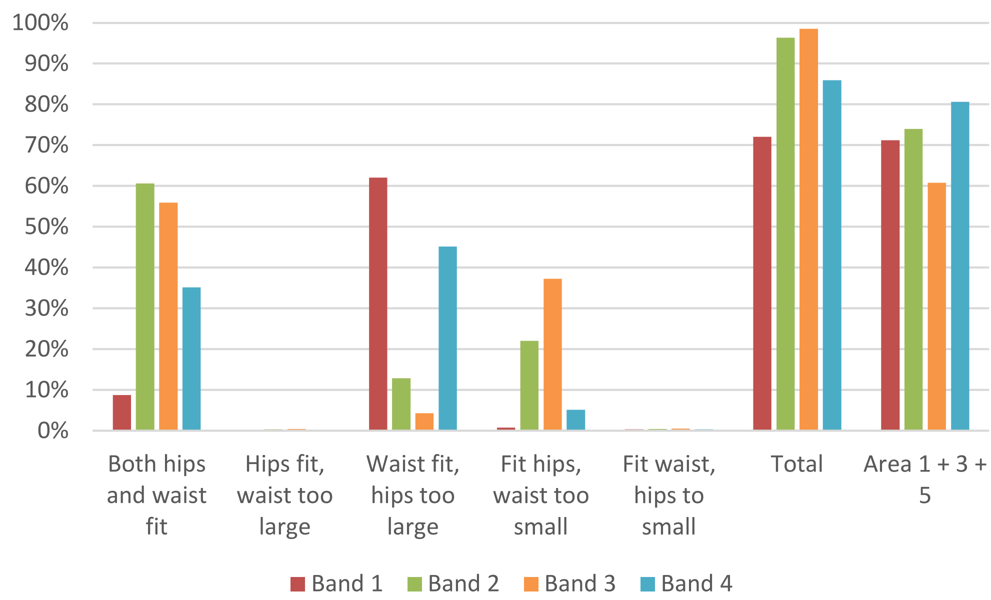
Band 1 is the smallest of all bands, and is optimised for area 3. The band is able to fit on 71% of people (area 1, 3 and 5).

Band 2 is optimised for area 1 (fits both waist and hips), and is able to fit 74% of the people (area 1, 3 and 5).

Band 3 is optimised for all areas (area 1 to 5), which can clearly be seen in the total (99%). However, in the areas that are more important (area 1, 3 and 5), this advantage is clearly lost (61% coverage).

Band 4 is optimised for area 1, 3 and 5, and is able to cover 81% of the people in this area.

Image 60, Coverage of bands in different areas



Conclusion

The target group of the myTemp system mainly consists of sport researchers or professional athlete coaches, and thus the system will probably be used by people such as endurance focused athletes, who are fitter than the average participants of the research project. Most endurance athletes benefit from having a low body fat percentage (NSCA, 2017), which often relates to having a lower hip and waist circumference. Thus focussing on the people with lower hip and waist circumferences seems to fit the target group.

Information that is currently missing is about what the maximum size of the band can be without compromising performance. The larger the band size, the lower the performance (“11. Antenna research”).

This means that currently it would be recommended to have a band on the lower side of the waist/hips circumference.

Since band 2 (P20 - P97 waist, P0.1 - P83 hips) and band 3 (P33 - P99 waist, P0.5 - P97 hips) sit on the higher end of the waist/hip circumference, the antenna band would first need to be tested for its performance for these sizes. This test should determine the maximum size the band should be, and the band should then reflect this maximum size.
Band 1 (P3 - P69 waist, <P0.01 - P12 hips) and 4 (P7 - P87 waist, <P0.01 - P38.75 hips) are both on the lower side of the waist/hip circumference. When comparing, band 4 performs better than band 1 when it comes to how many people the band is able to provide for. In area 1 (fits both hips and waist) band 4 has 35% and band 1 has 9%. In areas 1, 3 and 5, band 4 has 81% and band 1 71%, and when comparing all the areas, band 4 has 86% and band 1 72%.

This means that band 4 not only fits more people than band 1, it fits more people better. And since the band is on the lower side of the waist/hip circumference, it would make a good size to fit the target group of professional athletes.

Ideation 2

User experience

13. User interaction

The current prototype lacks a user-friendly interaction, as was noted in the interviews conducted with the researchers and in the observations. The current communication (mainly consisting of bleeps) is slow, it takes practice to correctly understand signals and can be overstimulating for both the researchers as well as the participants.

To improve this interaction, an interaction timeline was created. In this timeline, all the phases of the device are described, as well as what information needs to be communicated to the user. This creates an overview as to in what order and what type of information needs to be communicated.

A brainstorming session was held to seexx what actuators can communicate this information. These actuators were then rated based on how well they fitted the context of the product, durability, cost, and how many ways they are able to communicate to the user. Based on these results, the LED, vibration motor, and buzzer were chosen to be used in the user test later.

To be able to test the interaction, an interaction prototype was built that included different interactions based on the interaction table and the experiences of the researchers in the interviews.

The goal of the user test was mainly to find what interaction people preferred while exercising and how effective the signals are in communicating information. Mainly the difference between the vibration motor (feeling) and the buzzer (sound) were tested.

14. Interaction timeline

To get an overview of what information at what time needs to be communicated to the user, an interaction timeline was created. The steps describe the moments that the user interacts with the product. On the bottom the information the user needs is described.

The timeline (Image 61 on the next page) is based on the manual of the myTemp system (myTemp, n.d.), user interviews and the observations.

Timeline

The interaction timeline is divided into three parts; before use, during use and after use. Before use, the interaction is mainly about charging the battery. During use, the interaction starts with putting the antenna band on and turning the device on. Once it is turned on, the bluetooth connection with the computer, smartphone or smartwatch can be established.

To start measuring, the antenna belt needs to be properly closed. To close it properly, the electrical connections need to make good contact, something that cannot be seen clearly from the user's perspective.

Once the belt is properly closed, the device can search for the pill. If the pill can not be detected, the belt needs to be moved around the body, to try to get the pill in a stronger part of the magnetic field. If the pill is found, the research can properly begin.

As seen in the user interviews and the observations, the belt can loosen during exercise or connection with the pill can be lost. This creates a potential loop, in which the user or the researcher needs to troubleshoot the device during the research.

The research is done either when the research is completed successfully, or when the user exceeds the safe core temperature limit.

After use, the data are collected on a computer so that they can be used for analysing. It only needs to be connected to the computer when the device has not made a bluetooth connection to the computer before. When it had been connected to the computer, the data is already saved using the myTemp software.

The device then needs to be cleaned for the next user.

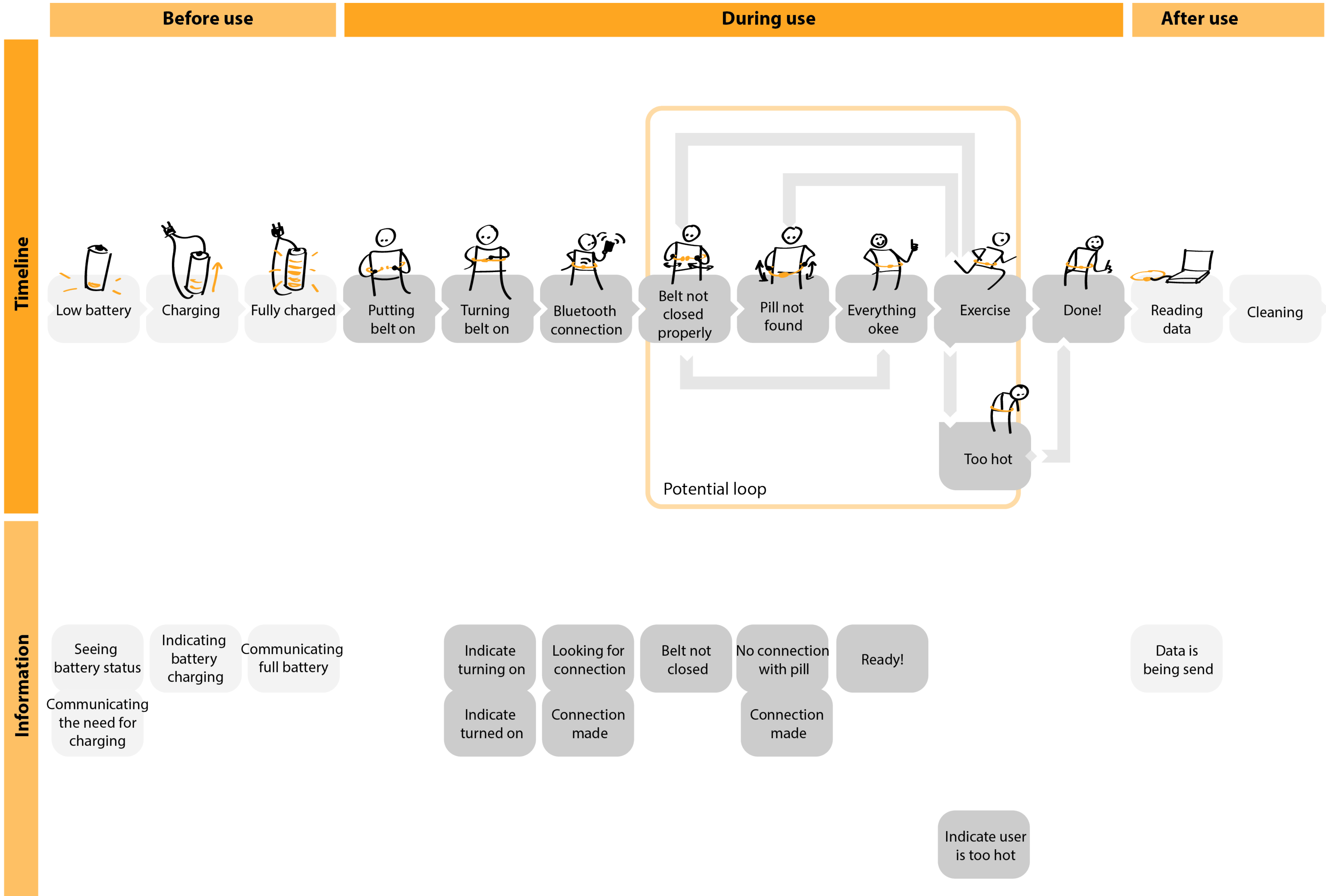


Image 61, Interaction timeline

Information

The device before use mainly has to communicate that it needs to be charged, is charging and is fully charged. Currently, it uses a specific LED for charging; it is red when it is charging, and green when it is fully charged.

During use, the device needs to communicate that it is turned on, what the status of the device is, if the antenna belt is closed properly or if the pill is detected/reading properly, if the user's core temperature is too high, the device needs to communicate that as well.

Currently, it communicates every time the pill has a successful reading by bleeping and having a green LED turned on, with the first reading having extra beeps. When the reading has failed, the device will also bleep and the LED will turn red. When the belt is properly closed, the belt will give off a long bleep.

Additional steps

The steps that were added are the 'too hot' step, and the status of the belt when it is not connected properly.

Currently the core temperature measurement is monitored manually to make sure that the temperature stays under 39.5°C. However, in field research this can be more difficult, so having the option of signalling directly to the user when their core temperature exceeds the safe limit could increase their safety during research. It also could act as an extra safety net in case the wireless communicating to the researcher is broken.

At the moment, only when the belt is closed properly, a signal is given. But as could be seen in the observations, this can lead to confusion because the user does not know whether the problem lies in the pill not being found or the belt not properly closed. So in the timeline, the status of the belt is split into closed and not closed properly.

Conclusion

The timeline shows a quite linear process. The main complexity lies in the potential loop, as there the user potentially needs to troubleshoot multiple technical problems, and the device needs to communicate multiple statuses. This can and has led (as can be seen in the user interviews and the observation) to confusion, as the users have trouble distinguishing signals, not knowing what they mean and how to solve them.

An overhaul of the signals, trying to optimise their effectiveness to communicate information to the user, needs to be carried out to make the system more user-friendly. In the next part, an iteration of the signals has been done. First a brainstorming session of different types of signals has been done and rated, and with the top three signals, new signals were designed and tested.

15. Actuator table

Table 4 shows the top six actuators that could be used in the concept. These are LEDs, vibration motors, buzzer (sound), e-ink screen, oled screen and a servo motor.

These actuations have been rated on sensibility (how well can you perceive the signal in the context), on durability (how well protected are they), in what ways one can differentiate between signals, how well they perform in broad daylight, and how they compare in costs?

The ratings are between 1 and 5, with 1 being the worst and 5 being the best.

Conclusion

Based on the results, the LED, vibration motor and the buzzer will be used in the user test, based on price, sensibility and durability. The question now is, how do these actuators perform in a user test in context, are people able to understand what the signals mean, are they able to differentiate between the different signals of one actuator and what do people prefer in a research setting?

Table 4, Actuator table

Actuator	Sensible		Durability		Ways to differentiate signals	Total signal possibilites (estimation)		Daylight comunication potential (estimated)	Price (estimatio	Total score
Led	Only in direct line of sight	3	Encased with little windows	3	Color = 4, rythm = 3, multiple leds= 4	48	4	2	5	360
Vibration motor	All the time	5	Encased	5	Rythm = 3, intensity = 3	9	3	5	4	1500
Buzzer	All the time[1]	5	Encased	5	Rythm = 3, intensity = 3 2*, tone = 3 3*	27	4	5	4	2000
E ink screen	Only in direct line of sight	3	Encased with larger window	4	Graphical = ∞, color = 2	∞	5	4	1	240
Oled screen	Only in direct line of sight	3	Encased with larger window	4	Graphical = ∞, color = 2	∞	5	1	2	120
Servo motor	In indirect line of sight	5	Movable parts that can break	1	actuate hight = 3	3	1	5	2	50

[1] Might be less when listening to music

2* Might be influenced by surounding noice

3* There might be difuculties with comunicating which tone is what

16. User test

By carrying out a user test, ideas can quickly be tested using a prototype without having the need of a fully functioning device. This allows one to quickly see what works and what does not in the desired context.

In this case, an iteration of the user-product interaction is tested, to find which actuator works in context, and to find out if people are able to understand signals and know what to do with them. Three types of actuators were tested (LED, buzzer and vibration motor), each with different signals to communicate different information.

The signals are rated based on three factors: how clear the signal is for the user to understand, how easy is it to differentiate between the different signals of the same actuator, and how pleasant the signal is for the user.

Method

The user test attempted to imitate a field research site; the participant and researcher would be outside, and the participant would be asked to exercise (in this case running) with the antenna belt, and asked to identify and react to the signals of the said belt.

The antenna belt in this user test was an interaction prototype, meaning that it was not functional. The users did not need to swallow a temperature pill, and all the interactions were controlled externally by the researcher. The prototype will be later described in more detail.

Six types of signals are tested. These are 'turning the belt on', 'belt not closed properly', 'belt closed properly', 'pill not found', 'everything okee' and 'too hot'. An overview of all signals will be given in Table 5 on page 78.

The participant would first get an explanation of the research, how it works and what the objective is. They would get an explanation of the problems and signals they might face, as well as a flyer that described the problems, signals and their solutions. This flyer can be found in the appendix (Appendix F).

The participants would then be asked to put on the belt, turn it on and try to troubleshoot the problems. When everything would be fine they would be asked to go for a run. During their run, they would need to react when a signal would occur. The process is done two times: the first time is done with the buzzer and LED signal, the second time with the vibration and the LED signal.

After their run, a questionnaire would be filled in about their experiences with the signals. This questionnaire is accompanied by an interview, which allows for more in depth information about their experiences.

In two of the cases the research had to be conducted inside, due to the weather conditions. These two cases did however follow the same structure as the rest of the research.

Collected data

There are two types of data collected; interviews and quantitative data in the form of 7 point Likert scales.

From the interviews, statements are collected about the users' experience with the system. These statements are analysed by means of clustering.

The questionnaire contained a 7 point likert scale that asks the participant to rate statements from 'strongly disagree' to 'strongly agree'.

The statements that they are asked to rate are the following nine;

- The LED signal was easy to understand
- The vibration signal was easy to understand
- The buzzer signal was easy to understand
- The LED signal was easy distinguishable from other vibration signals
- The vibration signal was easy distinguishable from other vibration signals
- The buzzer signal was easy distinguishable from other vibration signals
- The LED signal didn't bother me at all
- The vibration signal didn't bother me at all
- The buzzer signal didn't bother me at all

This created a matrix that the participant was asked to fill out 7 times; one for their general experience, and one for each type of signal.

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Participipnts

Six participants were asked to participate based on availability. Five of them were female, and all were between the ages of 24 and 28. Four of them were design students, and three of them had long-distance running experience.

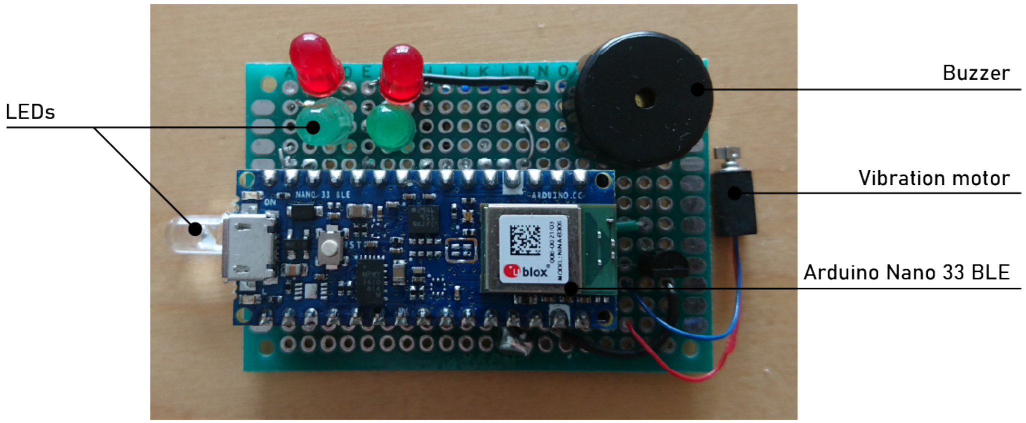
Interactive prototype
The prototype consisted of an Arduino with a small circuit, a 3D-printed housing, a belt, a powerbank and a phone for control.

The Arduino used was the Arduino Nano 33 BLE, which allows a phone to connect via bluetooth to the device for external control. The circuit uses five LEDs (one white, two red and two green), a buzzer (5V active) and a vibration motor (3-6V).

The two red and two green LEDs are substitutes for two RGB LEDs, which due to technical difficulties were not able to work on the used Arduino.

Image 62, Interactive prototype

Image 63, Internals of Interactive prototype



Types of signals

Tested are six types of signals: device turned on', 'belt not closed', 'belt closed', 'pill not found', 'everything okee' and 'too hot'. How they communicate with the user can be seen in Table 5.

In the following table you can see the different types of signals and their execution. By clicking on the icon, you can hear the signal for yourself. The sounds can also be found on https://tinyurl.com/rtzn9czk

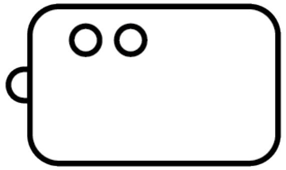


Image 65, Schematic representation of the prototype

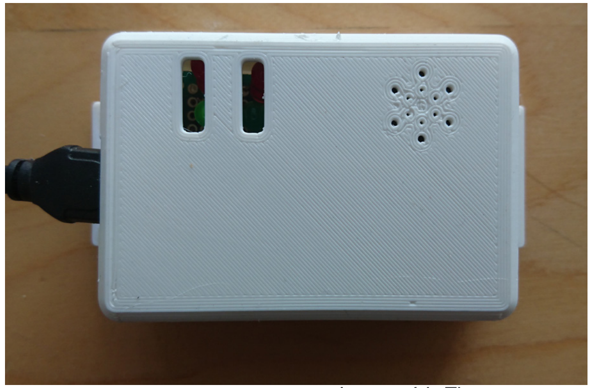


Image 64, The prototype

	LED	Vibration	Buzzer
Turning belt on	White LED on side	1 long vibration	4 bleep, going up
Belt not closed	Both LEDs red	1 short vibration, continuously	1 high bleep, continuously
Belt closed	1st LED from red to green	1 medium vibration	2 high bleeps
Pill not found	1st LED green, second LED red	2 short vibrations, continuously	2 bleeps, going down, continuously
Everything okee	Both LEDs green	2 long vibrations	2 high bleeps
Too hot	Both LEDs red flashing	Continuous long vibrations	3 continuous high bleeps

Table 5, Overview signals

Results

The number of instances in which the signal was understood correctly can be seen in the Table 6 below. The vibration signal performed better in the case of ‘belt open’ and ‘pill not found’, but still were often confused with other signals. The ‘too hot’ sigal was in both cases understood most of the time (80% with vibration and 83% with the buzzer signal).

Four out of six people preferred the vibration signal, and two out of six preferred the buzzer. Reasons mentioned for this were: it would be irritating to bleep during sports (2), the buzzer requires more focus to listen to it during sports (2) bleeping during sports might attract unwanted attention (2), the vibration signals were more easily to understand than the buzzer (1), buzzer signal might not be heard when wearing headphones (1).

One out of six preferred the buzzer signal, because the vibrations felt invasive on their body (1).

Only two out of six were able to see and use the LED signal. The LEDs had low visibility due to low brightness, so in bright daylight they were difficult to see. The two participants both mentioned that having icons with the LED would make it easier to understand the different signals (2).

Three out of six would prefer no positieve feedback from the buzzer or the vibration. The reasons mentioned were having less signals meant less signals to remember (3), they associated having no signals with something good (2) and it would make the product less overwhelming (1).

Three out of six mentioned voice commands as an alternative for the buzzer. Reasons were so that they did not have to remember what the signals meant (3).

All participants missed the belt closed signal for both the vibration and buzzer

Four out six mentioned that they missed a reference for the signals, because the written instructions did not prepare them enough for the different signals (4).

Table 6, Percentage of people that guessed the signal right

	Vibration	Buzzer
Belt open	57%	33%
Pill not found	66%	63%
Too hot	80%	83%

Discussion

The majority of the participants preferred the vibration signals over the buzzer signals, mainly because the buzzer would irritate them during sports. Also can be seen participants more often guessed the vibration signals correctly than the buzzer signals. However, this could have been because the buzzer signals were always used in the first round, meaning that the participants were more familiar with the signals and the way the user test was setup.

Both with the buzzer and vibration signals, ‘belt not closed’ and ‘pill not found’ are often confused with each other. The main problem probably is that the participants had to remember the signals and how to act upon them in a very short time, or they had to look up the signal using the flyer.

Three participants mentioned that when they are running, they are focussing on so much already that they do not want to have to think about what signal they are hearing and what they need to do.

Having voice commands could solve this problem, as it is able to inform the user about the problem as well as the solution. The user does not have to think about this. The voice commands could be a great solution, especially for those who like wearing headphones, or do not mind that the device makes sound sometimes .

For people that prefer no sound while running and switch sound off, the vibration signal could still be used to alert them that something is wrong.

If they have their phone or smartwatch connected to the myTemp system, they can receive status information in text or pictures on their mobile devices (smartphone, smartwatch) about problems and solutions.

The two participants that were able to see the LEDs, often looked at them during the test. Two participants that could not see them mentioned that they wished they could have seen the LEDs, because it would have helped them to determine the status of the device. So having LEDs on the device would give users a bit more quick reassurance if they are troubleshooting.

The participants were able to recognise the vibration signals better than the buzzer signals. The reason for this could have been the fact that the buzzer signals were always used in the first round. Therefore, the participants were more familiar with these signals and the way this user test was set up

Also, a limiting factor of the study is the small number of participants. With a small number of participants it is not possible to deduct any significant differences between the different types of signals, only a general idea of what people like and dislike and the reasons why.

Because of the small sample size, there were no significant results found in the questionnaire data. However, the questions did help aid the user in thinking about the different aspects of the signals in an structured way, which did provide useful insights.

Solution

17. Technical concept

In this chapter the final concept of this thesis is presented. This is not a fully complete and tested design, but a concept in which all the choices made throughout this thesis are integrated into one design.

The technical and aesthetic part will be discussed first, then the user interaction will be described.

The design is made up of five main components: the main housing, two side pieces that connect the antenna band to the electronics, the antenna band (Amotape® Conduct Nylon + Elastomer / 20 mm) and an extra elastic band for extra adaptability.

Image 66, Final concept

Aesthetic

The inspiration for the visual design came from medical wearables. These products tend to look reliable, safe and clean. These values are also important for the researcher, as can be seen in the interviews.

These values translate into a design made up of simple shapes, rounded edges, and large buttons and lights.

The inspiration can be found in Appendix H.

Technical

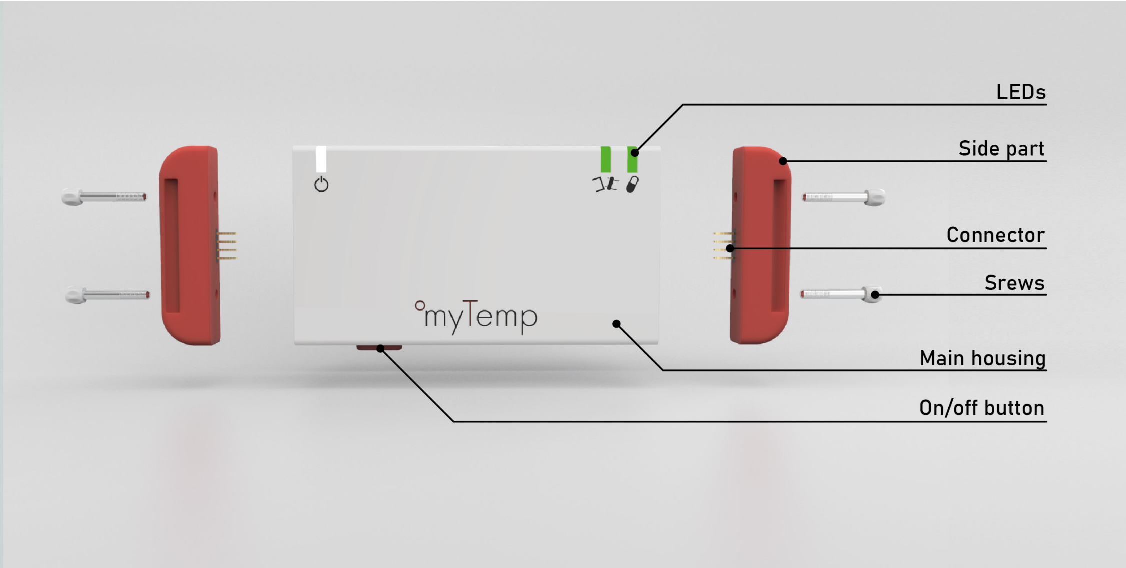
This is the main design. It can be divided into three parts: the main housing and the two side pieces. The main reason to divide the product into three different pieces is that in this way the antenna can be removed to be washed or to be replaced. The parts are held together by screws, which ensures a good electrical connection that does not open during use.

Since the belt is stretchy, the user wearing the device can simply step into the belt and pull it up to their torso, so the belt does not need to open and close when putting the device on.

The design is placed flat on the back. There is looked into whether the back of the device should be shaped to better form the body, however flat seemed to be the best shape to accommodate different sizes. The visuals of this can be found in Appendix I.

Image 67, Elastic and antenna band connected to the housing

Image 68, Parts concept



Main housing

The main housing contains the printed circuit board (PCB), battery, contacts for the antenna belt and all interaction electronics.

There are three LEDs on top. The one on the left indicates whether the device is turned on or switched off and indicates the battery level. The two on the right subsequently indicate if the pill is detected or not and if the belt is properly closed or not.

These LEDs wrap from the top to the front of the housing. Thus, the user wearing the device can see the status of the device without having to grab and turn it. The status LEDs are located on the right of the device, so that users can look to their right and see the status of the device, instead of having to turn the whole device to the front (idea based on user research).

The power button on the bottom of the main housing is the only object on the main housing that sticks out. This makes it easier for users to find the button without having to look for it. This is especially useful when the user wearing it has to turn on the device when wearing it, or when they want to silence the ‘too hot’ signal.

The micro USB is positioned next to the power button and can be used to charge the device and to transfer data. It is currently placed on the bottom of the device to prevent water from entering and damaging the electronics.

At both sides there are the antenna band connections and two screw holes. This is where the side pieces connect to the main housing.

To connect the side parts to the main housing, the connections have to be aligned and press fitted. The screws can then be tightened so that both pieces are secured together. This way the connections cannot move and open throughout use.

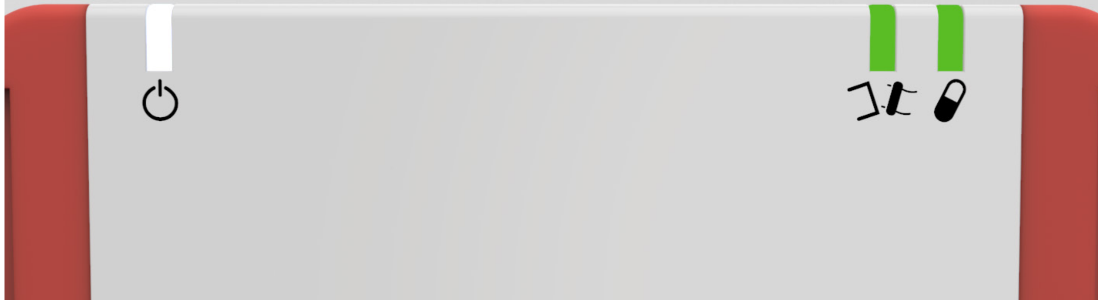


Image 69, LEDs on concept

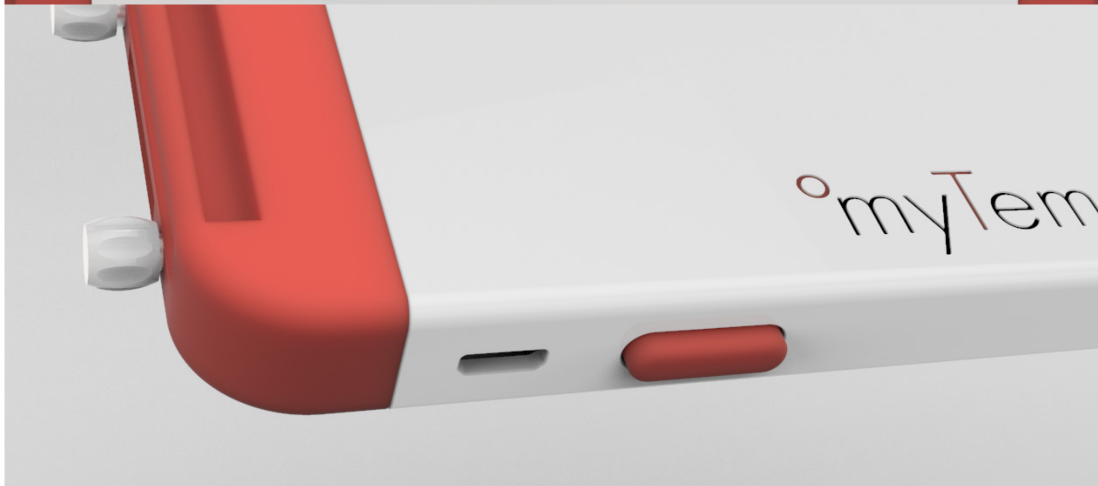


Image 70, Button and mirco-USB connection on concept

Image 71, Connection with side parts

Image 72, Place of attachment of antenna and elastic

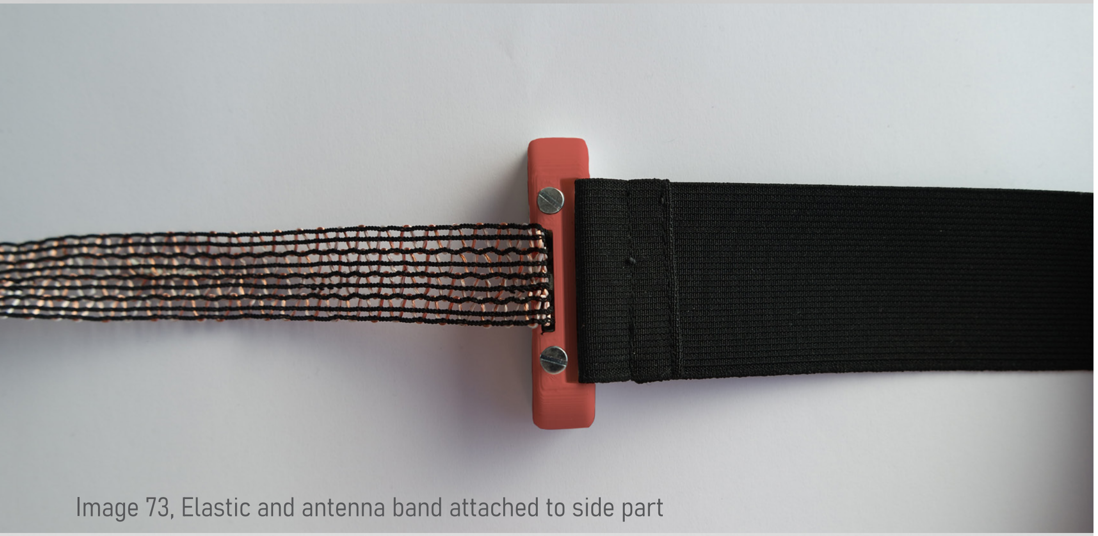


Image 73, Elastic and antenna band attached to side part

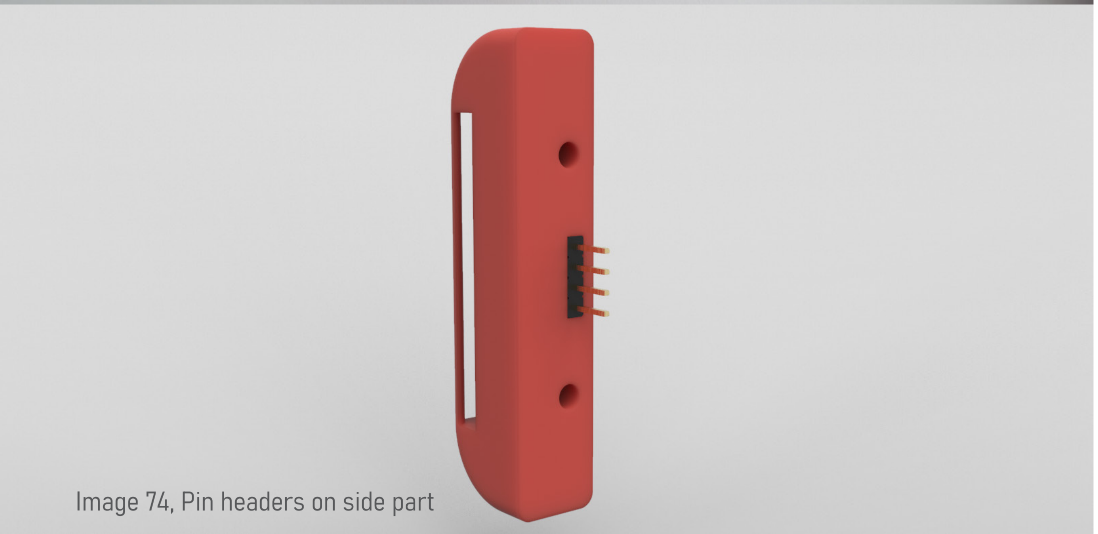


Image 74, Pin headers on side part

Side parts

The side parts connect the antenna band to the main housing. There are four main points of interest: the slot of the antenna band, the electronic connection, the attachment for the elastic and the screws.

The first is the slot for the antenna belt. Here the elastic antenna is inserted and soldered to the pin headers.

For extra comfort and to remove tension from the antenna band, a second, wider piece of elastic is attached to the side part. This elastic band can be adjusted for extra comfort, and to increase the longevity of the antenna band.

To secure the side pieces to the main housing and to ensure a good electrical connection, the pieces are screwed together.

18. Interaction concept

This chapter explains the interaction vision, which is based on interviews with experts, observations and the interaction research. This vision serves as a base for another ideation, as it proposes some new ideas that still need testing in context.

In the vision, the distinction is made between field research and lab research. Lab research will be referred to as the device being used inside, field research refers to the device being used outside. There is also a distinction made between the device being used as a standalone product, or used in combination with smart devices. It would be recommended to first develop the standalone interaction, as the smart interactions do require more integration with said devices, which could increase development time and costs.

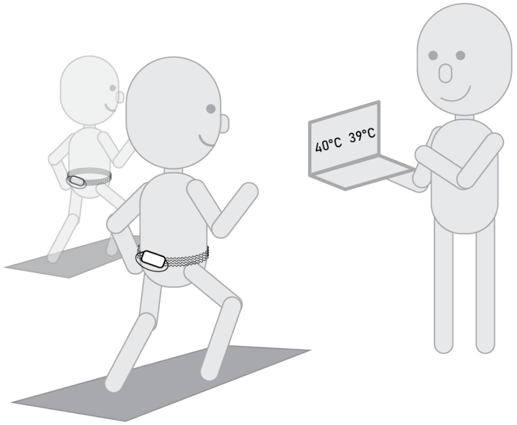


Image 75, Vision 1: inside and standalone

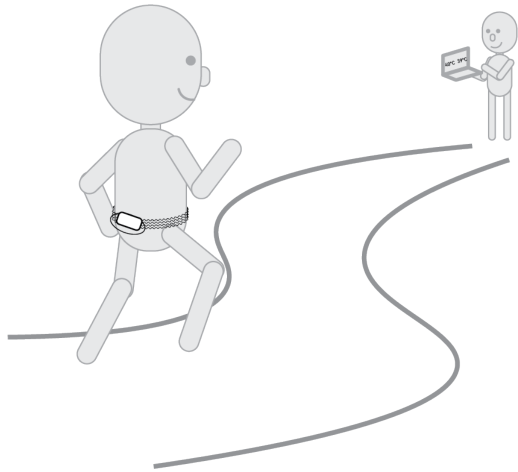


Image 76, Vision 2: outside and standalone

Image 77, Vision 3, outside and smart, without headphones

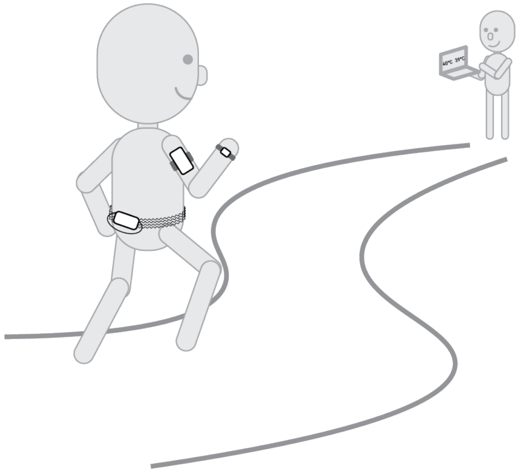
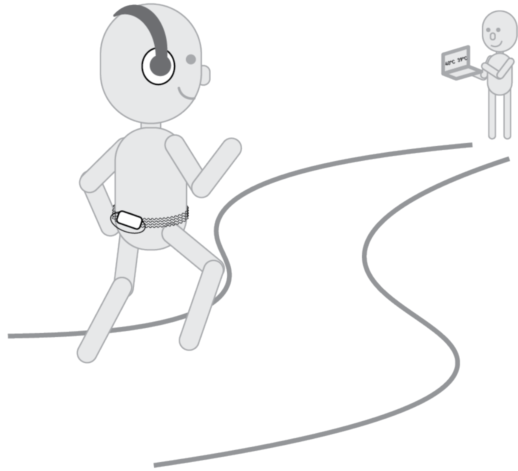


Image 78, Vision 3, outside and smart, with headphones



Vision 1: Inside, standalone

The first vision that will be discussed is the device used inside, as a standalone device. In this scenario, there are often multiple participants using the device simultaneously next to each other, with a researcher closely present monitoring the participants.

The main focus here lies on not distracting the participants. Since the researcher is closely present, the responsibility of troubleshooting and solving technical difficulties lies on the researcher, and not on the participant.

By using the myTemp program on their computer, they would have an overview of all participants and their devices' status. In case of technical difficulties, they would be able to see the type of problem on their computer, including how to solve them. They could then approach the participant and solve the problem, without distracting other participants.

As a safety feature, the belt could vibrate when the participant's core temperature is too high. This could be useful in case the researcher fails to notice the core temperature in time, or when the bluetooth connection between the computer and the device fails. Using vibrations, the participant could be notified without distracting the other participants.

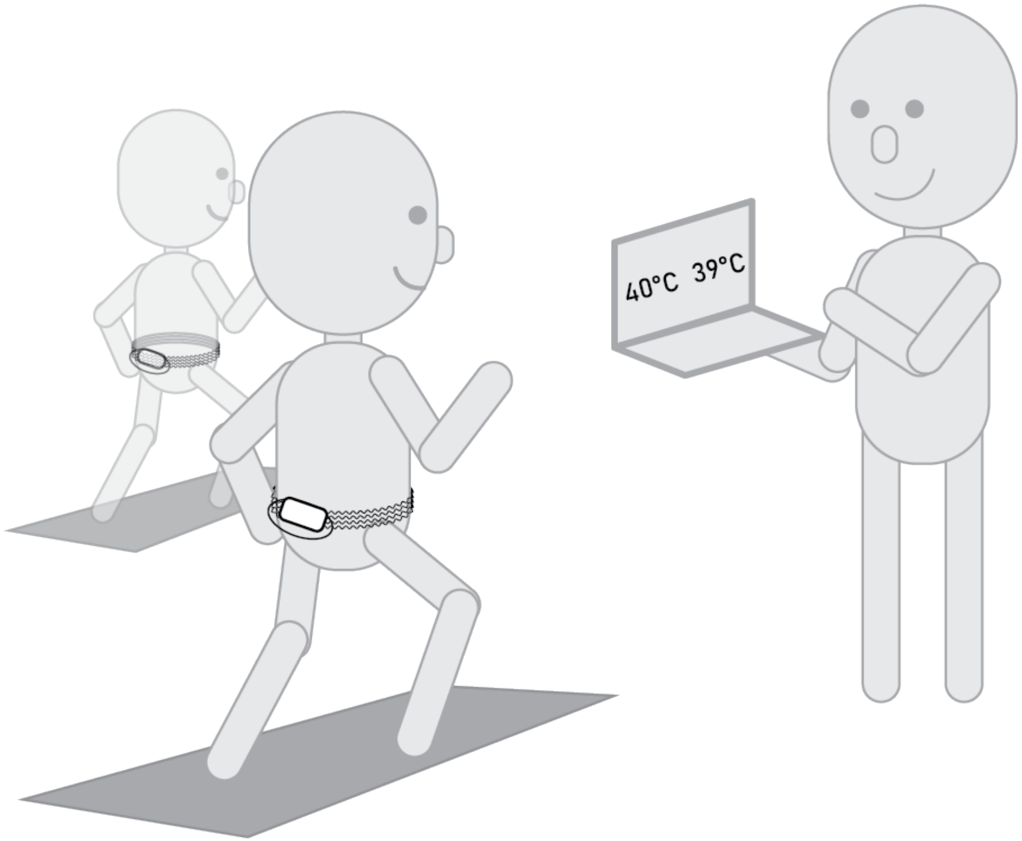


Image 79, Vision 1: inside and standalone

Currently, there already is a myTemp program that is able to detect certain technical difficulties, but only when the device is wired using a cable to the computer. Changes need to be made to the program so that it is able to give an overview of multiple devices and their statuses. Also this vision requires the ability to mute specific signals, so that the researcher can choose which statuses give signals and which ones do not. In this case the researcher would want to mute everything except 'too hot'. They also should be able to define their maximum core temperature threshold, dependent on the research.

Vision 2: Outside, standalone

In the second vision, the device is used outside in field research.
One of the main differences here is the role of the researcher. When doing research outside, the researcher is often further away from the participants and is therefore less able to intervene in case of technical difficulties. Thus, being able to detect the technical difficulties as a participant becomes more important for a successful research.

In this case, the device vibrates only in two cases; a technical difficulty or a core temperature that is too high. A technical difficulty would be two short vibrations every 10 sec, and a high core temperature would be continuously long vibrations. This way, the two types of vibrations are distinguishable from each other, which requires less attention of the user.

In case of a technical difficulty, the participant can choose what to do; solve the problem themselves, or return to the researcher. What to do can depend on the type of research.

Using an RGB LED, the technical problem can be more defined; red light for belt open or orange for pill not found. This does require the person solving the problem to know what to do.

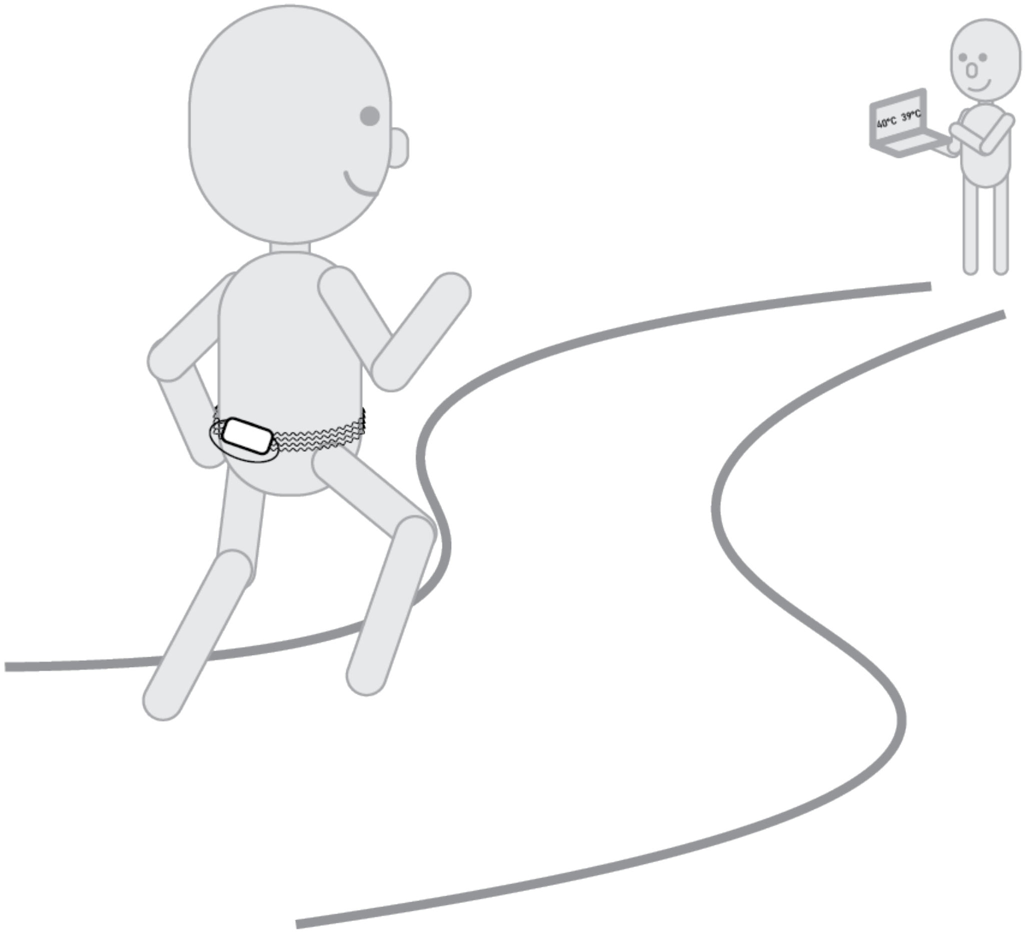


Image 80, Vision 2: outside and standalone

Vision 3: Outside, smart

In the last vision, the device can be paired with other smart devices like smartphones, smartwatches or bluetooth headphones. This interaction is preferred when the participant has to solve all technical difficulties by themselves, without the help of the researcher. Here it is about communicating solutions efficiently to the user.

When paired with a smartphone, the vibration can go through the smartphone, instead of the device. The benefit of this is that people are used to their smartphone or smartwatch vibrating, and will naturally look at their smart device when they receive a vibration signal. On the display of the smart device the problem and solution can be displayed using an app. This way, the user can quickly be notified of eventual problems and their solutions.

For people wearing headphones, voice commands could be beneficial. By connecting bluetooth headphones to a smartphone or smartwatch, voice commands could give detailed instructions of what to do without the user having to look at the phone or watch. This allows the user to know the status of their device without having to slow down or stop to check.

Both concepts would require the use of an app on a smartphone or smartwatch that is able to not only to display the core temperature, but also the statuses of the device and instructions as to what to do. It also should be able to toggle on or off voice commands.

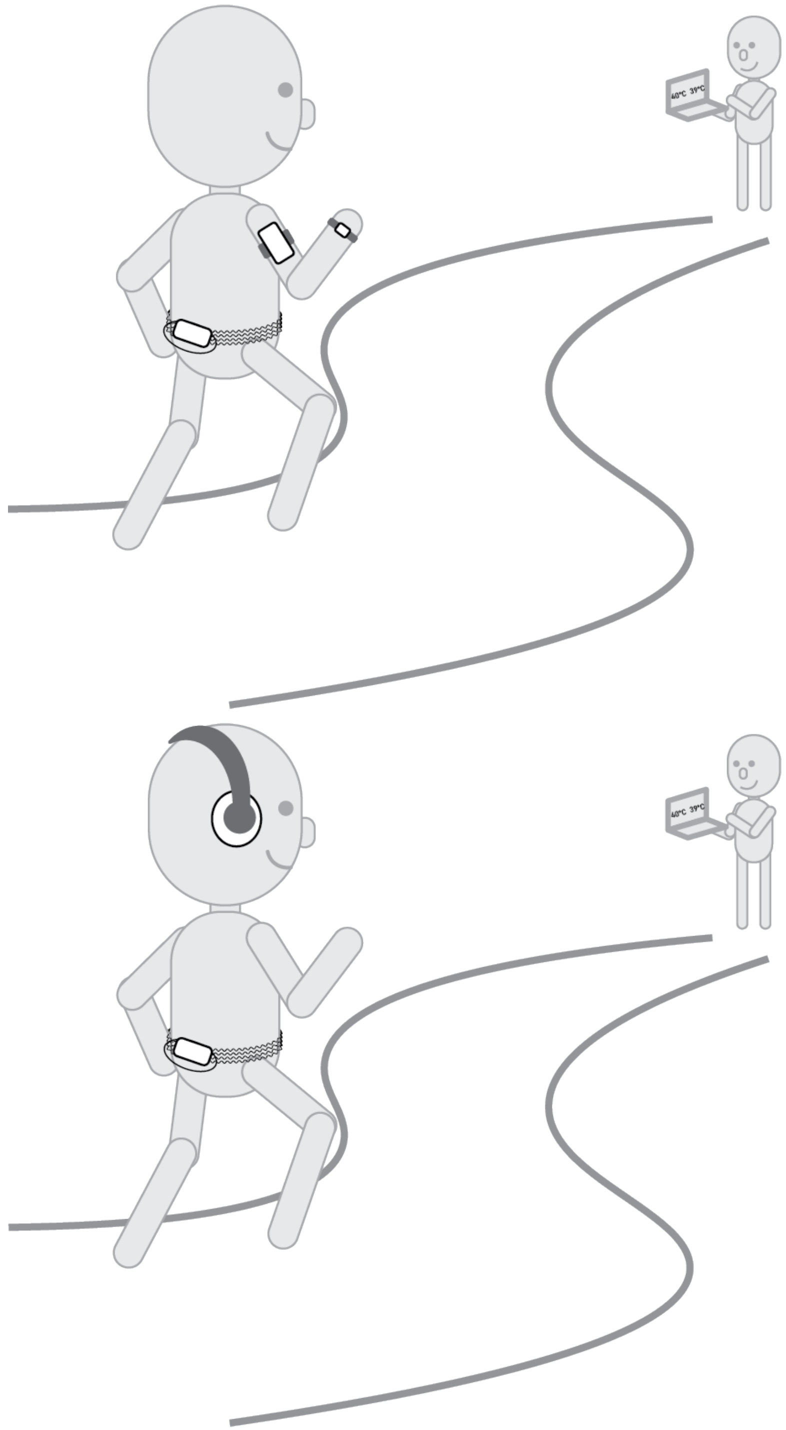


Image 81, Vision 3: outside and smart

19. Recommendations

There still is much that needs to be done to implement the findings of this thesis in the myTemp system to improve the current product. There are three steps to be taken, depending on the goal that is to be reached.

The first step is the implementation of the new antenna. This is about what needs to be done to create a minimal viable product using the new antenna.

The second is increased user experience. This is about adding integration of other devices to create an improved user experience.

The third is about what needs to be done to broaden the target group from researchers to sport enthusiasts.

Implementation of new antenna

First, the wavy antenna needs to be tested to validate its application as a substitute of the current wire antenna. The testing of the wavy antenna has only been carried out using 20V and since the myTemp system works with a voltage of 60V, it should be tested to make sure it works as intended and to prevent unforeseen problems.

The shape of the antenna on the back still needs to be determined. Another method should be used than described in the antenna research in order to fairly compare the two different antenna shapes, as the magnetic field behaves differently in both configurations.

Since the antenna tests had shown that there is a decrease in performance when using an extra antenna, this should also be tested when adding a back antenna. How much an antenna on the back adds to the overall performance of the myTemp system can only be determined when these tests have been carried out

As expected through the theory and validated in the antenna research, an increase in size of the antenna results in a decreased strength of the magnetic field. What needs to be determined is what maximum antenna size still allows for reliable core temperature readings. These findings will influence on the maximum size people can have that want to use the myTemp system, and on how many extra sizes band myTemp wants to offer.

The presented visual design should be discussed with a manufacturer to finalise the details, as it currently does not take manufacturing and PCB layout into account. The same goes with how exactly the connection between the PCB and antenna band will be made.

At present, the design does not take water resistance into account. By adding a gasket between the main housing and the side parts these connections could be waterproofed, using glue for the antenna belt connections and using a waterproof micro-USB port the design could be waterproofed. These solutions should be discussed with a manufacturer before implementation.

Increased user experience

For the user interaction, it would be recommended to test the user concepts described in “18. Interaction concept”. This should be done with the target group to find potential problems in the research context.

In order to provide a better user experience, the myTemp software should be updated to allow the user to be able to personalise what notifications they want to receive, so that they can tailor the myTemp product to their type of research. The software also currently lacks a professional look (“5. Interviews”) which also could be improved.

An app in which users can see more information about the status of their device could be the next step. As described in the “18. Interaction concept”, this app should be able to make use of the vibration motor integrated in the phone, and would display the status of the device as needed. Integrating voice commands could add to the value of the device, giving a way to quickly share relevant information to the user without the user having to look to the device.

Integrating the same type of app in a smartwatch would increase the user experience, as the smartwatch is often used for sport related activities, and thus the user would be more used to the experience.

Broaden target group

To be able to sell it to non-researcher consumers, the system would need to be thoroughly tested and have integration on smartphones and smartwatches. The main thing that would need to be tested is the data analysis. A consumer does not have the skills or knowledge to retrieve the information they want from raw data, something a researcher does have. Either the consumer should get aid in how to interpret the data from someone with knowledge on the subject, or an algorithm should be used to provide this service. However, this should only be a priority when the system is already on the market for researchers.

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Appendix

Appendix A, Stakeholders

	Who are they?	What do they want?	How will they get it?
Sport researchers	Researches the way heat influences performance and cooling techniques	An accurate, reliable tool to measure core temperature	Are the ones that decide on the tools that are being used in the research
Coach	Monitor their athletes performance	A way to protect athletes from overheating and to monitor their performance in the heat	By using core temperature measuring tools, and by instructing their athletes how to cool
Athletes	Endurance sports that partake in competitions in hot climates	To perform optimal in their competitions	By using cooling methods when necessary
myTemp	Creator of the myTemp prototype sensor and initiator of the project	To create a commercial core temperature sensor	myTemp have developed a prototype and have initiated this project
Sports doctor	Responsible for taking care of sport related injury or preventive care	Monitor the physical health of their athletes to help them perform optimally	Will do periodically tests to assess the current performance of the athlete and will recommend how to improve the performance
Manufacturing	Involved in manufacturing products	Producing the products using the tools that they have	Need to give advice on the prototypes so that it can be produced using their tools
Doctors	Responsible for taking care of ill or injured people	To asses the state of the patient and act accordingly	Already use core temperature sensors to asses the state of heat illness their patients are in

Organisers sport events	Responsible for organising sports events	To provide a safe environment for the athletes	Limited influence on current project, but might offer research opportunities to sport researchers
EHBO	Are responsible for providing first aid	To asses the state of the patient and act accordingly	Might benefit from assessing core temperature quickly
Sponsors	Parties that provide sport team with (financial) aid	Want to see their sponsored teams perform well	Little influence on current project, but might be interested in investing in tools that can help improve performance
Participant research	Participates in research	Are compensated for their time and/or are interested in the results of the research	Have to wear the product
Competitors	Producers of core temperature sensors	Selling their alternate version of measuring core temperature	Use their products as an inspiration to improve the myTemp sensor
NOC NSF	Organization that looks after the interests of Dutch athletes	Facilitating and providing aid to professional athletes to help them perform better	Setting up researchers and training facilities to aid athletes

Appendix B, Interview questions

Wat voor een onderzoek doe je?
Hoe gaat zo'n onderzoek? (Kun je dag van het onderzoek beschrijven?)
Wat voor een oefeningen worden gedaan?

Met wat voor een sporters werk je?
Zijn het professionele sporters of amateurs of sporten ze helemaal niet?
Hoe krijg je je participanten?
Merk je verschil tussen de verschillende sporten?
Wat vinden sporters fijn om te dragen qua meetinstrumenten?
Wat is belangrijk voor de sporters tijdens zo'n onderzoek?

Wat voor een soort meetinstrumenten gebruiken jullie?
Heb je eerder de myTemp/slikbare kerntemperatuur sensoren gebruikt
Wat voor soorten data/informatie heb je nodig? Hoe heb je deze info nodig?
Zitten er ook commerciële instrumenten bij?

Wat is voor jouw als onderzoeker belangrijk in een meetinstrument?
Wat heeft je echt een keer gefrustreerd met meetinstrumenten?

Zijn er echt no go's in meetinstrumenten?
Wat is de invloed van zweet op de meetinstrumenten?
Is het wel eens mis gegaan met een van de participanten? Wat gebeurde er dan?
Hoe zit het met hygiene?

Wat zou je me aanraden qua onderzoek doen vanaf hier?
Welke informatie denk je dat erg van belang is bij dit onderzoek?

Zijn er mensen die je me zou aanraden om mee te spreken?
Heb je nog tips voor mij?
Zou ik je later nog een keer mogen benaderen mocht ik meer vragen hebben?

Appendix C, Interview notes

Sport researcher 1

Lastig om in het lab echt goeie lichaam temperaturen te meten. Oksel of oor worden zijn niet betrouwbaar, maar oor wordt nog wel in het ziekenhuis gebruikt. Voor echt betrouwbaar moet het of in de slokdarm of rectaal, maar dan hou je het echt in een lab setting.

Zo'n temperatuur pil is eigenlijk de enige optie als je buiten het lab wil gaan meten, zoals sporten buiten of militairen. Groot nadeel is dat eten en drinken (speeksel ook) er een grote invloed op hebben, dat je het tussen de 3 en 5 uur van tevoren moet inslikken en dat het na 8 uur ook weer uit de spijsvertering is.
Daarnaast worden de metingen nog wel beïnvloed als de persoon heel veel water drinkt, zelfs als de pil al in de darmen zijn. Ook zijn er vaak problemen met de electro magnetisme, dat soms zorgt dat datapunten niet worden geregistreerd. Als dat teveel gebeurd is de data niet meer veel waard. Daarnaast zijn pillen wegwerp producten en duur (40 a 50 dollar per stuk). Dit is niet een groot probleem als je met 10 mensen gaat testen, maar op een grotere schaal wordt dat wel lastiger.
Met pillen met batterijen ging het activeren van de batterij ook wel mis, waardoor er geen metingen waren. Daarnaast ging er een batterij door je lichaam, en dat stond hem wat minder aan.
Volgens hem sloegen de pillen van eCelsius de data in de pil zelf op, wat betekende dat je geen extern kastje of telefoon nodig had, alleen slechts de pil

Nu wordt data van meetinstrumenten vaak in hun eigen software programma (van de producent) opgeslagen. Dit wordt later geëxporteerd naar excel of matlab, en gecombineerd met eventuele andere meetsignalen. Vroeger was het wat meer bij elkaar geraapt, waarbij je kastjes met extra plugins nodig had om metingen te kunnen doen.

Hij had ervaring met de myTemp sensor, en heeft er in papendal mee gewerkt.
Grote problemen daar waren dat sommige sensoren niet (meteen) werkte ("je zit dan een uur ermee te klooien"), of dat de pil soms niet wordt herkent. Dit is wel erg zuur, voor zowel de onderzoeker als voor de sporter. "Sporters hebben het snel gehad". (ik had het idee dat professionele sporters wat sneller ongeduldig zijn dan amateurs, N).
Hij had ook met amateurs en militairen getest.

Hij was sceptisch over gebruik voor amateurs, of mensen bereid waren om de sensor te gebruiken voor gewoon een rondje lopen.
Voor specifieke beroepen zoals militairen kan het handig zijn dat de commandant kan zien wie hitte ziek is, maar hij betwijfelde of het nuttig was voor het algemene publiek. Hij verwachtte dat het probleem voornamelijk zat in het interpreteren van de data. Want het is niet zoals bij een hardloopband dat je makkelijk schema's eraan kan verbinden omdat kerntemperatuur zoiets persoonlijks is. Sommige mensen kunnen boven de 40 graden komen zonder ergens last van te hebben, en sommigen zitten tussen de 38.5 en 39 en vallen om van de hitte.

Het liefst zou het systeem gewoon "click and go" zijn.

In het lab in klimaatkamers zijn de standaarden een loopband en een fiets, en in sommige gevallen een roeimachine. Maar het voordeel van de pil is dat je hem voornamelijk buiten kan gebruiken voor eigenlijk “alles”, zoals militairen in bossen, mensen die werken met hoogovens, stratenmakers in de tropen. Wordt ook wel gebruikt voor het team NL in training stages. Hij geloofde ook dat het beachvolleybal team de pil gebruikt hebben, hoe wist hij niet (vanwege het duiken en het zand).

Het belangrijkste voor hem was het het betrouwbaar en gebruiksvriendelijk (“makkelijk en snel”). Betrouwbaar moest het zijn want je kon weinig als de helft van je data weg was.

Voor de participanten was het handig dat je niet veel/niets merkt van het apparaat.

Data die ze nog meer verzamelen zijn hartslag, perceptuele schalen (vragen aan de participant over hoe warm ze zich voelen), GPS (voor afstand en snelheid), huidtemperatuur en zweetverlies. Zeker hartslag is de meest gebruikte combinatie. Want met hartslag kun je zien hoeveel iemand belast is, en een hoge temperatuur en een hoge kerntemperatuur is een risico.

Hygiëne was nooit zo’n ding (voor corona in elk geval). Meetinstrumenten werden onder de kraan gehouden of even afgenomen met een nat doekje. Hij zei wel mocht het een shirt zijn, dan moet deze zeker gewassen worden.

Het product moet zowel binnen en buiten gebruikt kunnen worden, met en zonder zweet.

Sport docter/trainer

Hij had een test sample gekregen, en op zichzelf uitgetest. Binnen fietsen ging prima, had hij er geen last van. Met hardlopen wel, en met buiten fietsen was het vervelend dat je andere kleding moet aantrekken, en dan de sensor connectie verliest met de band.

Het voornaamste dat de sensor moet doen is de atleten niet hinderen, het liefst dat ze het apparaat überhaupt niet voelen.

Sommige atleten houden niet van apparatuur op hen, gezien het hen kan afleiden van de sport. Een hartslagband kan hen bijvoorbeeld irriteren omdat het kan schuren op hun blote huid. Het is daarnaast ook een extra item dat je kan vergeten.

Hij focust zich voornamelijk op duursporten zoals hardlopen, wielrennen en de triathlon. Hij traint dan voornamelijk professionele of wedstrijd gerichte amateurs (echt wel serieuze mensen). Ook voor de ironman triatlon, waar mensen dan 10 tot 12 uur aan het sporten zijn.

Hij was geïnteresseerd in de kerntemperatuur omdat de kerntemperatuur gerelateerd is aan de prestatie; als de temperatuur te hoog is, gaat de prestatie omlaag, en dan moet je gaan beginnen met koelen. Een deel van de atleten die hij traint doet de ironman triathlon in Hawaii, waar zowel de temperatuur als de luchtvochtigheid hoog zijn. Hierbij moet je een plan hebben om oververhitting tegen te gaan. Zijn meest belangrijke punten waren; als de kerntemperatuur te hoog wordt, kan dat gevaarlijk worden voor de sporter en onherstelbare schade doen, en het kan de prestatie van de sporter verminderen.

De hartslag kon ook erg hard oplopen met de hitte,

Eigenlijk wilde hij een dashboard waarop je alle data kan zien van alle meetinstrumenten die je hebt (hartslag bijvoorbeeld en dan dus kerntemperatuur).

Qua data wilde hij voornamelijk een indicatie voor de sporter zelf, waarbij de kerntemperatuur in verschillende zones wordt gezet. Als je in de groene zone zit dan zit je goed, maar als je in oranje/rood zit dan moet je rustiger aan doen/koelen/wat drinken. Het gaat niet perse om precisie hier, hij is niet geïnteresseerd op de honderdste wat de temperatuur is, het gaat meer in welke 'zone' de temperatuur zit. Dit zou wel gekalibreerd moeten worden voor elk persoon, gezien iedereen anders op hitte reageert (sommigen kunnen er minder goed tegen dan anderen).

De sporters zijn volgens hem voornamelijk geïnteresseerd in prestatie. Als hij met ze praat over de risico's van hitte dan geven ze aan dat ze het wel weten en daar inderdaad moeten opletten, maar zodra ze bezig zijn met een wedstrijd dat ze dat toch een beetje vergeten. Dat ze toch zijn van, oh ik hoef nog maar 10 km, ik ga toch wel door. Guido moet tegen hen zeggen dat als ze toch doorgaan dat ze dan misschien de finish niet eens halen.

Als ze buiten zijn meten ze alleen hartslag op het lichaam d.m.v. een hartslagband. Verder kunnen ze het vermogen op de trappers van de fiets meten.

Het belangrijkste voor hem was dat het product gebruiksvriendelijk was; dat je er geen last van hebt het dragen, dat je data makkelijk kan uitlezen (met bijvoorbeeld een garmin horloge), en dat de connectie stabieler zou zijn dat nu.

Hij is bereid eventueel feedback te geven op onder andere concepten, omdat hij (volgens hemzelf) een goed idee heeft wat sporters fijn vinden om te dragen en wat niet.

Academic researcher
hij doet onderzoek naar bloedvergiftiging, naar hoe het ontstaat en hoe het immuunsysteem erop reageert.

Vorig jaar hadden ze een onderzoek gedaan naar hoe de temperatuur verandert bij gezonde vrijwilligers die op een veilige manier werden geïnfecteerd met een bepaalde bacterie. Daarnaast gebruiken ze nu vaak een oorthermometer om te temperatuur te meten, en ze wilden zien hoe goed de oor metingen overeenkomen met de kerntemperatuur gemeten met de myTemp sensor. Daarnaast hadden ze ook huid thermometers waarmee ze het konden vergelijken.

Doel was om te zien op het verloop van iemands lichaamstemperatuur je kan voorspellen wat er met het immuunsysteem gebeurd.

De mensen kwamen s'ochtends om 7 a 8 binnen, waarbij ze aan het infuus werden gelegd en ze de pil moesten inslikken. De rest van de dag lagen ze in bed, en waren de onderzoekers metingen aan het doen of labwerk. Rond een uur of 17 waren de vrijwilligers weer de deur uit.

Sommige proefpersonen hielden ook zelf de temperatuur bij op hun telefoon, wat sommigen wel leuk vonden, en anderen gaven er niet zoveel om.

Over het algemeen hadden de vrijwillige proefpersonen er weinig last van. Ze voelden niet zo veel van de band. Een enkeling had problemen met de pil slikken omdat hij wat groot is.

Hij verwachtte dat het signaal misschien matig was omdat de mensen in bed lag. Het signaal was wel af en toe matig, moest elke 10 a 20 secondes meten, maar er waren regelmatig data gaten van een uur of 2. Dus ze zaten vaak aan de banden om de positie te veranderen om het signaal weer op te pakken. Hij zei dat vaak de momenten waren waarop de mensen zich niet goed voelden, en “dat vond niet iedereen even leuk”.

Wel jammer dat data gat, het doel was namelijk om te zien of de oortemperatuur overeen kwam met de kern temperatuur. Alsnog hadden ze genoeg datapunten omdat ze veel proefpersonen hadden. Maar het gebeurde vaak op het moment dat vrijwillige proefpersonen zich heel ziek gingen voelen, dan krimpen ze een beetje in elkaar, en dan verloor hij juist het signaal terwijl dat juist het moment is waarop je zou willen meten.

Op zich was het wel een leuke toevoeging aan het onderzoek, maar voor ander onderzoek is dan toch niet gekozen voor myTemp omdat de tijd die ze erin investeerde niet overeenkwam met de winst. Dus terug naar oortemperatuur elk halfuur meten.

Maar het is nu nog gevoelig voor storing en de connectie is nog niet stabiel genoeg.

Met de software waren er problemen, het liep regelmatig vast. Zou wat gelikter kunnen zijn. Gebruikt wel de software van myTemp.

Hoe de data eruit kwam was wel prima, per studie schrijven ze een script voor data analyse. Maar als er een .csv bestand uit zou komen zou dat wel fijn zijn. Eigenlijk geen problemen ermee gehad.

Denkt dat het niet heel veel toevoegt aan IC patiënten, vaak zit er al een temperatuursensor in het infuus in een ader. Voor patiënten op de reguliere zorg zou het wel kunnen worden gebruikt. Nu moet een verpleger elke paar uur de temperatuur meten, maar het zou meerwaarde kunnen hebben als je maar een keer per dag zo’n tablet hoeft in te slikken en dat je een melding krijgt als iemand koorts krijgt.

Iets meer vrijheden waren geweest qua instellingen voor de band. Nu geeft de band een geluidje als die verbinding maakt en elke keer als die een meeting maakte. Maar als je 3 proefpersonen naast elkaar hebt en elke meeting een geluidje maakt, daar wordt je knettergek van. Dus vaak deden we het geluid uit, maar dan krijg je ook geen geluid als hij het signaal verliest, dus dan moet je handmatig naar de kleur van het LEDje turen of te zien of hij nog verbinding heeft. Dus geen geluid bij elke meting maar wel een geluid als hij de verbinding verliest zou wel fijn zijn.

Interfase mocht wel wat gebruiksvriendelijker zijn.
Maar voornamelijk de verbinding was het grootste probleem

Sport researcher

Ze kijkt voornamelijk naar de praktische toepassingen van het onderzoek. Tegenwoordig gebruikt ze e-celcius pillen, voorheen waren het de mytemp voor het termotokyo project.

Hoe het onderzoek gaat is dat ze eerst de sporters laten sporten in de klimaatkamer met 14 C en 40% luchtvochtigheid. Ze moeten dan eerst opwarmen op de fiets voor 20 minuten. Daarna gaat elke 3 minuten de intensiteit omhoog, totdat ze niet meer kunnen. Een week later wordt dit gedaan in een warme hitte kamer (?C, 80% luchtvochtigheid).

Daarna kijken ze naar het verschil tussen prestatie en kerntemperatuur, en aan de hand daarvan kunnen ze een persoonlijk advies geven en zien waarop de atleet zich moet focussen, op koelen of op accamatieren. Als bijvoorbeeld de prestatie erg af neemt en de kerntemperatuur niet hoog oploopt is acclimatiseren bijvoorbeeld belangrijker, terwijl als de kerntemperatuur snel toeloopt maar de prestatie niet erg afneemt, is koelen veel belangrijker. Aan de hand van het onderzoek wordt er een plan gemaakt voor elke atleet.

De myTemp band zou alleen in onderzoek settings worden gebruikt. Zeker voor team en buitensporten willen de sporters geen band om willen hebben.

De ervaring werd beschreven als moeizaam. Ze gaf aan een oude versie te hebben van de band. Het grootste probleem was de verbinding; de verbinding viel weg of er was geen verbinding te krijgen. Soms was er geen verbinding voor 15-20 minuten meer.

De software interface deed het soms niet. Ze hadden op een gegeven moment dat ze een band via de computer moesten uitlezen, en een ander via de app, maar dat dat niet andersom kom. Dat was nogal frustrerend voor haar.

Atleten hebben een scherp schema, en worden daardoor snel ongeduldig van oponthoud.

De band was prima op de fiets, daar waren geen klachten.

Tijdens competities zou het niet mogen en ook niet gewenst zijn om zo'n band te dragen.

Nu gebruiken ze voornamelijk e celcius. Iets wat ze daar heel fijn van vinden is dat je data kan opslaan en later kan bekijken. Soms ging het activeren van de pil wel eens fout, en dan had je helemaal niets.

Het belangrijkste wat eraan nog moet gebeuren is dat het product gebruiksvriendelijker moet, en dus dat het meteen doet wat het moet doen. Dit is zeker omdat de sporter een druk schema heeft, en ook omdat de onderzoekers bepaalde protocollen willen doen in een bepaalde tijd. Ze hebben geen tijd om eerst problemen op te lossen.

Naar de sporters wordt een instructie brief gestuurd met de pillen en instructies wanneer ze deze moeten innemen. Dit is op dezelfde dag, 2 uur van te voren ongeveer. Ze mogen niet drinken tijdens het onderzoek, dus dat kan geen invloed hebben op de sensor.

De piepjes en toontjes waren erg verwarrend; je had voor elk ding een ander piepje, en ze moesten opzoeken welk piepje wat betekende. Ook is het afleidend om elke meeting een piepje te hebben.

Het live kunnen monitoren van de temperatuur heeft wel meerwaarde voor haar. Een ander voordeel is dat het echt wel een stuk goedkoper is om te gebruiken dan e celcius. Het zou alleen geen complete vervanging zijn van de e celcius pil, die zou dan worden gebruikt meer voor buitensporten en competities.

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Academic researcher

Vooral thermopfysiogisch onderzoek, voornamelijk mensen laten inspannen op een fiets, waaronder lichaamskerntemperatuur, die is vaak wel de belangrijkste maat. Haar onderzoek is eigenlijk altijd in de hitte, in de klimaatkamer.

Qua deelnemers is het van alles, kunnen goede atleten zijn, recreatief actief. Ze plant nu om onderzoek te doen met mensen die een dwarslaesie hebben en dus in een rolstoel zitten. Brandweer en militairen komen ook wel.

De resultaten zijn voornamelijk voor hen academisch gefocust, maar eigenlijk is er bij bijna elk onderzoek een partner die zorgt voor de praktische terugkoppeling. Dan geeft ze advies aan de partners.

Participanten kunnen zowel van partners komen als dat ze zelf worden uitgezocht. Op het moment is er wel een project gaande waarbij defensie deelnemers regelt.

Ze doet voornamelijk onderzoek in het lab, maar ook wel eens in het veld. Daar zou dan zo'n band/pill wel fijn voor zijn, dan zou de keuze zijn tussen e-celsius en de mytemp sensor. Ze gaat (hopelijk) met rolstoel rugbyers meten, en dat zouden we met de myTemp banden dan doen. In het lab gaat het voornamelijk om fietsen en hardlopen dat ze dan doen.

Ze had een haat-liefde relatie met het myTemp systeem. Het idee vindt ze goed en het is goedkoper dan andere systemen. Er zijn altijd wel problemen mee geweest.

De band bijvoorbeeld verliest het signaal wel regelmatig. Dan moesten ze de band weer bewegen om het signaal weer terug te krijgen. Ze heeft het systeem wel al een tijdje niet meer gebruikt.

Er zaten veel gaten in de data, een minuut gat is niet zo erg, dan kan je het nog interpoleren, maar het kan wel zijn dat het op een cruciaal punt is. Ze hebben altijd een cut-off van 39.5/40.0 graden, waarbij ze iemand uit het experiment kunnen halen. Als het op dat punt is, "is het niet handig" als de waardes uitvallen. Of als ze naar lichaamstemperatuur willen kijken op een bepaald punt, dan is het vervelend als net op dat punt de verbinding uitvalt. Een klein beetje uitval is niet erg, zolang dat niet op cruciale punten valt.

Bij een steady state inspanning, dan kan je een groter gat ook wel opvangen omdat de kerntemperatuur relatief geleidelijk toeneemt (qua data gat), maar bij grillerette patronen, waarbij hoge inspanning en lage inspanning zich steeds afwisselen, dan is een minuut misschien wel maximaal.

Haar eerste ervaring met het systeem werd omschreven als, "er zelf maar een beetje mee rommelen". Ze vond het "wel een beetje vaagjes allemaal", ze miste een duidelijke handleiding, maar zag wel in dat het in een duidelijke beta fase zat, en dat het in die zin ook niet te vergelijken valt met andere (commerciële) producten.

Richtlijn was 6 uur van te voren inslikken, soms komt het wel voor dat ze vlak van tevoren de pil slikken, maar dan mogen de deelnemers niet drinken tijdens de inspanning. Als het vroeg in de ochtend is dan wordt het wel de avond van tevoren gedaan.

Een onderzoek in de klimaatkamer duur typisch 2 uur, maar dat kan wel langer of korter duren. Een veld meting kan variëren van een 1 tot een hele dag.

Wat ze handig vindt aan het myTemp systeem is dat je de pil niet hoeft te activeren. Daardoor kunnen ze de pil al een week vantevoren meegeven als de deelnemers in het lab zijn. Bij e-celcius kan dat niet omdat de batterij dan misschien niet meekan. Dan zou je de pil moeten opsturen. Nu kan je de pil al meegeven bij een kennismakings sessie, en anders zou je het moeten opsturen.

Bij de keuze van apparatuur wordt aangepast voor het soort onderzoek. Bij bijvoorbeeld een veldstudie is het eigenlijk al meteen een pil, en in de klimaatkamer zijn er meer optie. Maar zij wilde een onderzoek doen met mensen met een dwarslaesie, en bij hen is het minder makkelijk om een rectale sensor aan te brengen, dan kom je ook eerder uit bij een pil.
Prijs telt wel echt mee, maar omdat we wel echt problemen hebben gehad met het systeem, als we echt goede data nodig hebben, dan zijn ze eerder geneigd om het e-celsius systeem te gebruiken. Als ze zeker willen weten dat er goede data uitkomt en geen gedoe willen hebben. Haar afweging voor haar onderzoek met mensen met een dwarslaesie was, dat die mensen al allemaal apparatuur om hen heen hebben, een koelvest aan, en als ze dan ook nog aan de band moet gaan schorren om weer verbinding te krijgen, dat is niet handig, dat zou dan ook de meting kunnen verstoren. Dus vanwege het gedoe en omdat het voor haar een belangrijk onderzoek is voor haar PhD kiest ze dan voor de e-celcius. Dus het is een afweging tussen prijs, moeite die het kost en hoe belangrijk de data is.

De prijs van myTemp is voor haar de grootste reden waarom je voor myTemp zou kiezen.

Op de fiets is het dragen van de band volgend haar wel prima. Ze wist niet hoe het zat met hardlopen of in het veld, daar kon ze niet zoveel over zeggen.

Ze was zich niet zeker van hoe ze de band moest schoonmaken. Andere apparatuur leggen ze in wat water met dettol. Daarna spoelen ze het af en hangen ze het te drogen. Ze had geprobeerd met een doekje en wat dettol het af te nemen.

Academic researcher
Ze werk op de VU in het human performance lab, doen thermofisiologisch onderzoek. Vaak gefocust op presteren in de hitte (klimaatkamer). Haar onderzoek is op specifiek zweten. Brandweer, ministerie van defensie doet ook wel onderzoek daar.

Ze hebben verschillende promovendi die verschillende onderzoeksrichtingen hebben, waar onderzoek uit komt. Ook komt er vanuit de brandweer en ministerie van defensie aanvragen om onderzoek te doen. Onderzoek is op de VU, met iemand van de VU die het project in handen heeft.

Voornamelijk onderzoek met “normale, fitte mensen”. Ook wel eens atleten, nu ook sportende mensen met een dwarslaesie en ouderen. Alles behalve kinderen.

Bij een onderzoek is het belangrijkste wat ze meten de kerntemperatuur. Ook altijd de hartslag, huidtemperatuur, hoe de persoon zich voelt, metabole hitteproductie.

Voornamelijk in het lab (meestal hardlopen en fietsen), maar veldstudies komen ook wel voor.

Per onderzoek verschilt het heel erg wat haalbaar is, en dus welke data eruit te halen is. Dus hoe een typisch veldonderzoek eruit ziet kan ze niet vertellen.

Slokdarm, rectaal of de pil zijn de manieren waarop ze de temperatuur meten, en qua pil gebruikten ze voornamelijk de e-celcius.

Ze heeft het myTemp systeem in 3 experimenten gebruikt, qua prijs was het aantrekkelijk toen. Het was lastig om connectie te maken in vergelijking met de e-celcius. Ze moest een keer 3 uur wachten voordat ze kon beginnen met metingen doen, dat was “een afknapper”. Die band paste niet bij sommigen van de brandweer (zelfs de grootste maat), omdat zij best wel veel kleding en lagen dragen.
Er ging wel veel mis met de data. Er miste regelmatig data als je eenmaal connectie had, dus daarom zijn overgegaan op de e-celcius. Je moet gewoon wachten als de band geen connectie kan maken met de pil. Ze had dan wel opnieuw aanzetten en de band bewegen geprobeerd. “Het is niet zo netjes voor je proefpersonen als je daar maar zit te wachten, en voor ons is dat ook een beetje zonde van de tijd”.

Omdat veel berekeningen afhangen van de kerntemperatuur is het erg jammer als je een groot deel mist.

Het is gevaarlijk voor je proefpersonen ook als je data mist, je kan ze permanente schade mee doen. Ze gaan best wel hoog qua temperatuur, tot het randje van wat ethisch verantwoord is, dus als je dan daar net overheen gaat kan je blijvende schade doen, en dat wil je niet.

Liever heb je niet nog iets om de proefpersoon heen, eigenlijk iets wat niet aan het lichaam gebonden is. Liefst iets wat aan de muur kan hangen, van de persoon af. Wel dat je hem kan zien. Dit heeft te maken dat er al veel apparatuur op iemand zit of omdat het hindert met rennen.

De myTemp band werd niet schoongemaakt. Andere apparatuur wordt schoongemaakt met dettol, veel wordt met alcohol schoongemaakt. Zeker met corona moeten ze deze stappen maken.

Voordeel van myTemp is dat je het niet hoeft te activeren, bij e-celcius zit je aan een batterij houdbaarheidsdatum. Bij e-celcius moet je de pil de dag van tevoren geven/sturen aan je proefpersonen, terwijl bij myTemp heb je een grotere range. Dus qua logistiek vond ze hem wel beter.

Bij haar was de vraag of je de pil mag gebruiken bij het maken van een CT scan, voor het geval er iets misgaat. Daar was wel onduidelijkheid, bij e-celcius mocht het niet. Nu geven ze altijd een geel bandje als waarschuwing voor de patiënten. Omdat het niet zeker was of het wel mocht of niet, ging ze er voor de zekerheid vanuit dat het niet goed was. Maar graag werd het onderzocht en dan ook bandjes aangeleverd bij het product met contactgegevens en product omschrijving.

En een handleiding leveren zou erg fijn zijn. Nu moesten ze sessies inplannen om het product te demonstreren omdat studenten niet uit de handleiding kwamen. Nu als er iets mis ging moesten de studenten haar bellen, en dat wat minder handig.

“We hebben wel goede data ermee verzameld, maar er zaten net genoeg gebreken aan om het te blijven doen”

Academic researcher
Onderzoek op de VU voor thermophysologisch onderzoek. Met myTemp heeft ze onderzoek gedaan met jongeren, gericht op het kritische punt vinden (met bijbehorende omgevingsfactoren) waarop het lichaam niet meer z’n warmte kwijt kan. (het paper zou me worden toegestuurd zodra hij af is :D). Eigenlijk zou er een vergelijking komen met ouderen, maar door Covid is dat niet doorgegaan. Ook keken ze in het onderzoek of de myTemp pil overeenkwam met de rectale sensor.

Het onderzoek was in de klimaatkamer, waar alleen de luchtvochtigheid variable was. De deelnemers moesten deels stilzitten en deels fietsen, en het onderzoek duurde 90 minuten.

De pil was een backup systeem, de voornaamste metingen kwamen vanuit rectale sensoren. De sensor werd een uur van tevoren gegeven, omdat het op dat moment dat het logistiek makkelijkst was. Deelnemers mochten niet drinken tijdens het onderzoek om fluctuaties in de data te voorkomen.

Het systeem werkte voor haar meestal wel, en dan kwam er goede data uit, maar er ging ook wel regelmatig wat mis. Soms kon hij de pil niet vinden, of dat de band geen signaal gaf terwijl de kabel er wel in zat (in de zin, geen lichtjes gingen aan bij de band, batterij was opgeladen, pas als hij met een kabel in de computer zat kwam er verbinding).

Na het experiment werd de data uitgelezen, tussendoor werd er met de telefoon de waardes voor de veiligheid van de deelnemers uitgelezen. Deze werd ook eens in de zoveel tijd opgeschreven als backup, mocht er iets mis gaan met de data, maar dat was niet nodig.

Missende data punten kwamen wel regelmatig voor, dan had de band even geen connectie met de pil. Dan hielden ze hem soms even schuin, of even in een andere positie en dan vond hij hem meestal wel weer. Maar als hij de pil had, dan werkte hij erg goed.

Ze konden bewijzen dat het kritieke punt gelijk is met de rectale sensor en de myTemp sensor. Er zijn wel verschillen qua absolute waardes, gezien de sensoren op andere locaties zitten. Rectale sensor was wel de basis van het onderzoek.

Ze doen de myTemp band wel over de kleding, maar er komt nog steeds zweet op. Maar het wordt wel erg vies als je het veel gebruikt. Omdat de elektronica aan de band vast zit is het lastiger qua schoonmaken. Bij polar banden kan de elektronica er vanaf geklikt worden, en dan kan de hele band in water met dettol gedaan worden. Zeker met corona moet de band echt wel schoon kunnen worden gemaakt. Dus het liefst dat je de elektronica er vanaf kan halen of dat de elektronica tegen water bestand is.

Iets waar ze tegenaan liepen bij het data uitlezen was dat als er een missend punt was, dat niet dat punt als leeg werd gezien, maar dat zodra de band weer verbinding had met de pil, dat de data punten werden gecompenseerd. Dus dan ging je van geen data punten naar een flink paar aantallen achter elkaar. Dit maakt het qua data verwerken lastiger.

Ze hebben ook een paar studies dat mensen in een bad zitten, dus een waterdicht product zou daar ook goed voor zijn.

De banden zijn soms te klein, toen ze met brandweer mannen werkten dan ging de band niet om de pakken heen. Ook kan er dan niet getest worden met mensen met overgewicht. Dus of de band kan niet gebruikt worden met die onderzoeken, of de band zit dan erg strak bij de deelnemers, dat niet erg comfortabel is voor hen.

Zij hadden soms wel hun twijfels bij het myTemp systeem gebruiken omdat het soms minder betrouwbaar is, en betrouwbaarheid van data is bij hen wel echt belangrijk omdat hun onderzoeken voornamelijk gecentreerd zijn rond de kerntemperatuur.

“Als het wel goed werkt, dan is het ideaal”

Appendix D, List of requirements

Performance

The product should be wearable
The product should create a magnetic field that is able to communicate with the sensor pill
The product should be able to communicate with the sensor pil when the sensor pill is horizontal in the intestines
The product should have a battery life of 13h
The product's magnetic field should not interfere with other products' magnetic fields

Maintenance

All soft materials should be able to be washed
The antenna should be able to be removed from the main electronics

Target Product cost

The target consumer price for the band is €800 max

Target consumer price for a kit (20 pills + band + software) should be below max €1200, preferably €700. Pills are estimated around €20 a piece, so this means that the target consumer price for the band is €800 max, not including software.

Quantity

The product should be able to be manufactured with 2000 pieces a year
Aesthetic, appearance and finish
The product should have a professional feel

Ergonomics

The product should accommodate for different body shapes/sizes
The product should stay stable when worn
The product should not interfere with any movement the user makes
The product should not irritate the skin when worn
The status of the product should be visible on the product
The product should be able to communicate to the user its status

Reliability

The product should stay functional in temperatures from 10 to 55 degrees Celsius
A connection gap between the product and sensor pill should be maximum 1 minute

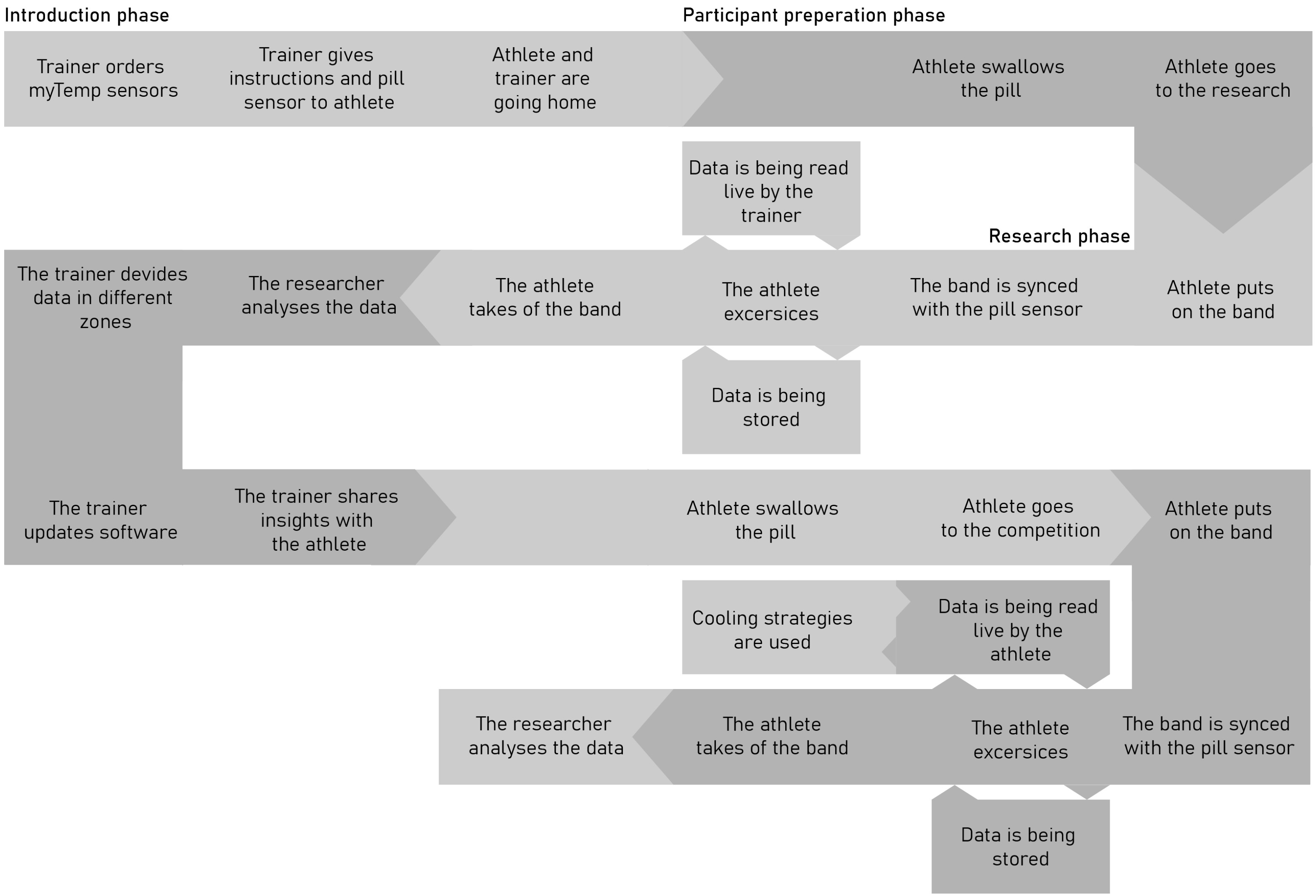
Safety

The user should not be able to touch any electronics
The product should be protected from water in the form of sweat and or rain

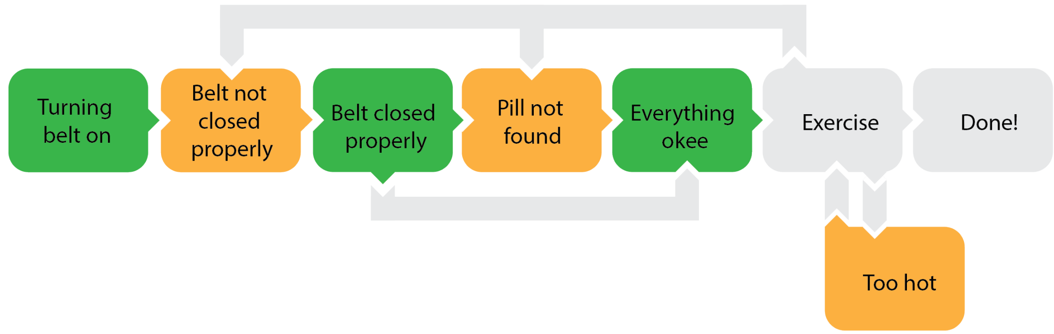
Wishes

The product should be as lightweight as possible
The product should be easy to use as possible

Appendix E, Timeline process



Appendix F, User research diagram



	Turning belt on	Belt not closed	Belt closed properly	Pill not found
Buzzer	4 bleeps, going up	1 high bleep	2 high bleeps	2 bleeps, going down
Vibration	1 long vibration	1 short vibration, continiously	When closed properly, 1 medium vibration	2 short vibrations, continiously
LED	LED on the side turnes on	1st LED will be red	1st LED will be green	2nd LED is red
	The device has turned on	Please open and close the belt		Please move the belt a bit up or down until the pill is found

	Everything okee	Excercise	Too hot	Done
Buzzer	2 high bleeps	No bleep	3 continious high bleeps	No bleep
Vibration	2 long virbations	No vibrations	Continious long vibrations	No vibrations
LED	Both LEDs are green	Both LEDs will be green	Both LEDs will flash in red	Both LEDs will be green
	You can start the exercise now	You can continue the exercise	Please stop excersising immediatly	You can return the belt to the researcher

Appendix G, Heatmaps

Circle shape

1038	341	276	363	613
348	214	189	211	355
320	203	185	207	338
501	254	233	283	758

Human shape

982	396	352	439	947
348	250	225	250	352
298	240	225	247	305
475	327	309	338	505

100 cm (wave generator)

141	62	36	40	116
53	31	34	38	46
52	40	37	36	54
163	65	59	52	101

70 cm (wave generator)

170	71	57	66	171
64	46	45	46	61
69	48	43	43	61
138	63	58	58	117

100 cm (wave generator) + 0° extra antenna

182	20	19	14	188
18	19	14	14	12
15	16	18	16	14
201	22	25	23	178

100 cm (wave generator) + 30° extra antenna

149	52	34	36	120
45	29	23	24	39
41	22	22	25	40
67	37	28	29	96

100 cm (wave) + 60 extra antenna

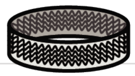
161	54	40	45	99
45	29	23	29	48
42	29	26	29	50
82	43	35	43	150

100 cm (wave) + 90 extra antenna

120	55	43	51	152
48	34	29	33	51
49	36	27	33	51
88	46	40	45	156

100 cm, strechy band (AMOHR)

115	51	40	50	95
54	34	29	33	52
54	33	29	33	52
147	52	43	49	96



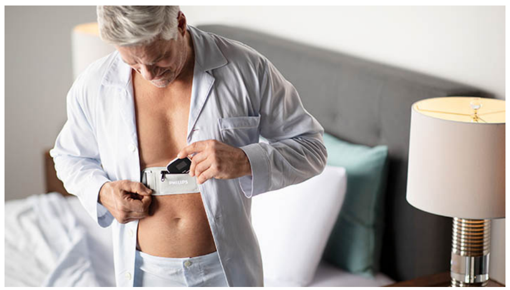
100 cm, Knitted band

35	18	16	18	30
18	12	13	14	19
18	12	13	14	17
34	17	16	18	36

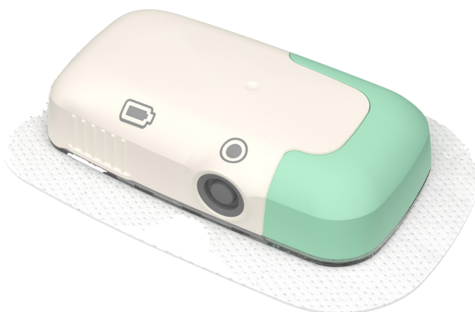
Appendix H, Medical wearables

Garmin, HRM-Tri Heart Rate Monitor

Philips, Nightbalance



Sensile Medical, SencePatch



Appendix I, Shape of back device

To see if the back of the device requires a curve, the short back shape analysis was done. Three 3D models of a P5, P50 and P95 were sliced on their waist (see images below). A bar the size of the current device (110 mm) was placed on their back, and seen was whether if a curve was needed.

An overlaid image can be seen on the following page.

As can be seen, the device is short enough that it does not need to be curved to fit around the person. Only with the P5 there could be a little bit added around the edges, but this is minimal. So chosen was to keep the back of the device straight.

Image 82, Slice of waist of P5 person (CEASAR NL, 18 - 66, f + m)

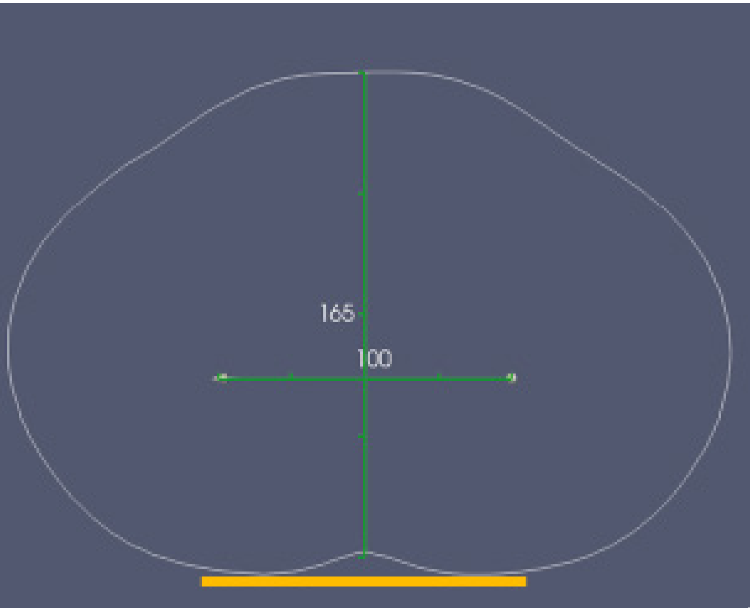


Image 83, Slice of waist of P50 person (CEASAR NL, 18 - 66, f + m)

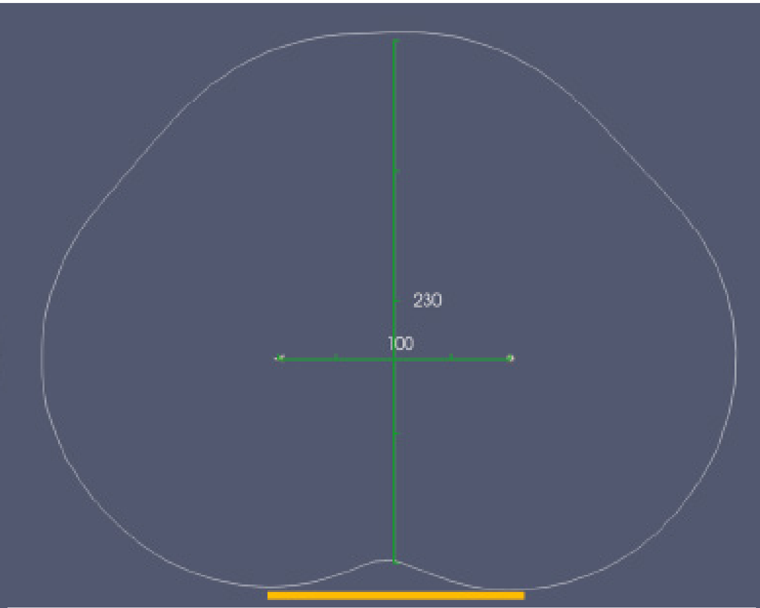
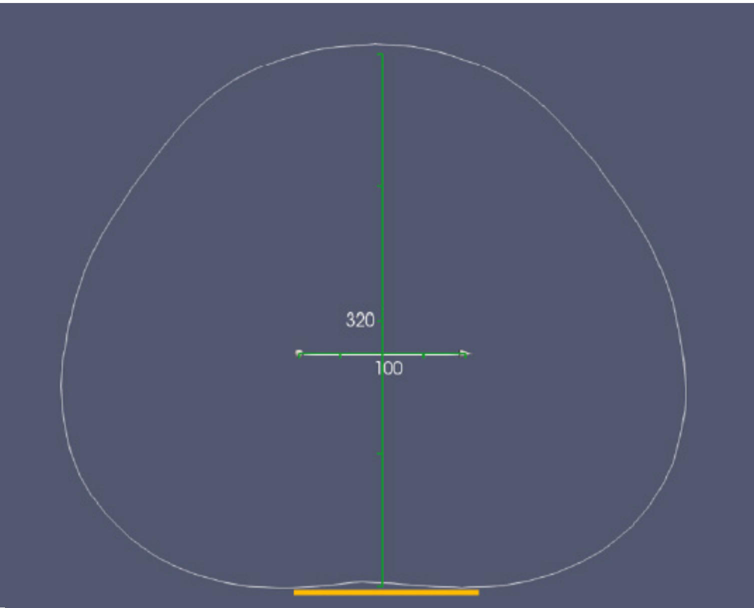


Image 84, Slice of waist of P95 person (CEASAR NL, 18 - 66, f + m)



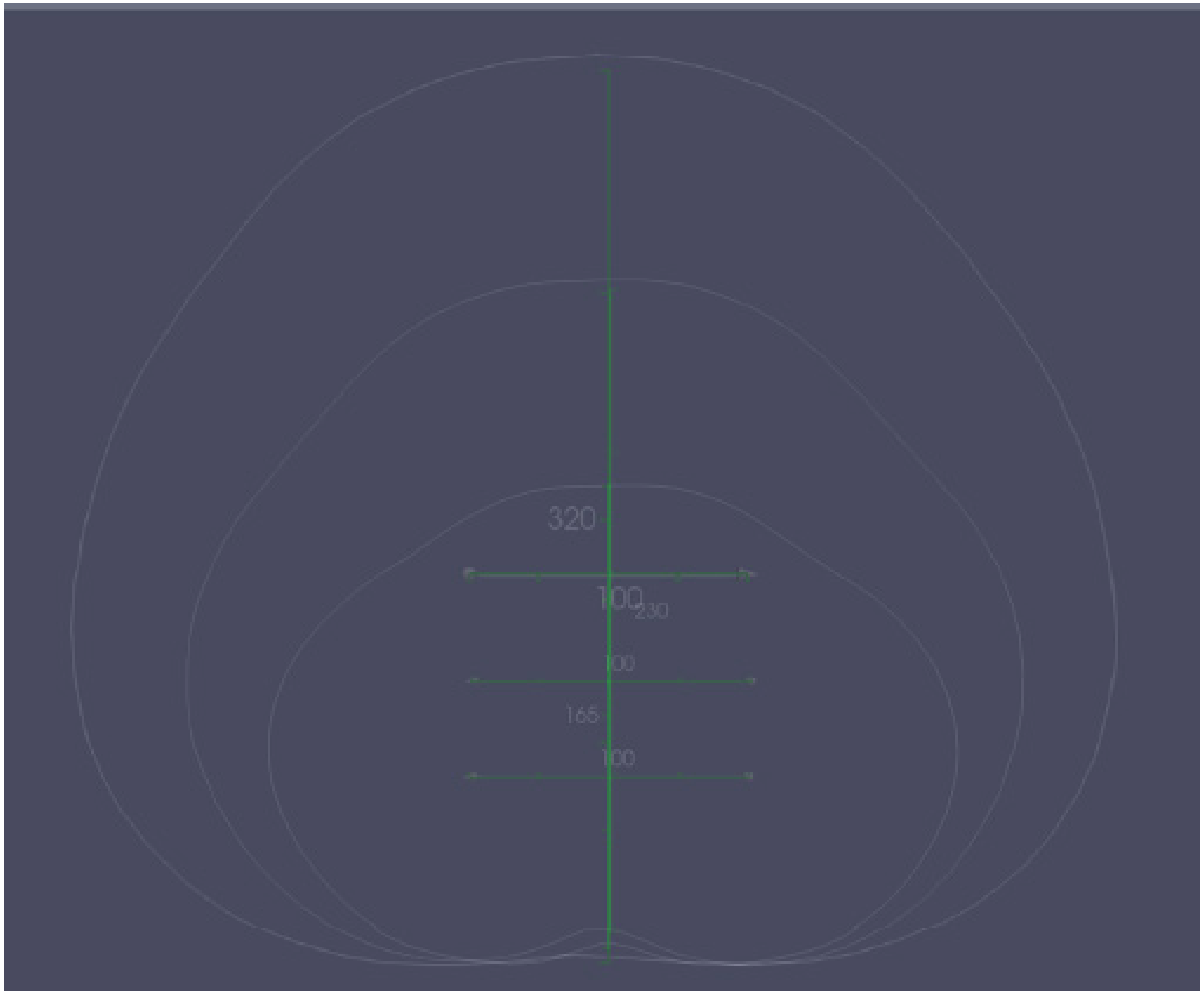


Image 85, Slices of waist of P5, P50 and P95 person ,
overlaid (CEASAR NL, 18 - 66, f + m)