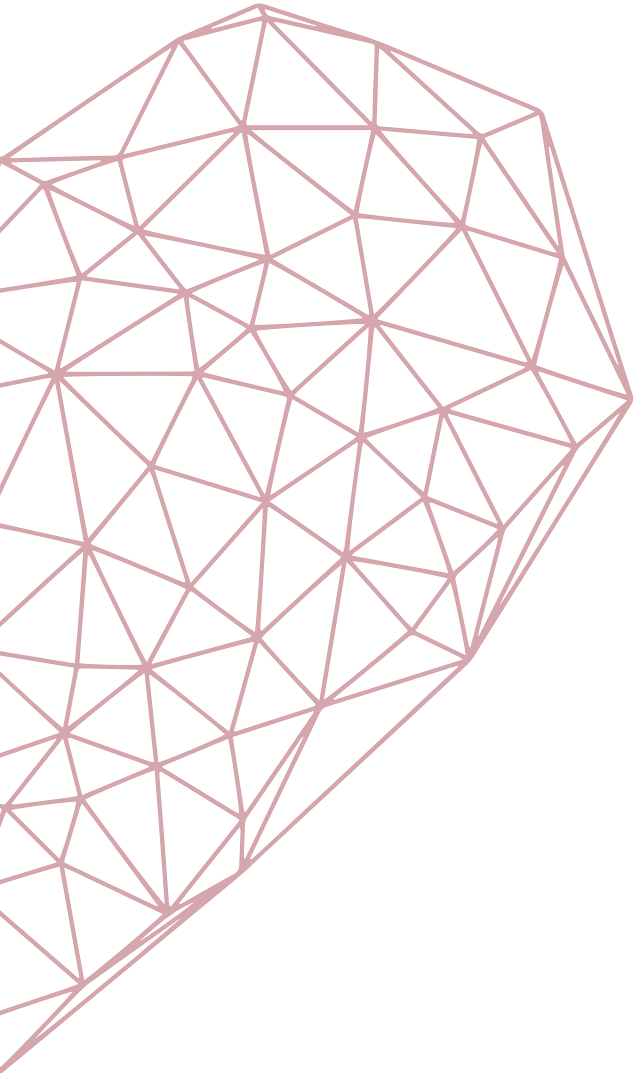

Personal Visualisation

A design research project on data visualisation and personal health

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Executive Summary

This report describes a design research process regarding digital health. Wearable activity tracking devices are seen as an important development in personal healthcare. By tracking user data in order to provide people with insights about their health. This leads to the following question: How to make personal health data understandable for people?

Several activities have been undertaken to provide insight in this question. A comparison of various activity trackers on the market (p. 13), a diary study after the legibility of data collected by an activity tracker (p. 34) and a study after the interpretation of visualisations on small displays (p. 55).

Findings of these studies have been used to design Qualica; a wearable device-as-platform that uses contextual information to improve visual display of data. Qualica has access to personal data from different sources. Furthermore, the system is based upon the notion that the perceived value of visualisation depends on how the data is presented *(Fens & Funk, 2014)*. For this reason, data is displayed using simple yet rich animations.

Finally some challenges facing Qualica are discussed. Especially in the processing of datasets; how to turn various data sources into personal insights?

Table of Contents

Introduction

Healthy living is becoming a serious challenge for people now and in the future. The aging population A report with projections by the OECD shows that the percentage of healthcare expenditure of GDP (Gross domestic product) will rise for each country *(De la Maisonneuve C., 2013).* There are some differences between countries, but the bottom line is: each country will have to provide more healthcare using less money in the future.

To make this happen, the following vision has been suggested *(van Hoof C., 2013)*: We should move from managing illness to managing health. Managing illness is expensive; surgeries, medication and other forms of treatment are very costly. Motivating people to take a proactive attitude towards their health should help reduce all these costs, as people become more aware of how their behaviour influences their health and what the risk factors are.

To specify even further, the World Economic Forum has researched trends in this area and found the following major risk factors for our health *(World Economic Forum, 2013)*:

- Raised blood pressure
- Tobacco Use
- Physical Inactivity
- Obesity

At least two of these risk factors can be countered by some small changes in one's lifestyle. For example, most office workers reside in so-called "*obesogenic*" (promoting excessive weight gain) environments for the greater part of the day. As a result, it is expected that the average American adult in 2020 will only spend 25% more energy than someone who sleeps 24/7 *(MacCallum Carter, L., 2013)*.

Wearable activity trackers are seen as the Holy Grail to counter this disturbing trend. These intelligent wearable devices provide people with insights about their health, in order to quantify their behaviour and motivate people towards change. Earlier research in the domain of digital health and wearable activity trackers focuses mainly on translating sensor readings, such as acceleration, into a number of steps, or energy expenditure *(Crouter, Clowers, & Bassett, 2006)*, But the relationship between activity trackers and their potential user group, however, has not received the same attention: for example, it is still unclear what motivates people to start tracking and how people make use of the gathered data.

Although the future looks bright for activity trackers *(ABI Research, 2012)*, the market is still far away from mass adoption. This leaves us with the question: “How do people perceive the digital health movement?”

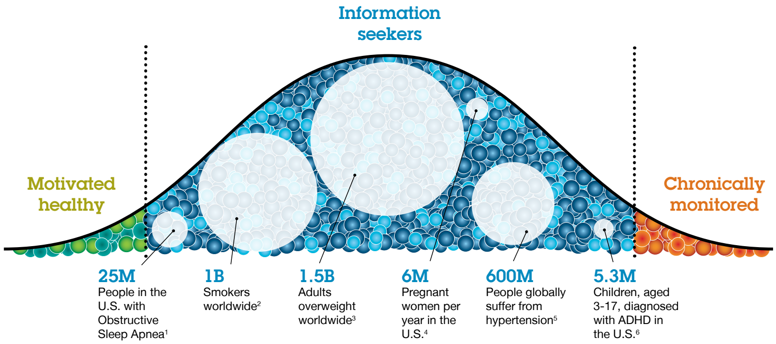
Related Research

A study by IBM *(Fraser H., 2011)* shows that a large group of people can potentially benefit from buying a digital health device. In the paper, this particular group of people is called the “information seekers”, referring to the fact that this group is seeking help managing a particular health issue, but is not getting the right help at the moment. A related survey reveals what people find important; and unsurprisingly, ease-of-use comes out on top.

Kaiton Williams (2013) describes an auto-ethnographic study after health. He experienced the contradictions of relying on apps to learn more about his own body. He takes a critical stand towards this movement, but acknowledges that this in fact helped him reach his goal of becoming “more healthy and fit”. This struggle leaves him with questions about how technology can be meaningfully integrated in people’s lives, and not limiting our behaviours too much.

A paper by Hilary Swan *(Swan, 2012)* provides a comprehensive summary about the internet connected and health related devices on the market today. It is clear that Internet connected devices (Internet Of Things) will play a major part in the future, but as she points out, there still isn’t a clear vision on how all these aspects should be integrated.

When thinking about digital health, data is inextricably linked with digitalisation. This is why visualisation of this data is an important starting point for increasing understanding of our health. Related research on visualisation has provided some insights already.



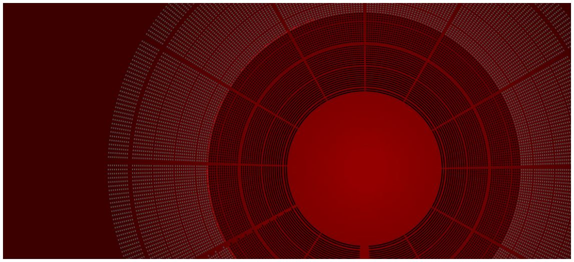
The Information Seekers, figure taken from the IBM white-paper (Fraser H., 2011)

For example, an interesting project by Jen Lowe shows how monitoring a specific signal (heart rate) and publishing this on the internet can be an interesting data source for others. This is mainly due to the way heart rate has been visualised in the context of a complete lifespan *(Lowe, 2014)*.

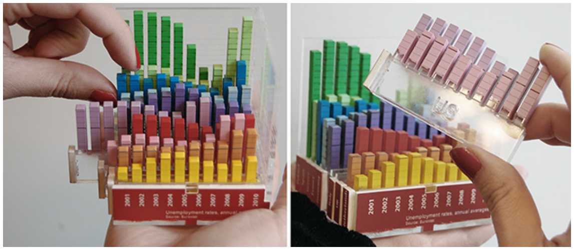
More research on data visualisation suggests that a physical visualisation can be more efficient to interpret than a digital one. Jansen has researched this and found that physical visualisations have features that make them more efficient such as *“their ability to be touched and perfect visual realism” (Jansen, Dragicevic, & Fekete, 2013)*.

Additionally, more experiments with physical visualisations of weather data in the form of a personal wearable (a bracelet) reveal that these kinds of physical objects carry an “intrinsic value” and can therefore evoke “a sense of preciousness” *(Whitelaw, 2009)*.

In conclusion, multiple papers have described the overall digitization of health and the resulting big data flow. To better understand digital health, these devices should be handed over to the actual users to find out if these people can understand the data these devices offer. Additionally, how do they actually feel about the implications of digital health? I assume confronting people with working devices will provide authentic information about whether people “like” the digital health movement and simultaneously spark ideas for future applications.



“One Human heartbeat” by Jen Lowe



Physical Visualizations by Jansen, Dragicevic, & Fekete

Client Context

This project is done in collaboration with Holst Centre. This research facility consists of two separate companies, namely the Dutch TNO and Belgian IMEC. I have worked together with IMEC during this project. Typically, technologies that are being developed are 5 to 10 years ahead of the market. This provided the interesting opportunity to envision healthcare in the future. It requires a broad understanding of how we live now, and how technology will develop in the years to come. Other research groups develop low power sensor technology, especially for the healthcare area. Next to this they're working on energy harvesting; the gathering of energy from movement to make electronics run without additional power supply.

When a technology is matured, it can be licensed to partner companies, which can then use these technologies in their products. Some developments might never make it into mass-production, when they're unable to find interested partners to work with.

Research

Health Tech

The human body contains a lot of information about the various biological processes that happen inside. Using the right sensors, these physiological signals can be measured. For each physiological parameter, there are various ways of measuring, each with their own pros and cons. For example, you can imagine that a heart rate sensor used in consumer-grade device is less accurate than a sensor in a clinical environment. Below are some technologies and sensors listed.

ECG

An electrocardiogram (ECG) provides the electric signal of the heart. It provides more information than just the heart rate itself; it provides the signal where the heart rate can be derived from. Moreover, the signal can be used to diagnose other heart related disorders, such as arrhythmia and cardiac murmur. Performing an ECG measurement can also be done in several ways. Depending on what information should be retrieved from the heart, electrodes will be placed on various places on the body.

Heart Rate

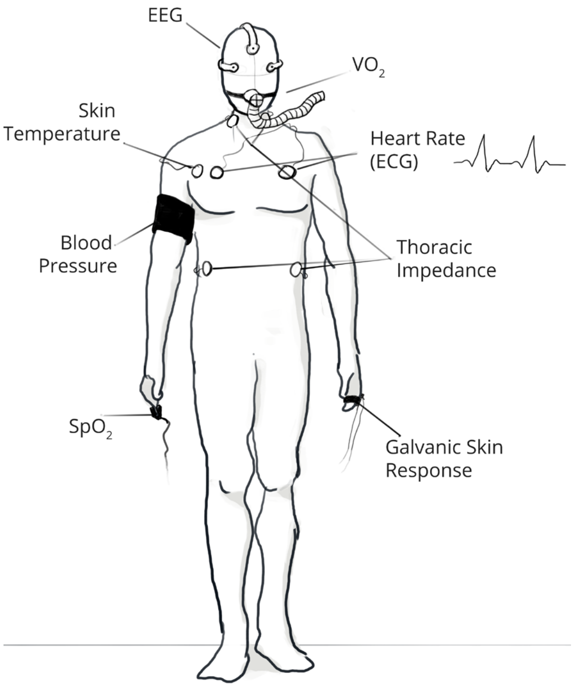
Heart Rate is the rate at which the heart pumps blood through the human body. It is typically measured in beats per minute. Each person has a baseline heart rate and a maximum heart rate; one is the heart rate achieved while resting, while the other can be achieved while having an intense workout. The maximum heart rate that can be achieved by a person decreases during life.

Blood Pressure

Blood pressure is the pressure that circulating blood exerts on the walls of blood vessels, measured in mmHg, which is the standard unit for measuring blood pressure. During heartbeats, this blood pressure constantly varies between a minimum (diastolic) and maximum (systolic) pressure. To measure blood pressure one-off, a sphygmometer can be used. This is a cuff that you put on your upper arm, and inflates during the measurement. Continuous non-invasive arterial pressure (CNAP) monitoring is also possible, using a cuff around the finger and a device that keeps the blood in your finger at a fixed volume. A large device is required for this procedure,

Oxygen Saturation (SpO_2)

Oxygen is transported through the veins using haemoglobin molecules. These can either be oxygenated or deoxygenated. The SpO2 measure describes the percentage of oxygenated molecules in the veins, usually measured at the pulse using an oximeter. SpO2 can be calculated by meas-



Physiological measurements and their places on the human body.

uring the absorbency of infrared light by the haemoglobin molecules. This is done with a small clip on the finger.

Maximal Oxygen Consumption (VO_2)

Maximal Oxygen Consumption is the maximal amount of oxygen (in litres) that someone can use per minute. This is often measured during incremental exercises to ensure a person will achieve his maximal performance. This is one of the most difficult aspects to measure; it involves measuring the amount of inhaled and exhaled CO2 and O2. Therefore, the participant should wear a special mask that is able to measure these factors.

Skin temperature

Skin temperature is the temperature measured on a person's skin in degrees Celsius. This measurement depends a lot on the context and the physical activity of the subject. Studies have shown how skin temperature changes during the night, reflecting the various sleep stages *(Horne, 1998)*. A distinction can be made between skin temperature at the torso (proximal) and at the limbs (distal).

Skin conductance

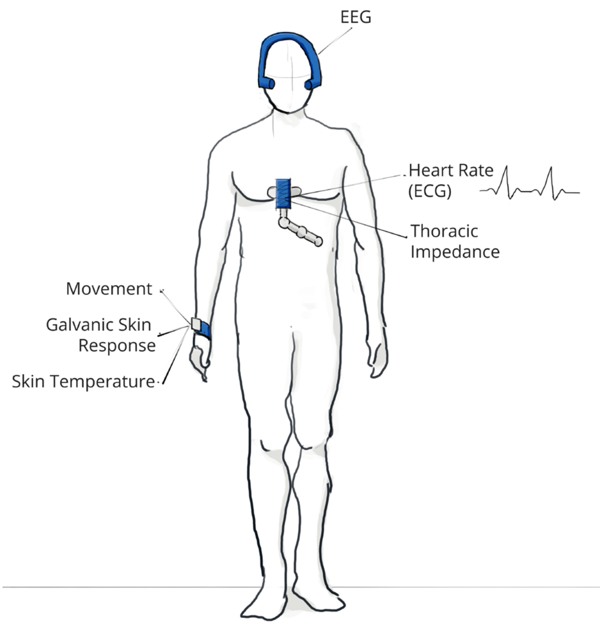
The skin is able to conduct electricity. Skin conductance is measuring the conductance of the skin. Sweat glands located in the skin are controlled by the central nervous system and therefore are able to influence the level of conductance when producing (electrically conducting) sweat. Measuring this aspect can provide information about a person's emotional arousal. Combined with other measurements such as heart rate and blood pressure this can be a valuable measurement for stress.

EEG

Electroencephalography or EEG in short, is the odd one out in this row. Where most physiological parameters are directly related to a person's health, the EEG describes a more complex aspect, namely the electrical activity of the brain itself. When performing an EEG, the result isn't a single number which can be "too high" or "too low"; it's a stream of numbers describing various frequencies. Deriving meaningful information from this data always requires a specialist, in contrast to skin temperature or heart rate, which speak for themselves.

The Body Area Network (BAN)

The traditional way of measuring all these signals is by using one device for each of these signals, resulting in quite a bloated setup on the body if all these signals need to be measured; and I haven't even mentioned the wires that come with each of these devices. To counter this, the Holst centre is developing a set of devices which are able to replace a big part of these traditional devices, without losing signal quality (which is crucial in medical contexts). The devices send their data wirelessly and they're small, so that the patient\user is able to continue the day without having the feeling of "being monitored". The image below shows several prototypes and their capabilities. Signals that aren't yet covered by the current devices are still in development.



The wireless devices developed by Holst are able to replace a big part of the current medical de vices

Market Exploration

The Holst Centre is currently researching into consumer healthcare and activity tracking. It is therefore valuable to look at what products are already available to consumers in this sector. Several digital health devices currently on the market have been explored. I started with a table-wise comparison of their functionalities and specifications. From this can already be seen how these seemingly identical devices have matching features, but also have differences that make each of these devices unique.

An important study in this field suggests that reasons for people to start tracking using activity trackers seem to relate to the human values they hold dear, rather than specific things they want to measure or specific goals they want to reach *(Rooksby, Rost, Morrison, & Chalmers, 2014)*.

Therefore I differentiated between the devices by analysing slogans and marketing material (website). From this, I derived the (intended) emotional benefits and the correlating human values, based on Schwartz's Universal value model *(Schwartz, 1992)*. This can be seen in the figure on the next page.

The other figure on the next page shows the positioning of products in the value model. It shows how the various products are differentiating themselves based on values.

For example, Bodymedia band is often used by people insecure about their health to provide validation that they're becoming more fit; for example during the TV-show "The biggest loser" *(Comstock, 2012)*. This is why the Bodymedia band fits the security (health) value, in the Universal Value model.

The Fitbit is unique since it is being used as a tool to show others your activity. Like many other products, the Fitbit uses accelerometry to measure activity. Additionally, it offers a platform to share statistics with friends, making the whole progress one big "competition". This is the feature that makes the Fitbit a tool to show off activity rather than consciously work on your health. This is reflected by the "social recognition" value in Schwarz's value model.

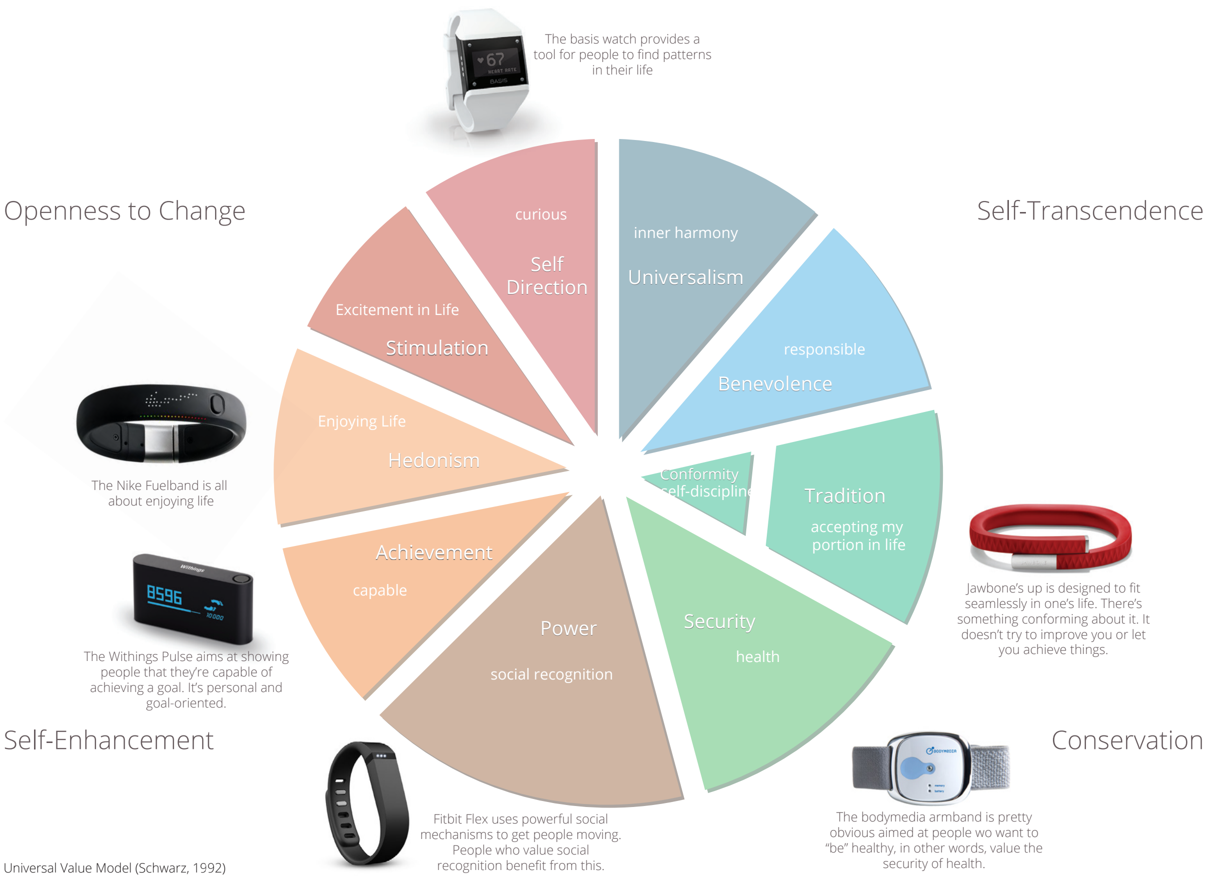
Another example is Nike's Fuelband. Because of the way this product is marketed, using slogans like *"Life is a sport, make it count" (Nike, 2012)* it implies that user's of the product identify themselves with Hedonistic values.

Comparing wearable health devices

	Fitbit Flex	Jawbone Up!	Nike+ Fuelband	Basis B1	BodyMedia Link	Withings Pulse
Stand-by time	5-7 days	10 days	1-4 days	3-4 days	5-7 days	2 Weeks
Wireless Sync	✓	✗	✓	✓	✓	✓
Calorie Estimation	✓	✓	✓	✓	✓	✓
Sleep Tracking	✓	✓	✗	✓	✓	✓
Galvanic Skin Response	✗	✗	✗	✓	✓	✗
Skin Temperature	✗	✗	✗	✓	✓	✗
ECG	✗	✗	✗	✓	✗	✓
Discriminator	Easy of use, product-app integration	Made for real-life, includes meal and emotion tracker	Nike, Brand Authority	More sensors: skin temperature, heartbeat and GSR	Precision, promiss of weight loss	Portable, including heartbeat
Slogan	“Make fitness a lifestyle with Flex”	" Know yourself, live better"	“Life is a sport, make it count”	“Supercharge your day”	“The leading on-body monitoring system. Accurate information about your body.”	track.improve
Emotional Benefits	Compete with friends on who's fittest	Support during the day to monitor lifestyle	Seeing how active you are motivates to move more`	Provide a platform of insight in your own health	Ensuring you're losing weight	Discreteley track steps during the day
Value	Achievement / Self-Recognition	Self-discipline	Achievement, Enjoying Life	Curiousity	Security of health	Achievement (capable)

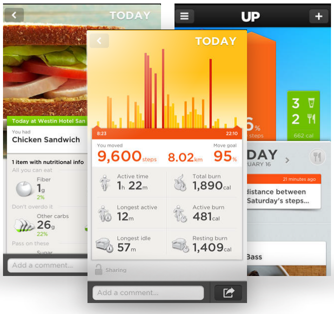
When comparing health devices it becomes clear that most of the devices rely on accelerometry and rely on marketing and emotional benefits to distinguish themselves

Product Places in the value model



Universal Value Model (Schwarz, 1992)

Fitbit

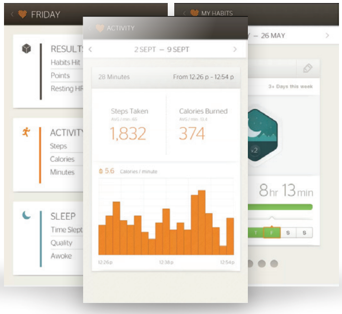


Jawbone UP

Nike+ Fuelband

BodyMedia FIT

Withings HealthMate



Basis Sync

Each of these products comes with a smartphone app, necessary for syncing data to the internet. These apps provide space to communicate values to the user. I compared various smartphone app interfaces to find out how each app does this.

The communicating of values by means of a smartphone app didn't become very clear from the app interfaces, but I did find the apps to be similar in functionality. It can be argued that the colours and fonts of each app have some relation to the values they want to communicate, but in general the values are derived from the functionality; so by actually using the app for a while.

UI Trends

The following trends have been defined after analysing the various User Interfaces in the figure on the left.

Clean interfaces, using white as main colour combined with bright saturated colours and optionally a light typeface.

Graphs form an essential part of representing performance over time. The graphs are often accompanied with a number indicating whether the user has done better or worse at a particular aspect compared to last day/week/month.

Often a percentage is given in the form of a gauge of some sort; this is to visualise the distance from a predefined target. Theory behind this suggests that this motivates users to put more effort into reaching this goal (progress dynamic) *(Kim, 2012)*. Next to this, social leader boards, as seen in the Fitbit and Nike interfaces are also a thought to motivate users to move more, by increasing the “social pressure”.

Other than that, some apps (UP, Healthmate) show additional lifestyle information that requires manual input from the user, such as food intake during the day. This could give an idea of caloric expenditure vs. intake, but is nowhere near accurate. On top of that, the manual input requires extreme consistent behaviour from the user, which often poses a problem in long-term use of such features.

Future products

This study has focussed on products currently available. However, products in this area that are currently in development (mainly funded via crowd-sourcing platform Indiegogo) are evenly interesting to take into account. Let’s take a look into the future;this new generation of products promises to go far beyond the current generation of activity trackers, in terms of accuracy for example.

Since these are still in development, I can only rely on the features promised by their developers. As development approaches the production phase, these features are often “simplified”, making more realistic specifications from their “overenthusiastic” claims. I’d like to name a few important products that are currently in development. These examples have set the bar for any other health care related product that is currently in development.

Scanadu Scout

The Scout by Scanadu (2013) offers basically all features people want from a medical evaluation device. Heart Rate, Skin and Core body temperature, pO2 levels, respiratory rate, blood pressure and “emotional stress”. This is more complete than any other device on the market and moreover, the measurement of blood pressure in a non-invasive way is an important achievement in the medical world. But there’s a downside; although it’s a portable device, it’s not wearable and therefore it will not monitor activity throughout the day. It will only measure when you activate the device. So even though it can measure more signals, it might “miss” important changes because of its periodic use. On the other hand, the features it tracks allow for such a medically accurate image of a person that health risks can be predicted and treated in a timely manner.

$1.664.574 USD

of a $100,000 Goal; that’s 1665% of it’s goal

Amiigo

The Amiigo differentiates itself in the area of activity recognition. It will do this using an extra accessory, next to the wristband. This extra accessory should be attached to the shoe and contains an accelerometer. This enables the amigo to accurately detect what workout you’re having, by tracking both movement of the arm and movement of the feet. Using this technology, the company claims to accurately detect more than 100 different exercises *(Amiigo, 2013)*. This varies from running and walking to biceps curls and even golf swings. Needless to say, this will greatly improve the accuracy with which people can track their lives.

$580.710 USD

of a $90.000 Goal; that’s 645% of it’s goal

Conclusions

I have attempted to find relationships between various "digital health" products. I have compared these products on various levels (specification, feature, experience). It looks like they only have the sensor technology in common; all of these products contain an accelerometer of some sort to track the user's activity. Some products feature additional sensors, such as a Heart Rate sensor to track the user's heart rate during the day.

Imagining the range of specific applications a single technology (accelerometry in this case) can be implemented in, it speaks to the mind how new sensors (such as the heart rate sensor, skin response sensor etcetera) can also be implemented in future products. Future products like 'Scanadu Scout' already claim to integrate many different physiological sensors in one device (a so-called "medical tricorder") , in order to predict health complications.

Next steps

With knowledge about the devices and their different "data outputs", I will start exploring visualisation tools which are able to make sense of such data sets. My goal is to find out how to go from using a device to understanding the data it records. I believe visualisation is the way to go from data towards understanding.

Data visualisation

As stated earlier, I want to use data visualisation as a method to make health data more insightful for peole. According to literature, data visualisation has two purposes; it is used to create a better insight in abstract information (data analysis), but it is also used to communicate abstract information better to others (communication), often in the form of stories. *(Few, 2013)* Both these definitions correspond to what I want to achieve.

Visualising complex data sets is a powerful mechanism to convey information. Almost half of the brain is devoted to recognising visual patterns and structures. This is why we often rely on visual tools to help us understand numbers better. *(Ware, 2010)* Creating geometric shapes that represent datasets are easier to interpret for people than displaying the "raw" data.

In order to make a "successful" data visualisation, the data must be represented according to some strict rules, defined over the years, and closely related to the "Gestalt principles" that are commonly used in graphic design.

Additionally, to fulfil the requirement of clearly communicating abstract information, a data visualisation should achieve the following *(Few, 2013)*:

- Clearly indicate how the values relate to one another.
- Represents the quantities accurately.
- Makes it easy to compare the quantities.
- Makes it easy to see the ranked order of values.
- Makes obvious how people should use the information - what they should use it to accomplish - and encourages them to do this.

"When principles of design replicate principles of thought, the act of arranging information becomes an act of insight"

(Tufte, 1998)

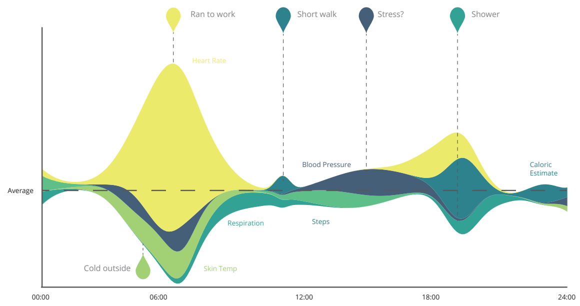
With the rapid development of the modern (interactive) web, more types of graphs have sprouted, which focus on aspects not possible on "paper ones", such as interactivity. Being able to zoom in on and filter data in realtime has made data analysis much easier. These new "interactive" graphs are often derived from the classical ones. It is fair to say that data visualisation has developed into a field where tailored visualisations are able to communicate information more specifically than the "classical ones". Both designers and scientists are looking for new designs to spot connection between datasets more easily, e.g. by introducing novel interaction and visualisation methods.

Tools for visualisation

Designers like tools, especially when they allow to "skip the boring stuff" and jump right in. However, every tool is tailored to allow a specific fidelity of result and requires a particular level of expertise to handle the tool itself. These two parameters are closely related and define what tool to use in a given situation. I'll describe some of the tools I worked with and what scenarios they're good for.

Illustrator

Adobe Illustrator is one of the few programs that you can use to directly create a data visualisation, focussing on the visuals appearing on screen. By dragging and dropping shapes on screen you can create a custom visualisation by hand. However it involves a lot of extra calculating from your side. Illustrator has some data-related features, but these actually limit the creative potential of Illustrator itself to make interesting data visualisations.

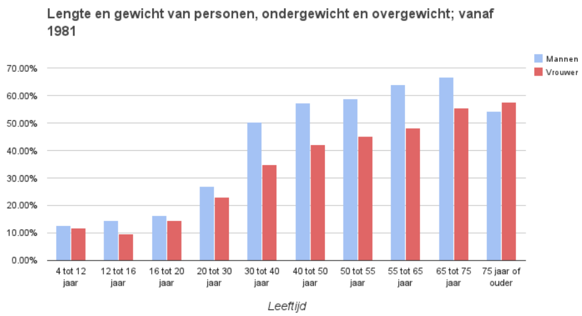


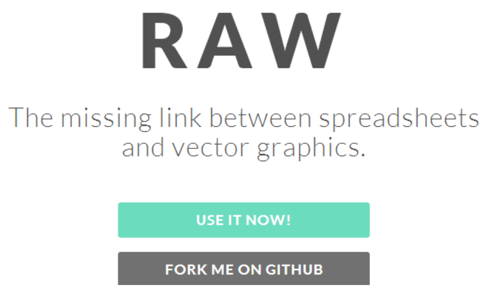
Excel/Spreadsheets

The standard tool that a majority of people use when working with data. Excel can quickly generate a wide range of graphs (visualisation) from datasets. It requires no programming, and it's included in a program that people already use to manage their data. A downside to these spreadsheet programs is that they don't allow for custom visualisations that might fit better to the data you're currently working with. Also, some of most popular features (3D bar charts) are strongly contradictory to what is considered a "good" data visualisation. The ways to customise the generated graphs inside the software is quiet limited as well.

RAW

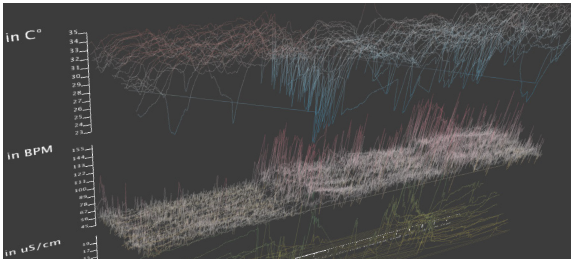
Raw *(Density Design, 2013)* is an online tool that allows people to quickly create interesting visualisations from raw data. It offers visualisation types that aren't included in standard office packages like Excel and it doesn't require any programming skills. For that matter, it is actually the perfect tool to get a high-quality result with minimal effort.





Processing

Processing is widely used for making creative and interactive visualisation. *(Fry, 2013)* You can completely define the way you want to visualise something from the start. There is no fixed library or approach to take into account; you can make it as complex or as simple as you desire. The building blocks for working with data are there; functions to easily read data from files, and to easily draw shapes on canvas. The downside of this approach is that it might take a while before you have your desired visualisation, so it is best used for "final solutions" rather than prototyping.



D3.js

D3 is a framework for 'Data Driven Documents' *(Bostock, 2013)*. It can be used to turn structural information from a document into visuals. The power of the framework is it's extreme flexibility which allows for interactive visualisations, meaning the user can influence what is shown on screen. However, the downside is that you need to be an experienced programmer to access the complete potential of the framework. It is relatively easy to adapt one of the many examples to use your own data.

Data-Driven Documents

Reflection

A wide variety of tools is available to create data visualisations. Some of these tools are rather specific in what they're able to produce, but provide the user with an easy to use interface and simple steps to reach this. Others are more advanced, serving as a framework for designing new kinds of visualisations.

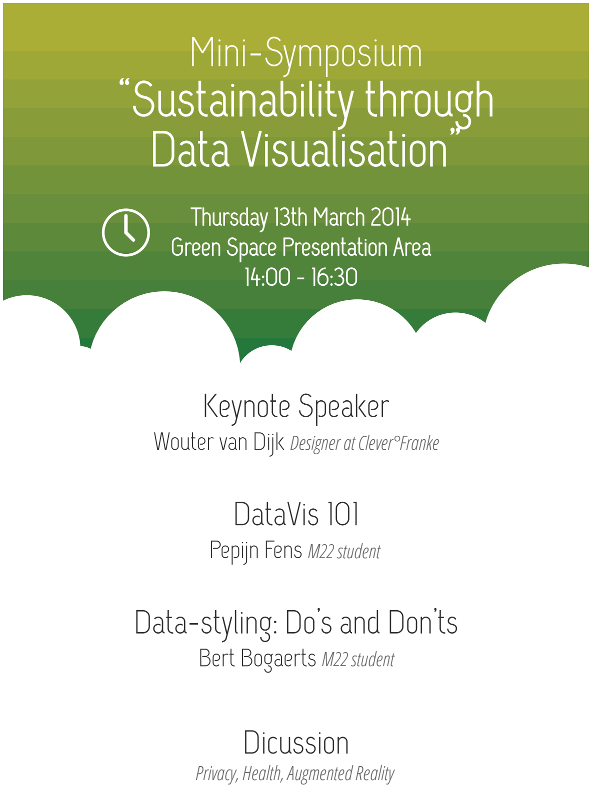
I am looking for new ways of visualising health data that will be more intuitive for people to understand, therefore using the more advanced tools, such as Processing and D3 will give me more freedom to explore such new visualisations.

Data visualisation symposium

In order to exchange experiences about data visualisation in general, I have turned towards the design discourse. In this case, fellow ID students. During a small symposium we discussed the role of data visualisation within a design process.

I spoke about simple tools to create visualisation from data sets (Datavis 101 in the poster on the right). Additionally I discussed whether visualisation is just a means to get somewhere (e.g. new insights, validation), or whether it can also be a goal in itself. Especially in a health context, where “being healthy” is a clear goal, how important is the visualisation of one’s progress towards “being healthy” and how to visualise this?

During the discussion I learned how some concepts within visualisation are able to provide users with a better understanding of their data. For example through the use of benchmarking; putting data in context of other data to enable comparison with people of the same age and the same gender for example.

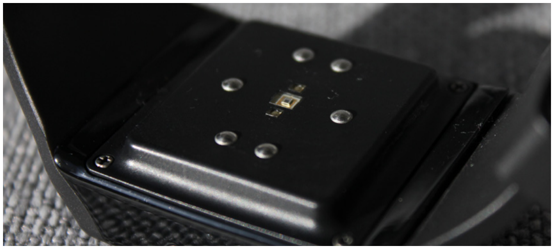


Exploring & Probing

Self-study

To find out more about my daily rhythm from a physiological perspective I initiated a self-study. Gathering the data has been done by wearing an activity tracker (Basis B1) for several consecutive weeks. The activity tracker is able to continuously measure with a resolution of one minute. To get better insight into the data the band collected it was necessary to get access to the RAW data. I was able to download the data from the product's service to using a tool created by Quantified Bob (2013). In turn, an interface containing different visualisations of the data was developed. More information on the technical aspects of how I have obtained and visualised the data can be found in appendix A. The resulting interface is used during evaluative user sessions.

When skimming through the data visually I noticed how some parts of the graph stand out from the rest. Sometimes this is caused by repetitive patterns, other times this is due unusually high or low values. However, using only the data available it was difficult to define the source of these striking features. For example minor bumps and typical fluctuations in skin temperature can originate from both internal processes and external influences like the weather. Some of the curves in the graph look very similar from each day to the next; I assume that these curves



describe a personal circadian rhythm. I assume that every single person has its own "rhythm".

All in all, the data lacks a frame of reference, since I don't have other data to compare against. Does it tell me I am healthy? Are there any structural abnormalities present? I can't tell by looking at this isolated dataset. I can only tell something about it by comparing it with someone else's.

Graph View: In the figure above, the graph is shown how the user sees it during the evaluation. The three signals are joined in a single graph, but the user will have the possibility to zoom in on specific parts and hide individual streams of data.

The Interface

The interface to browse the recorded data has been designed with some functional requirements in mind. First, the user has to be able to see the various data streams all at once, and be able to zoom in on a specific time-frame. Second, the user should be able to make annotations on a specific time-frame. These annotations can be about an activity that has been performed at that moment in time or about a specific contextual clue that would remind the user about this specific moment when reviewing the data. Other than these basic functionalities, the interface contains several different views, which visualise different datasets. The “main” view is the graph view. This is where the raw data is plotted in graphs, each graph having a distinct color to distinguish between the different streams.

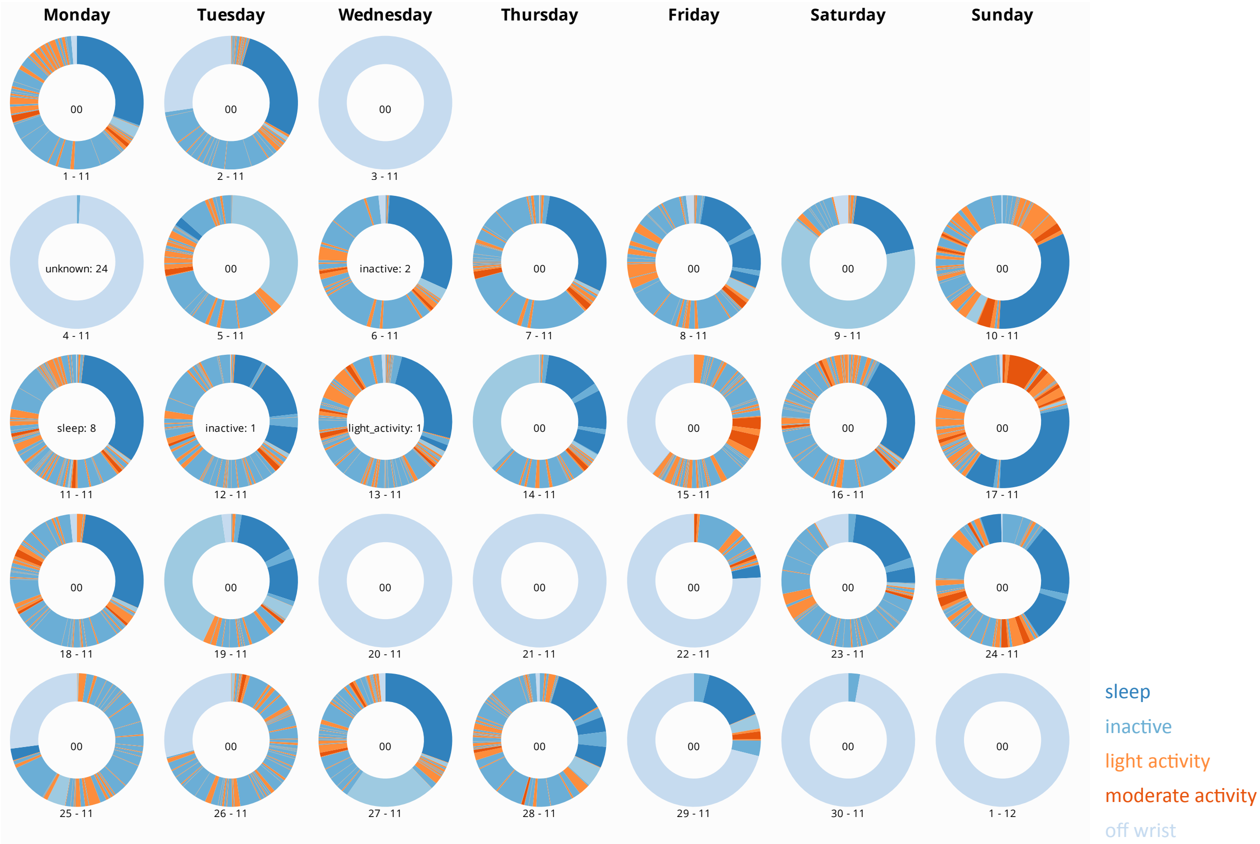
The second view is the “profiles” view, showing graphs representing average values on a particular time of the day. For instance, when I am always outside around 9 AM, my average skin temperature will be relatively low in this graph. This way of representing data reveals a lot about structural habits ingrained in our behaviour.

Finally, there is also a “body states” view, visualising the various states (inactive, sleep, moderate activity) during the day in a calendar-like format. From this view it is easy to derive the amount of sleep during the night or the “general activity level” of a day.

A last view on all data collected during this project can be found in Appendix B.

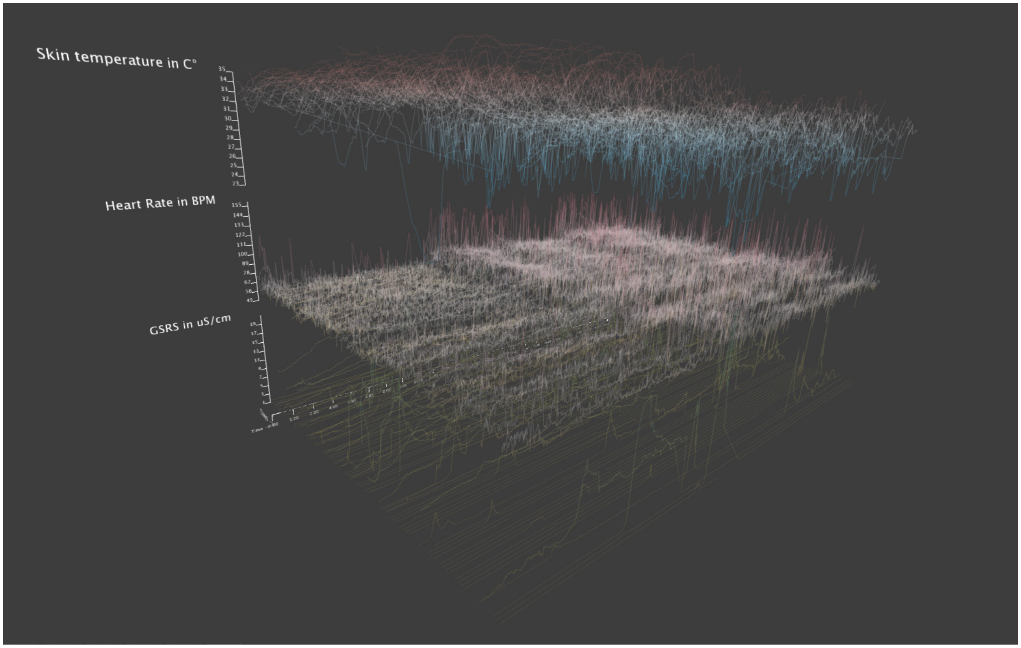
Reflection

Granting access to data by means of an interface is a first step to creating an understanding about health. It is however not the ideal way of communicating this type of data. I’d like to gauge the understanding of this type of communication with potential users by means of a test.

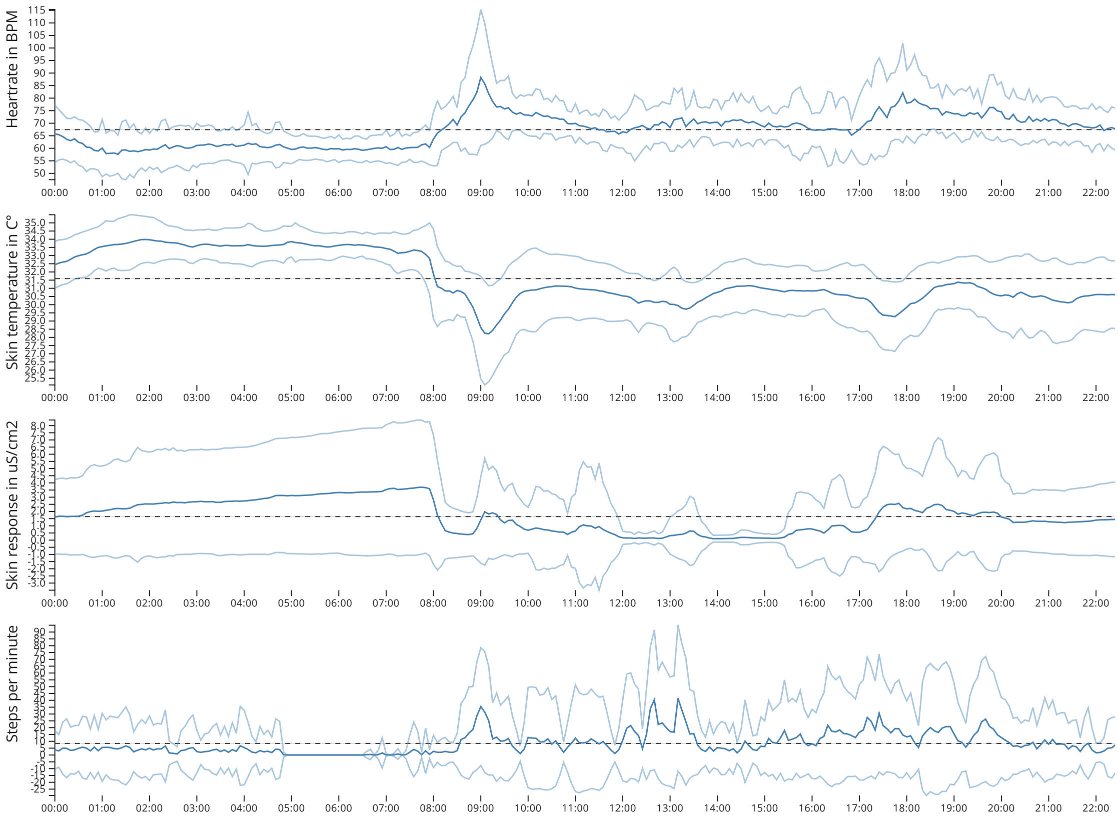


Body states View: This figure shows the distribution of body states during the day. They're represented as 'small multiples' in a calendar view to allow the viewer to quickly find patterns. As can be seen, the Sunday is being used as a true " resting day"; sleep has been shifted forwards in time and lasts longer than the sleep states during the week.

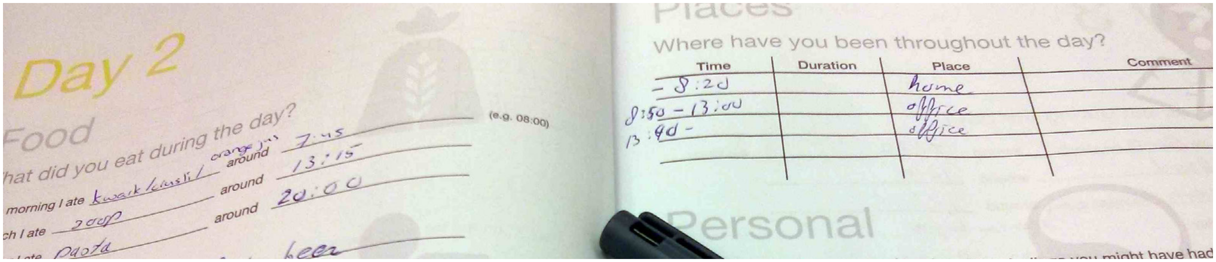
(The lightblue parts are time spans of which I do not have the data)



Using Processing, the data can be layered in 3D space for a bigger overview of the various patterns throughout the day.



Profiles View: The figure above visualises the daily pattern of physiological parameters. The dark blue line is an average of measurements done at a specific time, while the lighter lines show the standard deviation. These graphs are unique for each person. In this case, heavy fluctuations around 9AM and 5PM suggest that the graphs belong to a 9 to 5 worker, who often travels from and to work around these times.

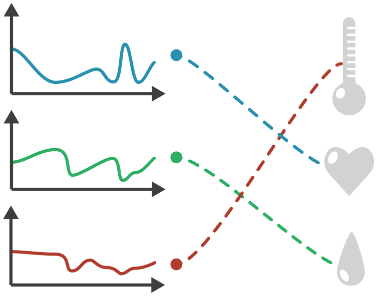


Diary Study

To validate my assumptions about data collected by digital health wearables and to probe for other opinions I prepared a study. It is focussed on the (future) user aspects of digital health devices. Using a diary study approach, I let people experience a "digital health" device that is able to monitor an elaborate amount of information without interfering with the user's daily life. According to Rogers et al. in Interaction Design (2011), *"Five to twelve participants are the norm for diary studies*". The data gained from these studies is qualitative, which means I will look for patterns in the results afterwards. It is also possible that intermediate outcomes inspire new insights in the user.

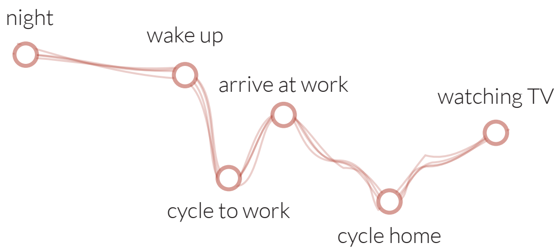
Participants to the study receive the same activity tracker I have used to capture my own data (see previous chapter).

The participant will also receive a booklet (the diary) containing questions about his /her day. These questions are contextual, for example: "What have you done today?" or "How do you feel?". Filling in this booklet serves two purposes. First, it forces the participant to actively be involved in this experiment and to reflect on his daily activities. This is helpful for the second part of the test. Second, the data from this booklet can be compared with the digital information, allowing for insights into one's feelings (written down) and the objective measurements (sensor data).



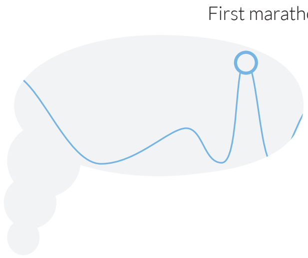
Mix & Match

Result graphs will be shuffled and their labels will be removed. Participants will have to match the graphs with the correct signals.



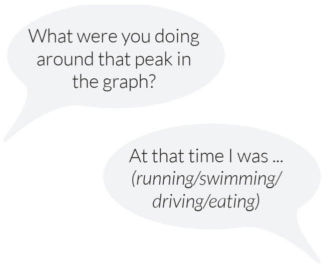
Descriptive curve

Next I want to find out how descriptive such a curve actually is. For example, heart rate follows a strict daily rhythm while skin response curves tend to be rather random. What curve/combination of curves describes your average day best?



Storytelling

Furthermore I think health data can be used to recall memories. Is it possible to recall what you did during the day based on a line graph? And is it possible to recognize what a stranger did when looking at a line graph? What other data is necessary to make the story complete?



Discussion

Finally I want to discuss the data with the participant. For this purpose I have created a visualisation utility. We will be looking for similarities between measurements (peaks, interesting deviations) and try to match those with the qualitative data from the booklet.

User Insights

In view of time, the diary study has been done with 4 participants. The participants vary in age and lifestyle as to get a broad picture on participant's habits. Participants are in the age range of 25 to 43 years old living an "average" to "very active" lifestyle (self-declared).

I have clustered the information from the interview into subjects, trying to find the most common "themes" throughout the user study. The results are represented in the visual on the right.

In general, participants who regularly performed one or more sports were interested in the ability of the watch to gather heart rate data during sports. This proved to be disappointing in all mentioned sports, since the heart rate measurements suffer from heavy motion artefacts.

Another recurring subject was sleep. Since the watch has been worn during the night, the data offers a window into one's sleep behaviour. From the interviews I notice how sleep is still a poorly-understood phenomenon for most people. The consequences of a bad night sleep however, were visible in measurements the day after; a heightened skin temperature was visible in one particular case.

All participants were like-minded about privacy. All objected the idea of uploading the data together with additional personal information to the cloud, even if this would mean gaining greater insights in the long run. It's unknown if this is a typical attitude for the subgroup of people researched, or if this attitude is shared by a greater group of people.

My aim was finding out if elaborate tracking of lifestyle combining sensor and contextual data is a valuable thing to do. I see some possibilities for specific applications but in general the 24/7 monitoring of physiological parameters is an extreme approach to dealing with personal health. Additionally, adding contextual information in a booklet doesn't seem to motivate people to 'go the extra mile' to discover the connections between their physiology and what they actually do on a daily basis.

Lifestyle

Lifestyle aspects discussed

Eating Habits;
does being a vegitarion result in different data?

Travel to work by car versus taking the bicycle

Walks during Lunch

Stress

stressfull moments identified during reflection on data

Is this work related?

Not always apparant in data

Sleep

Skin temperature rises during day caused by bad night sleep

Health

Aspects related to health

How does sickness influence measurements?

Heart Rate

Good performance measure in sports

Fatigue

Influences physiology during the day

Visualising

Reading graphs during evaluation

Recognising blank graphs is difficult

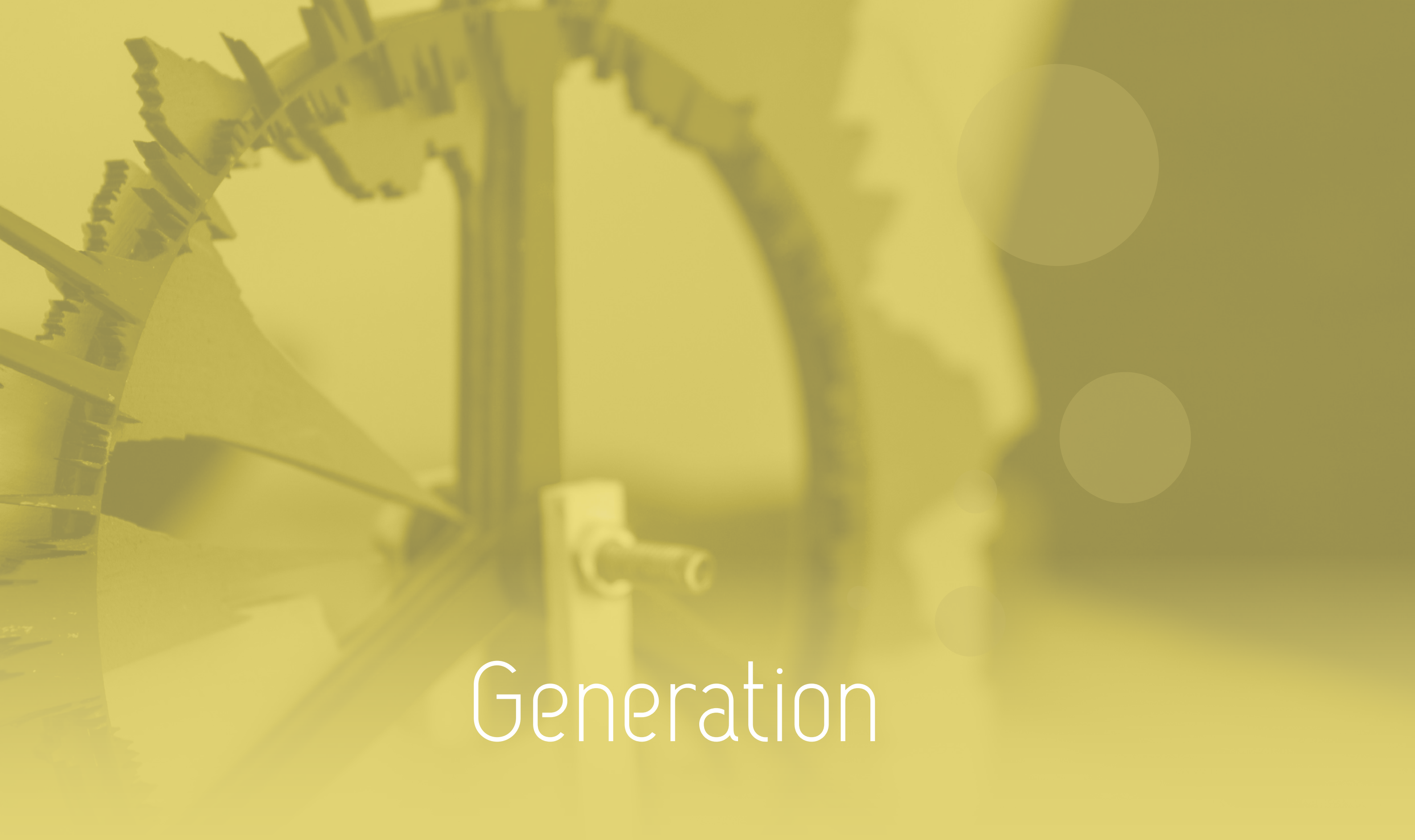
Colored graphs with axes and annotations trigger stories an curiosity.

Heart rate graph is very noisy, caused by noisy sensor

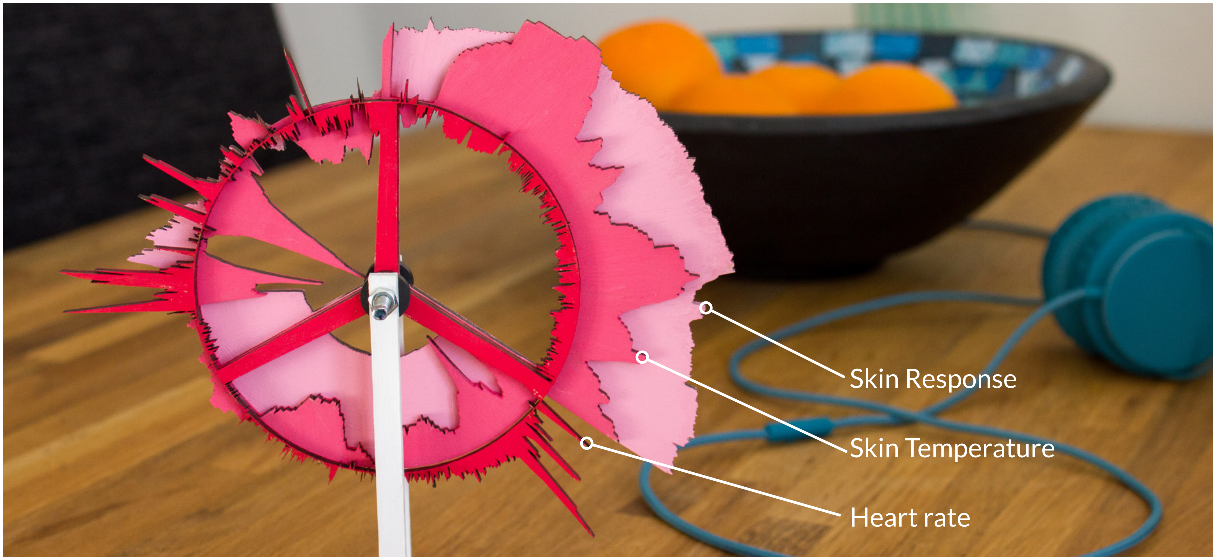
Privacy

Who will see my data?
What will they do with it?

Nobody wants to share data with third parties
"The product is not to be trusted"
"I wouldn't like to upload my data"



Generation

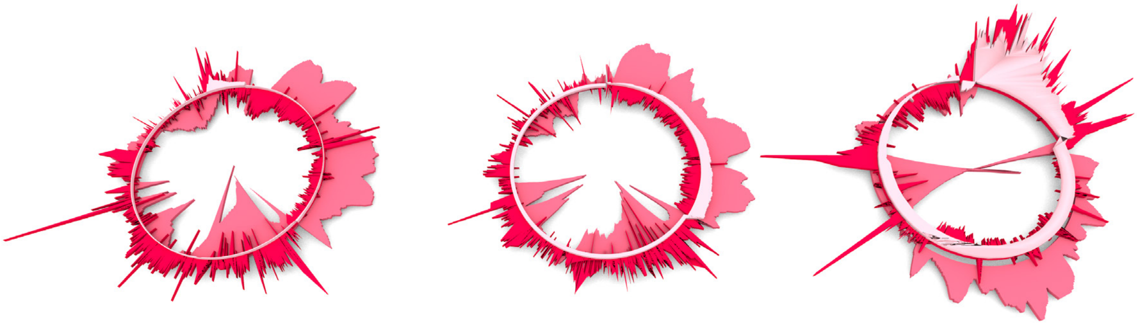


Tangible Visualisation

I decided that the visualisation based on radial display of skin temperature, heart rate and skin response had the potential to iterate further upon. Circular display of data feels intuitive for people, since it mimics the appearance of a clock. I want to find out if a tangible display of this data would make it feel even more intuitive for people to read the data.

For this purpose I created a tangible version of the radial data display; displaying exactly the same information as the virtual, on-screen one, but now created from stacked and laser-cut MDF wood. The result of this activity is a small artefact displaying the information in a tangible way. The prototype shows 3 datasets, namely the heart rate, skin temperature and galvanic skin response. It shows these sets in relation to their mean; the graph will be inside when it is below, and outside when it is above the mean value. This way of visualising results in the distinct peaks; for example, a big peak to the inner side of the circle means the signal deviates a lot from the average at that particular time.

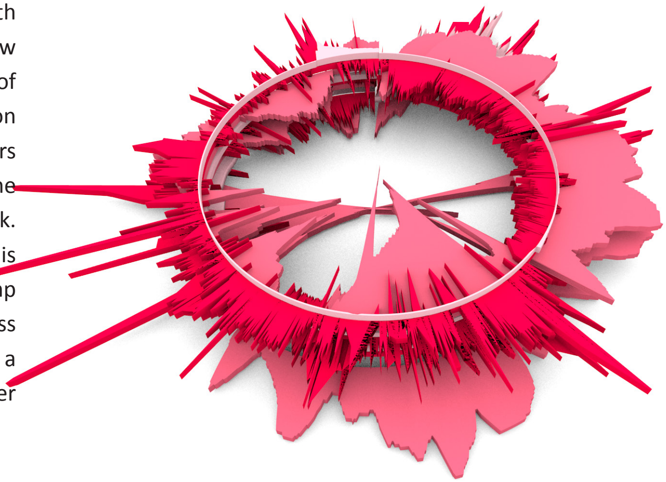
To me, the tangible display of such data feels intuitive, but

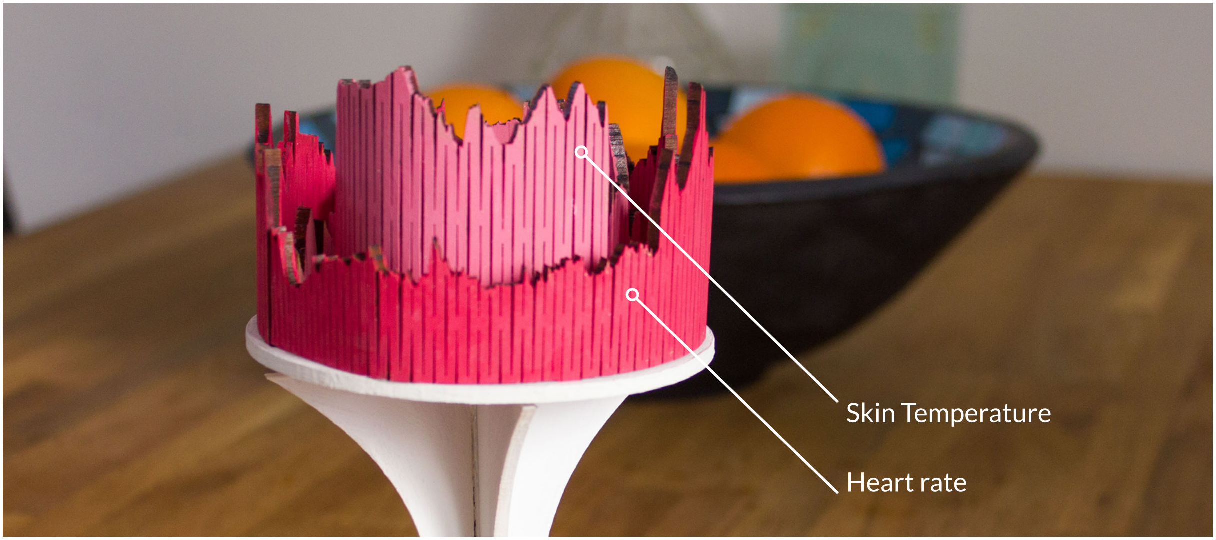


it's still early to say how other people interpret the artefact's shape.

The artefact displayed in the image above provided me with food for thought for possible health-related services. *"Discovering health through making"* is one of the ideas. It revolves around the idea of creating a personalised product by keeping track of your health. This will add a rewarding element to the experience of keeping track of one's health and moreover, associate health tracking with fun. So how does it work? The user receives tangible visualisations of his health once a week. These visuals will be produced on laser cutters in the area, based on the health data users send from their accompanying wearables. Each week the visual shows the average results of the user's past week. By stacking these visualisations of each week, the user is creating a personal lamp from these objects. This lamp serves both as a symbol for perseverance and the progress of health over time. In addition, now the data has taken a physical appearance in space, which might trigger the user to change his lifestyle for the better.

Top*: 3D renders of various datasets. As can be seen, the shape of the visualisation changes per day.*
Bottom*: Stacking the various daily visualisations creates a 3D structure. It looks interesting, but it is difficult to read.*

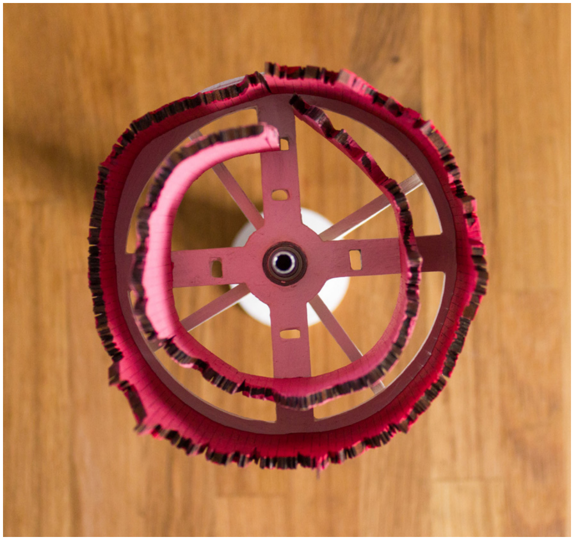




Tangible Visualisation #2

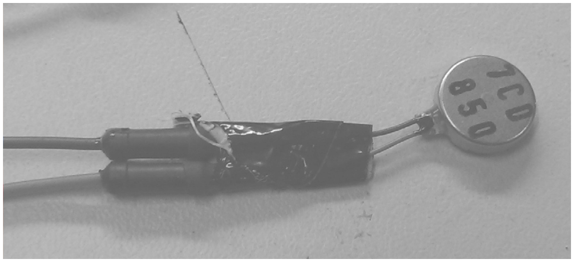
Based on the result of the first exploration a variation on the first prototype has been made. The second artefact is based around circular display as well, however uses a different axis to rotate around. Different datasets are displayed as rings with different radii; the height of these rings represent the value of the dataset at that particular moment in time. Because of this, the interaction with this artefact is different. It isn't possible to view the complete dataset all at once, only one part of it at the time. Scrolling is therefore a necessary interaction with the artefact to be able to view the complete dataset.

All in all I argue this artefact does a lesser job in communicating the data effectively. On one hand this is because the mapping of the data is different (I don't use a mean value here with peaks that derive from this value, on the other hand this is due to the shape, which does not allow the user to perceive the complete "data-landscape" in one view. This makes comparing different points in time more difficult. A scroll-interaction on the object is not desirable,

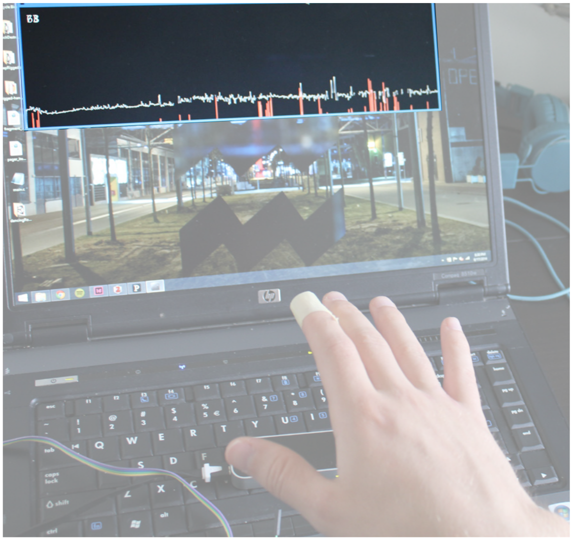


since It makes comparison of data more difficult. Interaction with an artefact however, creates a feedback loop between user and object and therefore can be a powerful tool to let people engage with prototypes. From this perspective, a scrolling interaction with the artefact can actually increase the user's understanding of the data, by adding feedback on user interaction.

Based on the previous two prototypes, I am inclined to continue on a dynamic way of visualising data. I like the static appearances of data sculptures, however they are difficult to work with in the context of "intelligent systems" and "user interaction".



Tactile "Visualisation"



To further explore ways of communicating data physically, I have looked at other senses. Tactile feedback for instance, provides an interesting alternative, since the human body is one tactile sensor with varying degrees of sensitivity. Objects inherently have physical aspects which means they have tactile properties that people can utilize to "read" the data. A deliberate tactile solution in the form of a small vibration motor can provide this kind of feedback in a direct way. Moreover, a tactile actuator can provide dynamic feedback while a physical artefact can only provide a fixed set of "tactile stimuli".

In this prototype, the user is able to scroll through a data set (in this case, heart rate data) while the actuator provides tactile feedback in real-time in the form of a heartbeat. It seems that this way of communicating heart rate data makes people understand more of their heart rate than when looking at a line graph on a screen. Heart Rate data seems to be suitable for translation into tactile stimuli because of the physical nature of heart rate data itself. Not all data can be easily translated towards tactile stimuli.

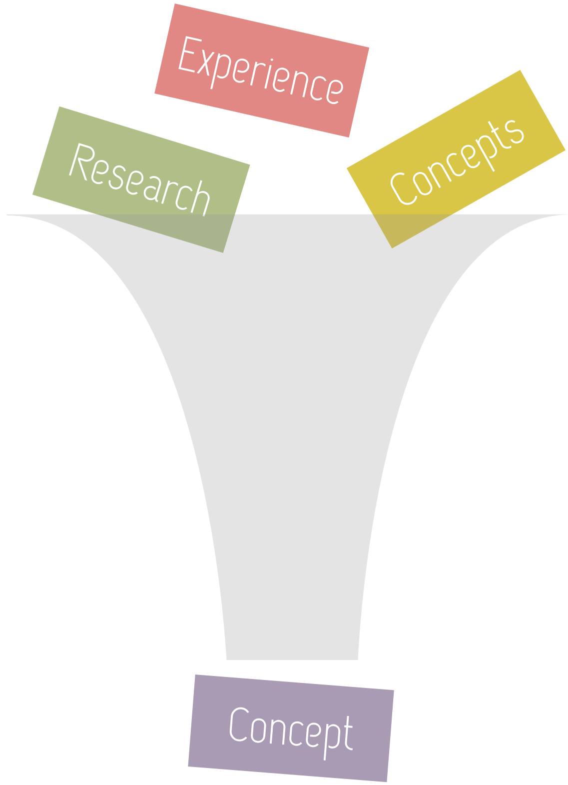
In conclusion, not all data is suitable for display using tactile signals. However, tactile feedback can function as a additional stimulus to augment visual cues dynamically.

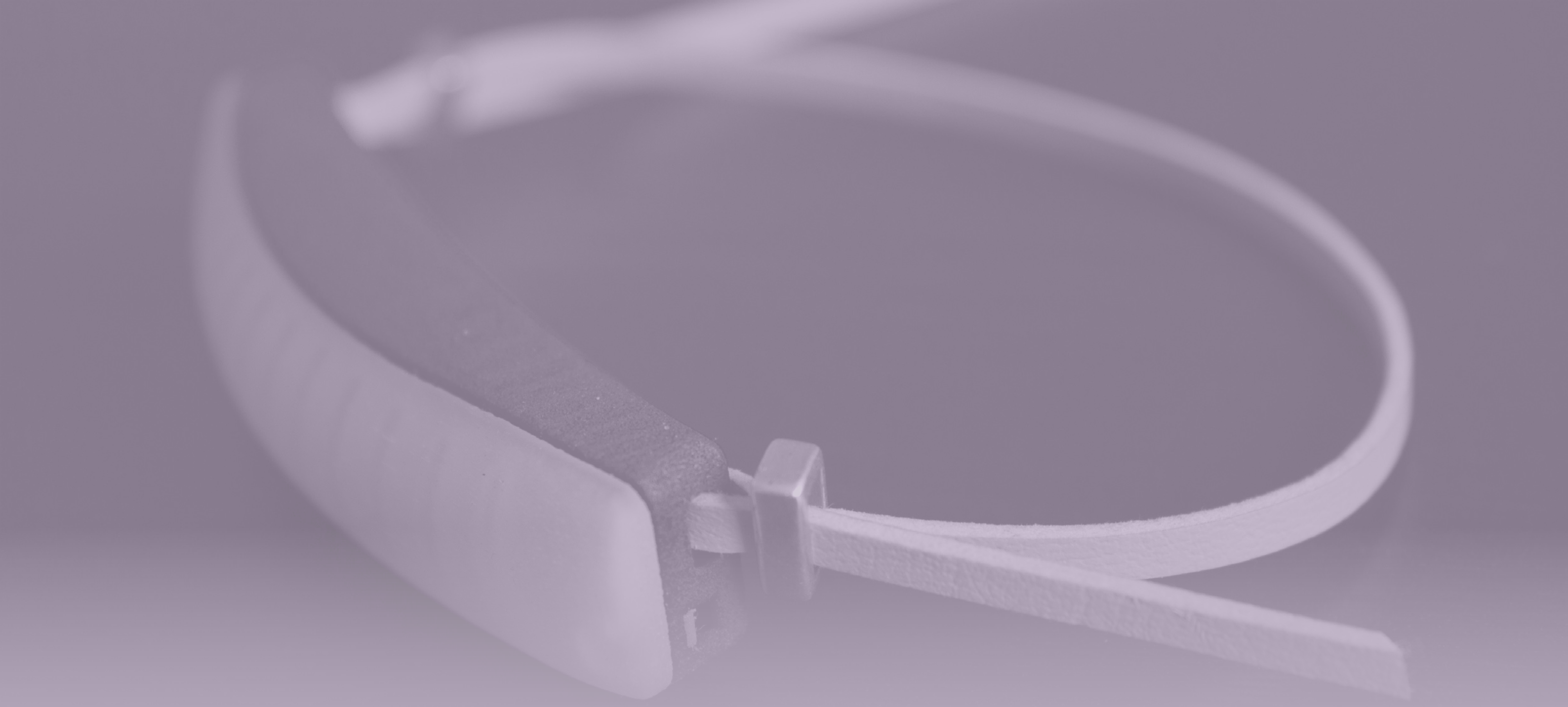
Towards an integrated solution

During the various explorations and experiments the following insights have surfaced in relation to personal health:

- Health data comes in lots of different forms. Not all data is immediately valuable and understandable by the people that can possibly benefit from it.
- Even personal health trackers currently on the market, such as the Basis B1 struggle with the problem how to make the measured data meaningful for the user. This mostly has to do with context; how to create a context in which the data can valuable to the user.
- The way data is communicated to the user is an important aspect in creating "value" for the user. This can be done using digital communication methods, but physical/tangible modalities also play a part here. I have compared various modalities of displaying data in a research paper to show how this influences the perceived value of the data *(Fens & Funk, 2014)*.

In the following chapter I will show how these various aspects can be integrated into a product concept.





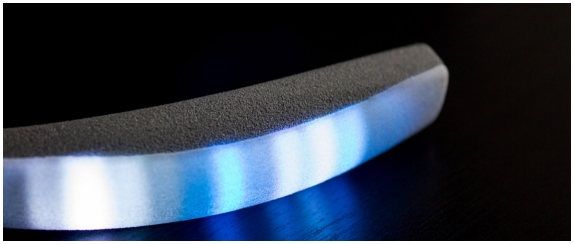
Concept

Qualica

Throughout the day people often experience a series of different contexts; one wakes up at home, goes to work, maybe go for sports and relaxes. Within these contexts different information flows can be important to the user. A smartphone typically shows all information all the time, making it difficult to distinguish valuable information from the “junk”.

Qualica displays personal health information in a contextual way. It is a simple product that lives outside the user’s direct attention and is able to communicate important data by means of light patterns. A small array of light takes care of communication back to the user. This keeps the displayed information simple.

Users can easily glance at the bracelet for information



The casing diffuses the light in a barred pattern

Personal display

In theory, everything can be displayed; from WhatsApp notifications and emails to new Twitter followers. Integrating such functionalities would make it feature-wise comparable with what smartwatches are currently doing. However, Qualica focusses on health- and behaviour-related data to provide insight in one’s life rather than acting as a “*platform for distraction*”. It is this restriction that sets the product apart from smartwatches and smartphones; this device provides insight in one’s health and factors that contribute to this, rather than bluntly displaying a constant stream of notifications throughout the day.

Data sources

Qualica aggregates data from multiple sources in order to provide the user with a contextual visualisation in various situations. The figure on the right shows 5 categories of data sources that are addressed to gather this data.

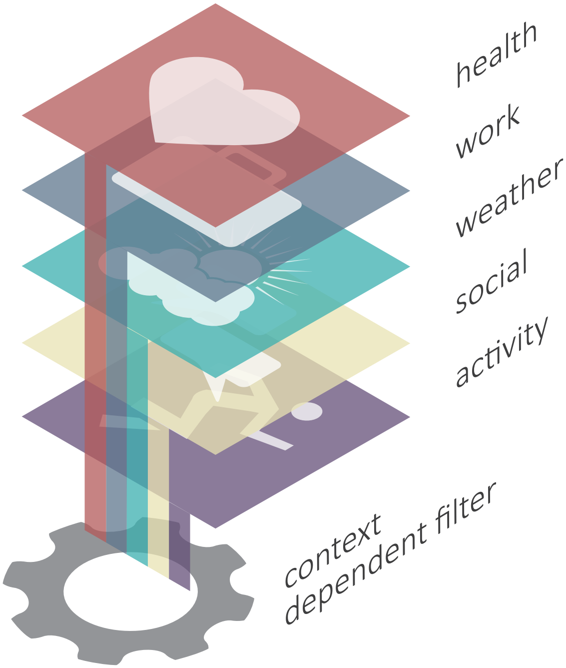
First one is health data, which can be gathered from smartwatches and activity trackers, such as the Basis B1 that is used during this project.

Work related data can be gathered from productivity software such as RescueTime for desk jobs, or comparable work-monitoring systems.

Weather data can be downloaded from the internet in real time using Forecast.io. It provides information about hours of sun, millimetres of rain and humidity at a give time and location.

Social data is all data related to social media; think about Facebook, Google and Twitter messages.

Activity data is related to health data, but is more specifically tailored for sports. Activity data is often run data, providing information about the speed and distance of the runner. This also works for different sports like cycling.



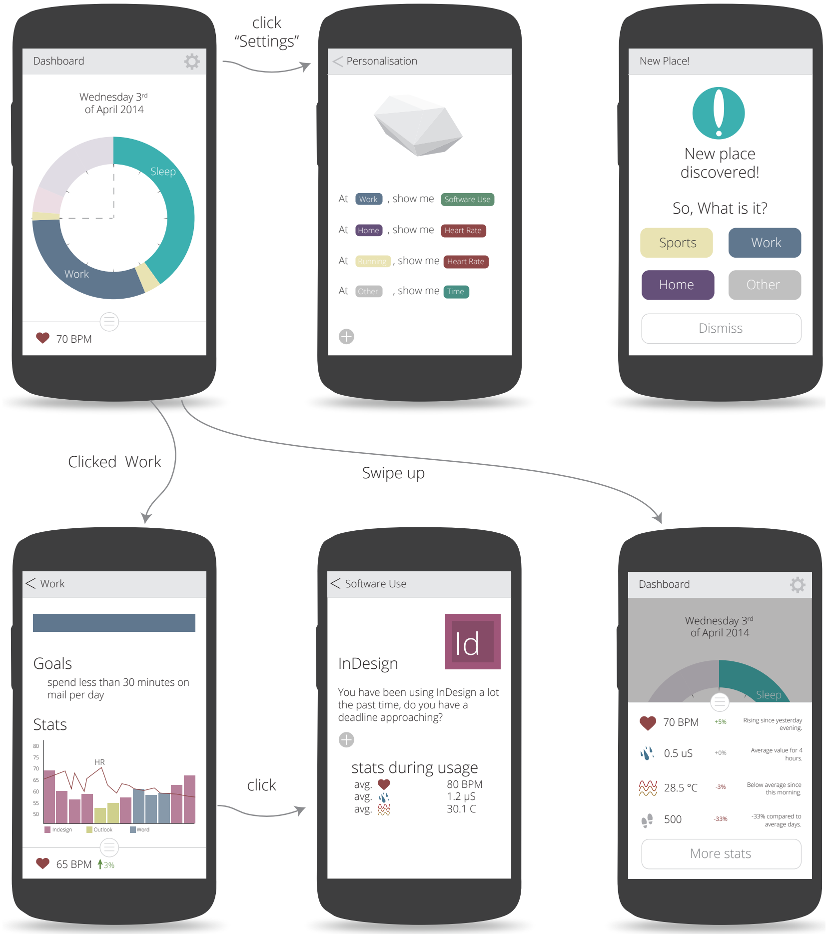
Data from different data layers serves as an input, but depending on the user's context only one data set is used.

Taken together these data sources contain a lot of information about one's life. However, as stated before, it isn't interesting to display all data all the time. A context dependent filter therefore ensures that in a given context only small "valuable" pieces of this data are shown.

Connectivity

The product works in combination with the user's smartphone. The sensors in a smartphone are an important source of information to determine the user's context. Additionally, the smartphone app can be used to explore the various datasets further. In the picture on the right can be seen how a user spends his time at work and how this influences his physiology.

Using the app it is possible to teach the bracelet about new contexts. A notification will be given when users are at new places and they will be prompted for what the default behaviour in this place should be.



Using the app, that comes with the Qualica device, the user is able to drill down into the gathered data.

Platform

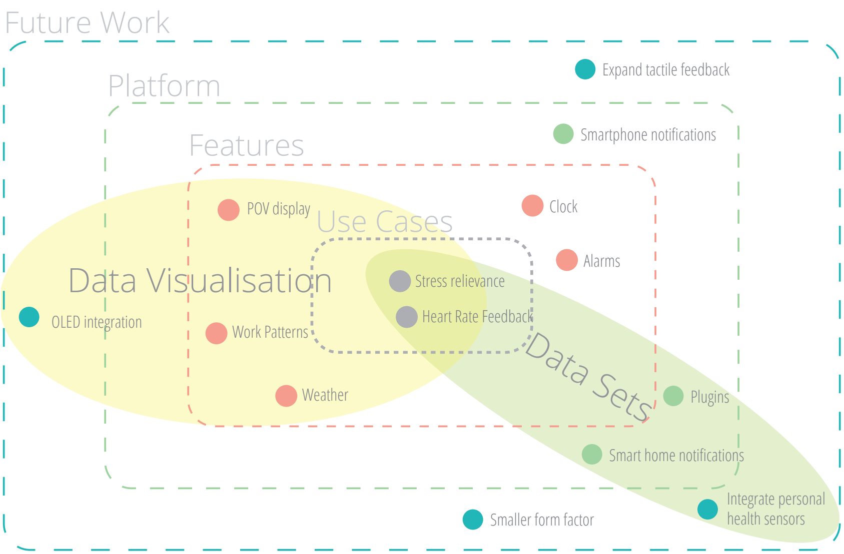
Essentially the device is a wearable display; the more functionalities it provides, the more useful it can become. However we should keep in mind the core function of the device is about health-related data. The connection with a smartphone allows it to act as an information display for virtually any app the user has already installed on his smartphone. This broadens the application space of the device. While it is tempting to further analyse this direction, I will focus on the new experiences this device brings in the personal health and well-being context.

Applications

Throughout the day the device is able to provide the user with contextual information. The following features are part of the standard functionality.

Weather

Weather has always been a valuable information source to carry along throughout the day. Some decisions made during the day, are made based on weather information. Should I take an umbrella? Should I cycle to work today? For this purpose, the display of weather information has been integrated. Using elegant and subtle animations weather information can be displayed at any time of the day.



An overview of the possibilities within the platform and the aspects I will be focussing on (Use Cases).

Clock

The clock features a simple way of displaying time on the limited space available. The need to track time has been a basic requirement for any intelligent and wearable product

Contextual Alarms

Adding to the clock functionality of the device is the alarm, these alarms shouldn't just trigger on "time", which is what traditional alarms do; but could benefit from the extra functionalities this device has in comparison to more traditional wearables. If it is able to "know and understand" the user's context, then it should also be able to give alarms based on this additional information. For example: "alarm the user when it has been working with software X more than 4 hours" or "alarm the user when leaving work, reminding to visit the supermarket on his way home". This should also work the other way around for not alarming the user in particular contexts or locations, such as: "Don't alarm the user when in a meeting", or "disable all work-related alarms when user is at home".

Work Visualisation

During office hours the device can serve as a display for work related information. For example, information from productivity software such as click time can be displayed, creating a real time display for insight into work habits.

Physiological visualisation

Visualisation of physiological parameters in general, can be used to provide more insight in one's health. For example heart rate, skin temperature and galvanic skin response can be shown by the device. Historically, these parameters have always been measured with great precision using medical devices, so it feels counter-intuitive to start displaying these using a very low-resolution display. However it can be interesting to find new ways of displaying this data using low resolution displays that can be equally accurate in communicating this data.

POV display

It can be used as POV (Persistence of Vision) display, allowing the display of text and more elaborate information, using just the available 8 LEDs. An accelerometer should be added to provide the proper calibration of this feature, but the theory behind this feature has already been tested multiple times.

An interesting possibility for wearable POV displays is the sending of highly temporal text messages in public spaces. One quick swipe with the arm could shortly display a personal message in mid-air. This could give a more physical dimension to apps already providing highly temporal messaging, such as SnappChat *(Snappchat, Inc., 2014)*.

However interesting this direction is to pursue, it isn't related to personal health and well-being and therefore I'd like to leave it at showcasing this application to show the added value of a platform.

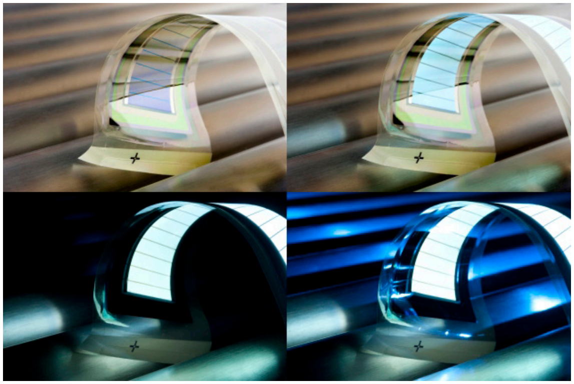
Future Work

Future display technology

Currently an array of RGB leds is used to display the information. I have studied alternative display technologies, looking at what the future brings. Within Holst Centre, TNO is working on applications for OLED lightning. I have discussed the possibility of integrating OLEDs in the Qualica prototype with an expert on OLED technology, Tim van Lammeren. In comparison with LEDs, OLEDs are flatter and provide a homogeneous lightning across the complete surface. This is a more natural way of lightning than LEDs currently provide. LEDs act as point lights, which are very bright up close and usually reduce in strength quickly when moving away from the source. OLEDS emit light from the complete surface, which is comparable to the way skylight shines on earth; it does not light up one point, but homogeneously lights up large areas. OLEDs can be produced in different sizes and colours. In relation to the Qualica, OLEDs can replace the LED array to provide an even more natural way of communicating information. Additionally, integrating OLEDs can reduce the size of the product considerably, since they're only 1.5mm thick.

Smart Home notifications

With the rise of the "smart homes" more people rig their houses with intelligent sensors. These sensors can work in favour of one's health when monitoring toxic gasses and air quality. This kind of data can be particularly valuable to monitor in combination with one's physiological data, therefore visualising this data on the wrist is an interesting future application.



OLED prototypes by TNO (2014)

Use Cases

Apart from the standard functionalities of Qualica, this device focusses on making health data valuable. For this purpose, the following use cases will be extended further.

Heart Rate Feedback during running

The tactile feedback can be used to provide the user with tactile cues when it isn't possible to easily take a glance at the visual cues of the product. Running is such a situation; the runner is focussed, taking care of his breathing rhythm and posture. At the same time, feedback on his physiological parameters could help the runner to perform even better. This can be provided using tactile feedback, as a confirmation of the tactile feedback the runner already receives from the heart itself.

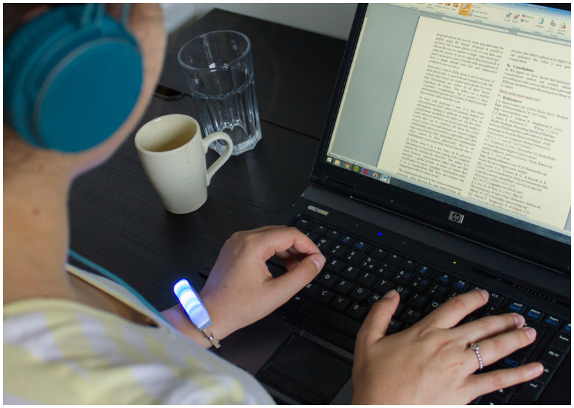
In case it is possible to glance at the wristband, visual cues can be used to display distance towards a pre-defined goal, or deviation from a pace pre-defined by the runner

When wearing the bracelet during casual sports it will display heart rate.

During recovery heart rate remains high for a few minutes.

Stress reduction in work environment

Combination of tactile and visual signals in a rhythmic way can be used to improve health and well-being, for example by reducing stress *(Dijk, Nijholt, van Erp, Kuyper, & van Wolferen, 2010)*. As such, the device can be used as a measure against work-related stress in office environments, by providing access to timely periods of "de-stressing" in an office setting. During these periods the device will start vibrating in a decreasing pace, based on the user's heart rate. Meanwhile, a tranquil animation will be displayed that confirms the tactile feedback and therefore provides a stronger signal.



During work sessions Qualica can indicate stress levels.

During a break, focussing on visualisations can have a stress-relieving effect, which is helpful at work.

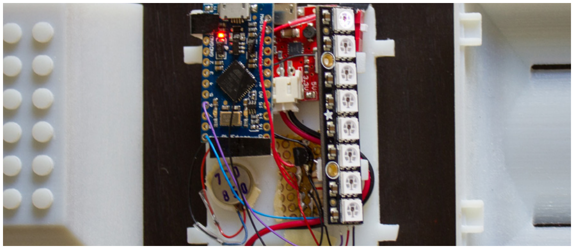
Validation

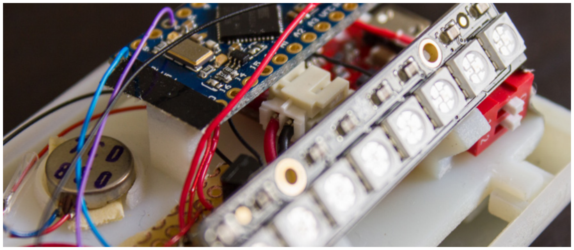
To dig deeper into some questions revolving the visualisation mechanisms of Qualica, a user test has been set up. It will answer the basal question: Are people able to make sense of visualisations on a low resolution screen (microvisualisations)? In our case, low resolution means, an array of 8 multicolored leds.

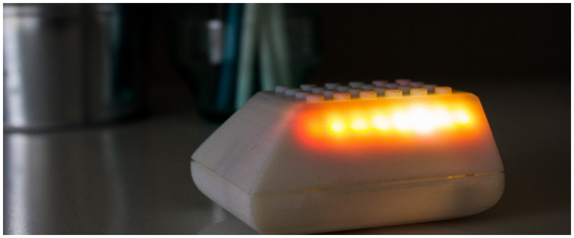
Prototyping functionality

To answer this question, a prototype has been made. The electronics have been assembled using various ready-made electrical components, such as Blueduino *(camealone, 2014)*, a LiPo (Lithium polymer) charger and a NeoPixel strip from Adafruit. These components together allow for a device that controls the 8 LEDS and communicates via Bluetooth LE, while being battery powered. Because of all these components the prototype's appearance does not match with the concept photos, however the test only focusses on the visualisations.

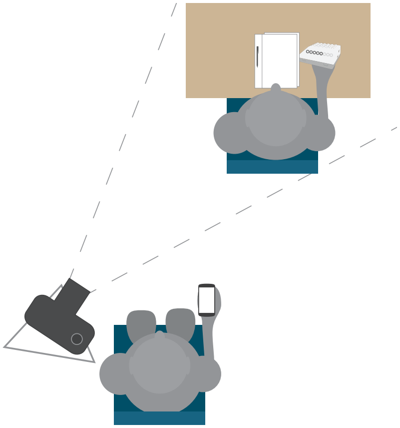
A casing for the components has been designed using Solidworks. It has been 3D printed, ensuring portability and making it possible to hold the prototype in one's hand. On the software side, the device communicates with an Android application to enable switching between various (pre-programmed) contexts. These contexts express themselves as various light patterns on the Led array.







Top to Bottom: Top view of internal components, Perspective view and assembled and functioning prototype



The participant sits at a table with the functional proto-type, the behaviour is controlled using a smartphone app

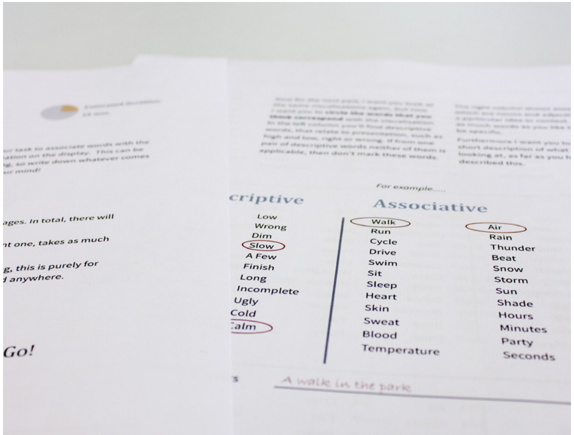
Validation Test

The use of "*microvisualisations*" in a wearable device to communicate information understandable to the user is hasn't been tested so far. Therefore, I set up an isolated test of these visualisations, combined with a survey and followed by an interview. This provides more reasoning why particular aspects of the visualisation are more clear than others.

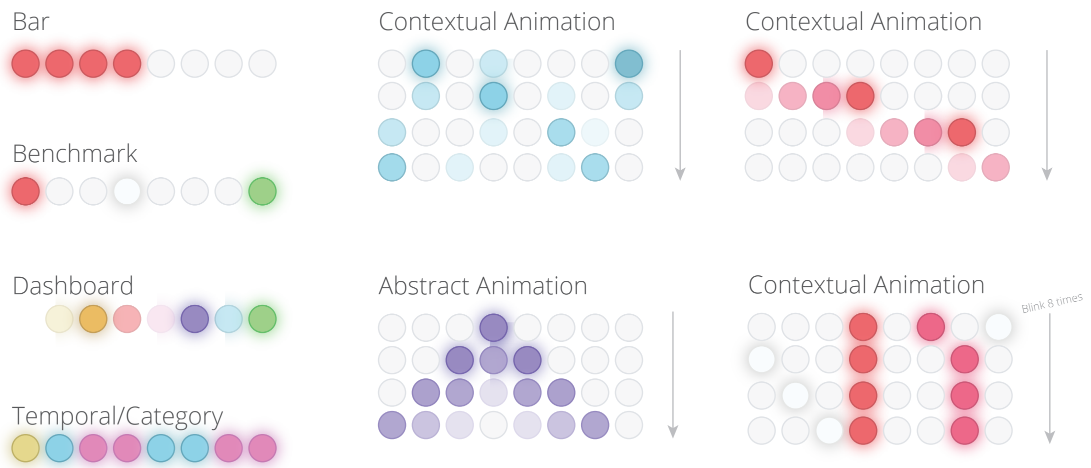
Procedure

The participant will be seated in a room and given the functional prototype in his hand. I will be in the room (out of sight of the participant) controlling the prototype wire-lessly. During the test, video will be shot from behind the participant, as not to distract while gathering information about the time it takes to complete the test and catch any auditory feedback the participant might give during the experiment.

Starting off, 8 pre-defined display methods will be shown to the participant (see Image and description on next page). The participant should write down any word that comes up in his mind regarding the display.



Participants receive clear instructions on paper before starting the test.



From left to right, test setting 1-8

Secondly, they will be shown again, together with a list of words to choose from. These words will contain concrete phenomena, such as "*rain*" or "*walking*" as well as abstract descriptive terms such as "*high*" and "*low*". Although the list of words contains quite some words, it is impossible to completely rule out the influence these words have on the participant, therefore their initial thoughts are already captured in the first round.

After these tests some additional questions are asked regarding the display methods. For example, what display method came across as most clear? And was it possible to quantify some of the graphics displayed on the screen?

Quantitative display methods

The following quantitative display methods have been tested.

Bar

Displaying a static quantity of something, such as the amount of steps. This is done by using the led array as a "bar" and filling the bar from left-to-right, based on the value that is displayed.

Benchmark

Display "you" relative to two other points (e.g. "good" or "bad"), or the majority of people and the minority of people.

Dashboard

Use each "pixel" in the array as a measure of a different data source, to create a quick overview of various parameters. For example, this can be done by using brightness of each pixel as a measure to communicate the value of these parameters. Another option is to use pulse frequencies to communicate the value, this would be appropriate when communicating heartbeat for example.

Temporal/Category

Using the bar to display quantities relative to each other; e.g. 4 yellow dots and 1 blue would mean I've spend 4 times as much time on activity "yellow" than I've spent on category "blue".

Qualitative display

Displaying qualitative information can be done by "l*eaving the numbers out*" and focus on the qualities that are displayed.

Contextual animations

Using a give dataset as a basis to generate representative animations. Such a display can be useful when trying to convey information that mimics other phenomena, such as the weather. When it's raining, generative raindrops can be shown to communicate "rain" in a qualitative way. When rain turns into sun, the display can slowly fade to a display of sun.

Abstract animations

Abstract animations have the same qualities as contextual ones, visualising abstract data using generative animations rather than relying on a strict translation of a value. However it does not mimic known phenomena but relies on more "abstract" display of these values. This can be helpful when displaying values that do not have a clear visual display. Also, abstract animations can provide valuable in a user test setting to find out what other people associate when looking at these animations.

Results

During the first round, participants could freely associate words. A notable amount of participants associated display number 3 with a traffic light and test 7 with water. These display methods seem to have strong cultural associations, since multiple people indicates this independently. This can either be leveraged to strengthen my application or it can be avoided to ensure these cultural associations don't conflict with my intended meaning of these methods.

A different result surfaced from the second round, where participants had to choose from a pre-defined list of words. Top circled words were often from the descriptive column (high/low) rather than the associative (temperature, clock). This implies that it remains difficult to associate the animation with a concrete phenomenon, even when given a limited set of options. Only test 7 has a clear associative word that received lots of notions, namely "*beat*" This is in accordance with my expectations, since test nr. 7 was meant to communicate a heartbeat.

In general it looks like the participants respond better to the contextual and abstract animations than to static displays. However, animated displays are perceived as being more active and attention demanding than their static counterparts. This is not always the desired effect, depending on the context the user is currently in involved.

Searching for meaning

The last test setting (8) proved to be difficult for participants. The intention was to visualise a clock mechanism, however, nobody interpreted the animation as such. Interestingly, this resulted in all kinds of far-fetched associations being done, from *"planets orbiting around the sun"* to a "*surveillance monitor"*. It's interesting to see how these simple animations can trigger such associations; it shows how simple animations can be used to communicate more complex phenomena, if done right.

Conclusions

Visualisations on low-resolution displays can be used to communicate information to a user. However, I suggest the visualisations should all be build from the same "visual vocabulary". The test used various vocabularies and this seemed to have caused confusion.

First Round results

1	
5	**2**
lego	2
flash light:	1

2	
traffic light	**7**
seasons	1
flag:	1

3	
disco	**5**
playground	1
stadium	1

4	
2 types of groups	**1**
hierarchy:	1
medicine capsule	1

5	
water	3
communication	1
migration	1

6	
power generated	**1**
movement & light	1
galaxy	1

7	
speed	**2**
fish	1
highway at night	1

8	
spinning planets	**1**
passing energy	1
car indicator	1

Second Round results

1	
high	**5**
cold	5
bright	5
balance	3
clear	2

2	
warm	**3**
alarm	3
temperature	3
complete	3
incomplete	2

3	
intensive	**5**
dance	5
music	4
beat	3
fast	3

4	
bright	**5**
pretty	4
complete	3
warm	3
calm	3

5	
waves	**6**
cold	4
sea	4
bright	4
pretty	4

6	
slow	**5**
dim	4
confusing	3
start	3
short	2

7	
fast	**6**
beat	5
bright	4
blood	4
heart	4

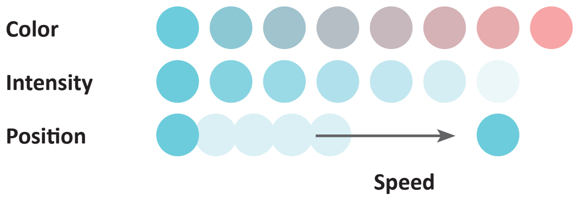
8	
slow	**6**
confusing	4
dim	3
distance	3
warm	2

Micro-Visualisations

A theoretical framework

As suggested in the previous chapter a consistent visual vocabulary would allow for more clear and understandable visualisations, especially when dealing with a low-resolution. To create a consistent visual vocabulary, a few dimensions have identified that make up visualisations.

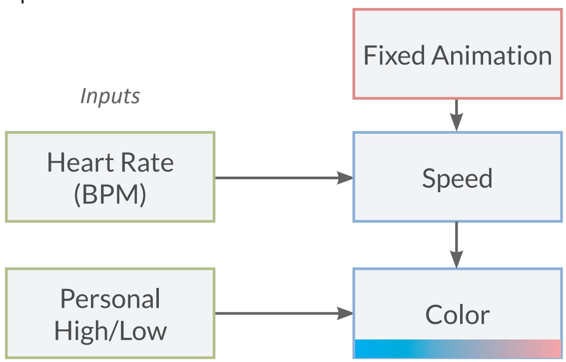
Dimensions



These consist of position, speed, color and intensity. We can map data to these dimensions in order to create a variety of visualisations with a consistent way of interpretation. Not all dimensions have to be used, as some of them conflict with each other. The best way to show how input data can be mapped to a visualisation is through an example.

Example

A rich heart rate visualisation showing both heart rate (in beats per minute) together with a personal judgement of the system whether this is closer to the resting or to the maximum heart rate (see “From data to visualisation”). This would look as follows, when writing it down using data inputs and dimensions.



A summary of a visualisation mode. It starts with a fixed animation, of which the speed is influenced by heart rate data and the color is influenced by which zone the user is running in.

Even though the starting point of this research has been health-related, these guidelines apply to other application areas as well.

From data to visualisation

Each dataset requires some sort of signal specific processing before it can be visualised. This is to ensure the visualisations are personalised. I will illustrate this using a few scenario's.

Heart Rate

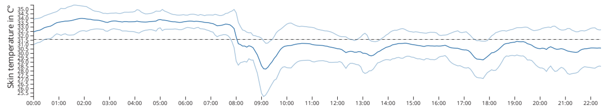
For example, heart rate is a signal that varies a lot from one person to another. To make this signal valuable to the user, it is important to establish the resting heart rate (H_{rest}). Next, it is important to know what the H_{max}, or maximum heart rate is. These two can be derived when continuously monitoring one's heart rate. Next, using these two numbers it is possible to define what the Heart Rate reserve is by subtracting these two *(M J Karvonen, 1957)*:

$$HR_{reserve} = HR_{max} - HR_{rest}$$

This number can be used to create personal exercises based on one's available "Heart Rate reserve". In conclusion, when visualising one's heart rate as shown in the previous section, one's HR_{rest} and HR_{rest} are mapped to a blue-red gradient, where $HR_{reserve}$ is a number that defines roughly the "amount" of exercise that one can handle. This ensures the visualisation is both personal and valuable, without displaying numbers.

Skin Temperature

In case of skin temperature, a similar calculation can be done. Typically a user wants to know whether his skin temperature is high or low, relative to his own average. Skin temperature is closely related to the user's circadian rhythm *(Refinetti & Menaker, 1992)*. Hence, by constantly capturing the users skin temperature throughout day and night, a personal temperature profile can be created, containing the average skin temperature of a specific user, like so:



When a new measurement of skin temperature is done we can look at the user's profile and tell if this is within expectations (given the current time) or if this is a deviating measurement. An earlier project I did on sleep *(Fens, 2011)* shows that deviating measurements in skin temperature can indicate fatigue, which is a valuable data source to display to the user. We can then map this data to color and have more information about our relative skin temperature displayed.

Discussion

The final concept proposes a method to improve communication of (health) data to people. It does this by improving visual display of data based on context and the way it is communicated (simple, using a small array of lights). This results in an intelligent wristband that provides the user with context-dependent data throughout the day

The proposed prototype is "*experience focused*". The sensing part is taken for granted, since it is outside of the scope of this project. As a result, the technical specifications of the device are low-tech, utilising Arduino-based prototyping solutions. However, the final prototype aims at showing how the prototype creates a unique User Experience, within the context of digital health, regardless of the technical specifications.

The theoretical model behind the notion of "*microvisualisations*" builds upon earlier work done in the project concerning various display modalities (digital and physical) *(Fens & Funk, 2014)*. This work has been accepted as a short paper at the WSCG conference in Plzen. Therefore it is sensible to look at possibilities to publish continuation of this work as well. This will provide a foundation for further research on low resolution displays and communication of data. Additionally, the Qualica concept is a concrete application of using microvisualisations in product design.

The main challenges for further integration of the theoretical model and an integrated concept is the processing of various datasets, a topic briefly touched upon on page 63. In particular how to create personalised insights from health data; some simple processing can already provide the user with valuable insights, however additional signal processing is required to filter out unwanted points and find patterns over longer periods of time.

Appendices

Appendix A

Obtaining and storing: MySQL

As I already mentioned, I have used a script by Quantified Bob to download the data from Basis (the company behind the Basis b1 Band) to my own computer. The files I downloaded are all RAW text files, meaning the data was one big chunk of text. This made it difficult to perform data modifications on them (sorting, grouping etcetera). To set this right I put the data in a relational database format, namely MySQL. This is a widely used database format, and allows me to easily group data, sort data and run some small statistics, such as calculating the average.

The unique index for all the tables was time, since all the measurements have been done at some point in time. After importing all the data, the MySQL table structure looks like this:

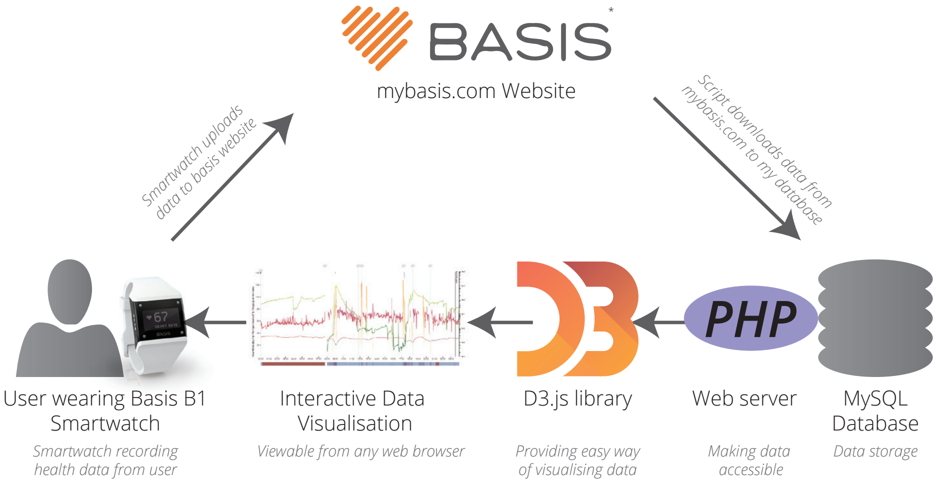
Database: sensordata

Each row in one of these tables contains these properties. Tables like this allow to find out at what point in time I had the highest skin temperature. This can be done by "sorting" the 'sensorvalues' table on the 'skintemp' column. Much more of these commands are possible, all aimed at gaining more insights in the data.

Visualisation: D3.js

MySQL is often used in combination with web technologies, such as PHP for access to the database, running on a web server, so that everyone with a web browser is able to view the data. Being experienced in both MySQL and PHP, I

Table: sensorvalues	Table: bodystates	Table: annotations
date	start	id
heartrate	end	date
steps	date	text
gsrs	duration	type
skintemp		

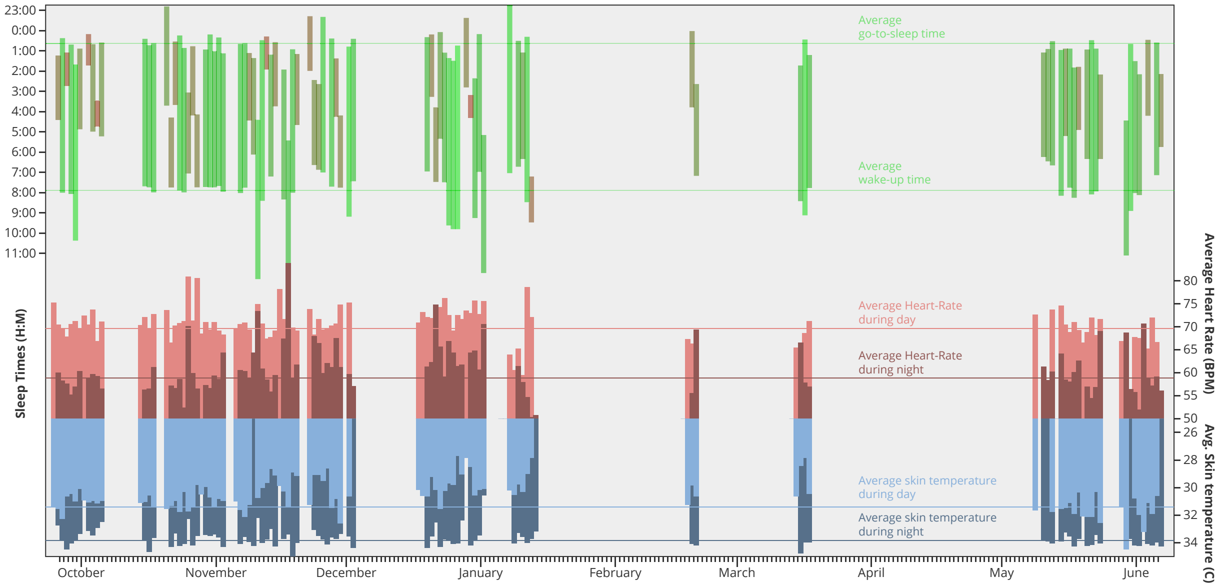


decided this was the most efficient way of getting my data out of a database, on the screen.

At this point I discovered D3.js, a technology which enables the creation of rich interactive data visualisations. Needless to say, this was exactly what I needed to make the data come alive. It didn't take much time to learn and it is extremely versatile. Using D3, I have created several visualisations of the data from the database:

- A simple graph, plotting all the raw data. It also allows the user to add annotations, clarifying some of the data.
- Averages per day, showing the average of the signal, and how this changes per day.
- Averages per hour, showing the average of the signals at a particular time during the day.
- Calendar of body states, showing the different "body states" (sleep, inactive, moderate activity), and how much time is spent in each state for each day.

Appendix B



Above figure summarizes all captured data from the B1 sensor band during this project. The top graphs show my daily sleep and wake-up times (if available), while the bottom two graphs show average heart rate and skin temperature during both the night and day. For example, daily skin temperature is significantly lower during December and January while it is higher during May and June. This reflects the influence of the weather on skin temperature. It looks like a similar fluctuation also takes place on average heart rate during the night, however due to the gaps in the months March, April and May I am unable to clearly demonstrate this fluctuation.

Bibliography

ABI research. *(2012, February 22)*. Wearable Sports and Fitness Devices Will Hit 90 Million Shipments in 2017. Wearable Sports and Fitness Devices Will Hit 90 Million Shipments in 2017. Research news. Retrieved August 13, 2013, from *http://www.abiresearch.com/press/wearable-sports-and-fitness-devices-will-hit-90-mi*

Amiigo. *(2013, January)*. Amiigo: Fitness Bracelet for iPhone and Android. Indiegogo. Crowdfunding Platform. Retrieved from *http://www.indiegogo.com/projects/amiigo-fitness-bracelet-for-iphone-and-android*

Bostock, M. *(2013)*. D3.js - Data-Driven Documents. D3.js. Retrieved October 1, 2013, from *http://d3js.org/*

camealone. *(2014)*. 2 pcs Blueduino with iBeacon feature/Arduino Compatible/Pro Micro+BLE 3.3V/8MHz. eBay. Retrieved May 20, 2014, from *http://www.ebay.com/itm/2-pcs-Blueduino-with-iBeacon-feature-Arduino-Compatible-Pro-Micro-BLE-3-3V-8MHz-/261468694938*

Comstock, J. *(2012, November 23)*. BodyMedia on board for new Biggest Loser season | mobihealthnews. mobihealthnews. News. Retrieved March 27, 2014, from *http://mobihealthnews.com/19185/bodymedia-on-board-for-new-biggest-loser-season/*

Crouter, S. E., Clowers, K. G., & Bassett, D. R. *(2006)*. A novel method for using accelerometer data to predict energy expenditure. Journal of Applied Physiology, 100*(4)*, 1324–1331. doi:10.1152/japplphysiol.00818.2005

De la Maisonneuve, C., & Oliveira Martins, J. *(2013, June)*. Public spending on health and long-term care: a new set of projections. OECD. Retrieved January 10, 2014, from *http://www.oecd.org/economy/growth/public-spending-on-health-and-long-term-care.htm*

Density Design. *(2013)*. RAW. RAW. Retrieved December 12, 2013, from *http://app.raw.densitydesign.org/#/*

Dijk, E. O., Nijholt, A., van Erp, J. B. F., Kuyper, E., & van Wolferen, G. *(2010, July 1)*. Audio-tactile stimuli to improve health and well-being. Conference or Workshop Paper. Retrieved May 8, 2014, from *http://eprints.eemcs.utwente.nl/17988/*

Fens, P. *(2011, December)*. Smart Sleep. Retrieved from *http://pepf.nl/content/project/smart-sleep.html*

Fens, P., & Funk, M. *(2014)*. Personal Health Data: Visualization Modalities and Their Perceived Values. In Proceedings of WSCG 2014. Plzen.

Few, S. *(2013)*. Data Visualization for Human Perception. The Encyclopedia of Human-Computer Interaction, 2nd Ed. Retrieved from /encyclopedia/data_visualization_for_human_perception.html

Fraser, H., Kwon, Y., & Neuer, M. *(2011, March 28)*. The future of connected health devices. IBM. Retrieved from *http://www-01.ibm.com/common/ssi/cgi-bin/ssialias?infotype=PM&subtype=XB&htmlfid=GBE03398USEN*

Fry, B., & Reas, C. *(2013, May 9)*. Processing.org. Product Page. Reference. Retrieved March 26, 2014, from *http://processing.org/*

Jansen, Y., Dragicevic, P., & Fekete, J.-D. *(2013)*. Evaluating the efficiency of physical visualizations. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2593–2602). ACM. Retrieved from *http://dl.acm.org/citation.cfm?id=2481359*

Kim, B. *(2012)*. Harnessing the power of game dynamics Why, how to, and how not to gamify the library experience. College & Research Libraries News, 73*(8)*, 465–469.

Lowe, J. *(2014, March 25)*. One Human Heartbeat. Datatelling.com. Retrieved March 27, 2014, from *http://datatelling.com/projects/onehumanheartbeat/*

M J Karvonen, E. K. *(1957)*. The effects of training on heart rate; a longitudinal study. Annales Medicinae Experimentalis et Biologiae Fenniae, 35*(3)*, 307–15.

MacCallum Carter, L. *(2013, April 9)*. We've turned the whole world into a couch. The World Economic Forum. Retrieved August 6, 2013, from *http://forumblog.org/2013/04/weve-turned-the-whole-world-into-a-couch/*

Nike Inc. *(2012, January 19)*. Nike+ FuelBand makes life a sport. NIKE, Inc. News. Retrieved January 30, 2014, from *http://nikeinc.com/news/nike-fuelband-makes-life-a-sport*

Refinetti, R., & Menaker, M. *(1992)*. The circadian rhythm of body temperature. Physiology & Behavior, 51*(3)*, 613–637. doi:10.1016/0031-9384*(92)*90188-8

Rogers, Y., Sharp, H., & Preece, J. *(2011)*. Interaction Design: Beyond Human - Computer Interaction. John Wiley & Sons.

Rooksby, J., Rost, M., Morrison, A., & Chalmers, M. *(2014)*. Personal Tracking as Lived Informatics. Presented at the CHI, Toronto, Canada.

Scanadu. *(2013, May 22)*. Scanadu Scout, the first Medical Tricorder | Indiegogo. IndieGogo. Crowdfunding Platform. Retrieved January 16, 2014, from *http://www.indiegogo.com/projects/scanadu-scout-the-first-medical-tricorder*

Schwartz, S. H. *(1992)*. Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. Advances in Experimental Social Psychology, 25*(1)*, 1–65.

Snappchat, Inc. *(2014)*. Snapchat (Version 7.0.1). Los Angeles, California: SnappChat, Inc. Retrieved from *https://itunes.apple.com/nl/app/snapchat/id447188370?mt=8*

Swan, M. *(2012)*. Sensor mania! The Internet of Things, wearable computing, objective metrics, and the Quantified Self 2.0. Journal of Sensor and Actuator Networks, 1*(3)*, 217–253.

TNO. *(2014)*. Intelligent light Management for OLED on foil Applications. TNO. Company Website. Retrieved June 17, 2014, from *https://www.tno.nl/content.cfm?context=kennis&content=expertise_euproject&laag1=1&laag2=55&item_id=1812*

Troia, B. *(2013, April 20)*. Liberating Your Data from the Basis B1 Band - Quantified Bob. Quantified Bob. Blog. Retrieved January 14, 2014, from *http://www.quantifiedbob.com/2013/04/liberating-your-data-from-the-basis-b1-band.html*

Tufte, E. R. *(1998)*. Visual explanations: images and quantities, evidence and narrative. Graphics Press.

Van Hoof, C. *(2013, March 6)*. From managing illness to managing health. Presented at the Sensors in medicine 2013, London. Retrieved from *http://www.sensor100.com/SensMed2013/C.van%20Hoof.pdf*

Ware, C. *(2010)*. Visual Thinking: for Design. Morgan Kaufmann.

Whitelaw, M. *(2009, July 10)*. Weather Bracelet - 3D Printed Data-Jewelry. the teeming void. blog. Retrieved from *http://teemingvoid.blogspot.be/2009/10/weather-bracelet-3d-printed-data.html*

Williams, K. *(2013, May 27)*. The weight of things lost: Self-knowledge and personal informatics. Personal Informatics. Blog. Retrieved from *http://personalinformatics.org/docs/chi2013/williams.pdf*