University of Twente

# From data to wisdom: making HR data meaningful for the running regimen of recreational runners

Bachelor thesis

Noor de Feber

18-7-2022

Dees Postma

Armağan Karahanoğlu

# Abstract

This research aims at making heart rate data more understandable for the running regimen of recreational runners. The current market offers a lot of self-tracking devices; however, not all runners understand the data presented on these devices due to a lack of data- and graph literacy. This research serves as a means to find a way to use design practices to fill the gap between the insights available and the insights gained from heart rate data. The goal of the research is to visualise heart rate data in combination with other data streams in such a way that users can convert the data into wisdom.

To reach this goal, a background study was conducted to uncover the possible insights runners can get out of heart rate data and study the currently available systems. The target group was interviewed to understand their current situation, wishes, and needs. After an ideation phase which consisted of brainstorming and developing the preliminary requirements, the final idea was further developed into a more specific idea that then was realised. After expert and client feedback, the final prototype emerged.

The final design is a 3D, location-based, interactive, and explorative visualisation where the user can change the external load, consisting of speed and distance, to see its influence on the internal load consisting of heart rate, heart rate zones and the RPE level. In the design, three different running goals are shown, accompanied by the effectiveness of training for those goals. These effectiveness levels change as speed and distance are adapted by the user. This way, the user can find the optimum combination of speed and distance to train for a specific goal.

The prototype then was tested, resulting in an increase from 12% to 29% in the number of wisdom statements made during the test. The design proposed by the researcher offered more insights into the patterns and relationships in the data. It showed the participants actionable moments where the zero measurement interface was more effective in showing specific data points and the course of the data over time. The effectiveness of the prototype was created through its interactivity, the 3D visualisation where multiple data streams could be linked and the focus of the prototype that lays on the three specific running goals.

# Acknowledgement

I want to thank my supervisor Armagan Karahanoğlu for her enthusiasm and passion for the research topic and for helping me with the practical aspects of the research, such as finding participants and data. I would also like to thank my critical observer Dees Postma for the creative insights he shared and his critical view on my research, which helped me sharpen my works. Secondly, I want to thank them both for the time and effort they put into our weekly meetings and the very helpful feedback they gave. They were supportive and tried to get the best out of me. Without them, the this thesis would have never existed the way it does now.

In addition, I want to thank all the participants who voluntarily participated in my interview and user tests for their contribution and kindness. Without the participants, this research would not have succeeded.

# Table of contents

# List of figures

## Abbreviation list

HR = Heart rate

HRV = Heart rate variability

Bpm = Beats per minute

BP = Blood pressure

CV = Cardiovascular

RHR = Resting heat rate

MHR = Maximum heart rate

SV = Stroke volume

RPE = Rate of perceived exertion

HRR = Heart rate reserve

# Chapter 1: Introduction

Running is one of the most popular types of exercise. About 75% of runners use self-tracking wearables to track their running [1]. However, it has become clear that the users of these devices cannot always make sense of the data offered by the device [2]. The data is presented with numbers and graphs, which are hard to understand for many users because of a lack of graph literacy [3]. People with a lack of graph literacy are unable to read graphs, they are unable to identify essential features of graphs and also relate those features to the context. This is a problem because most information is currently presented in graphs, and the users have to get their knowledge from them. An example is the Apple watch [4], where the HR is shown in numbers and graphs without adding any other factors except for time. This is a problem because if people cannot understand their HR data correctly, proper decision-making regarding their running regimen cannot follow out of it. This gap between the available knowledge and the actual knowledge runners have is what this research addresses. The lack of data literacy has been a long-known problem where non-data-experts have a hard time retrieving meaningful information from data or data analysis [4]. It has been a field of research for a longer time to fill the gap between data specialists and people without this data literacy because data has relevant information that should also be meaningful to non-data experts [5].

The little understanding of health data is a problem, especially for recreational runners. Recreational runners are defined as runners who have run 1 to 3 times a week for the past six months [6]. Recreational runners have individual motivations for running, varying per person [7]. However, where 68.2 % of recreational runners track HR data, only 22.3% use this and other data to adapt their training [8]. This is a missed opportunity since HR data can give rich insights into one's health and running performance. The problem is to uncover how this data literacy can be made more meaningful. Therefore the process of convergence from data into meaningful information should be researched. The data-wisdom pyramid proposed by Ackoff [9] is a theory on how humans' data interpretation process works. The pyramid consists of 4 layers with the bottom layer being data followed by information, knowledge, and wisdom. A better understanding of the data is present at each level of the pyramid. Data could be a number shown on an interface where wisdom is knowing how to interpret and use this number. As Ackoff [4] proposes with his Data-Wisdom pyramid, people's decisions are based upon the information they have and how this information is being processed in their heads in combination with context. If the information is not correct, there is a chance incorrect decision-making will follow. Regarding HR data and thus, health, these decisions could be significant.

To provide the context that should give meaning to data, highlighting the influencing factors of data is very important. Combining HR data with other factors such as fitness level and speed can give rich insights. For example, when a recreational runner wants to be in better shape, it is important to understand how HR plays a role in this. The runner should understand his HR and know when to increase difficulty or speed based on this HR to get into better shape.

Technology is rapidly evolving. An increasing number of technological innovations appear, but sometimes a gap exists between a technology's potential and its actual usage. When looking at wearables, this gap is the data analysis provided that can give meaningful insights and the lack of insights gained by some users. Another gap is that there are a lot of theories on how to make data more meaningful and examples of applications of these theories, but there is still a lot to be researched and implemented. The way data is presented is essential, here design comes in place. However, the proper design practices have not yet been found to meet our goal: to make HR data more understandable. Also, HR data is being presented together with other data streams but not always combined into a singular interface. The correlations between two data streams are not always clear to users. This prohibits the user from gaining valuable insights and connecting HR data and other factors. Li et al. [10] did a case study to find out what self-reflection needs users have for understanding themselves. Here they state that the users “had to look at their data one at a time. Even when data was stored in the same tool, they had to look at different graphs separately” [10, p. 401]. This is an excellent example of the inability of technology to show insightful correlations between data.

The scope of this thesis is to find design practices that can help make HR data more understandable. Therefore the question “What design principles can be employed to improve the understanding of HR data for recreational runners?” will be researched. To answer this question, several sub-questions should be investigated as well;

What insights can HR data give in combination with other data streams?

What deliberate health decisions can recreational runners make based on HR data?

What are the data interpretation practices of recreational runners, how do they interpret their HR data?

How do recreational runners make use of HR data to improve their running regimen?

With the aim of using design practice to solve the problem also a design question is formulated;

How can design principles help to present HR data, in combination with other health-data streams, in a way that makes sense to recreational runners and elicits better decision-making regarding their running regimen?

In this thesis the process in making a data visualization that helps recreational runners with their understanding of HR data for their running regimen will be described. This includes a literature research and the ideation of the prototype which was then evaluated through user testing.

# Chapter 2: Background research

This section gives an overview of the existing literature and the topic's state-of-the-art. This overview will consist of a model that describes how the human mind converts data into something more meaningful, a list of what self-tracking devices offer regarding HR data, insights that can be gained from HR data, an existing system that makes data more understandable and an interview to help understand the target group. This background research is a basis for the final research and will help the design process.

## 2.1 The data-wisdom pyramid

A model that describes how higher levels of understanding are typically reached is the Data-Wisdom Pyramid. The Data-Wisdom pyramid represents the relationships between data, information, knowledge, and wisdom. The pyramid is used to describe the convergence of data into wisdom in different hierarchies where each level in the hierarchy includes the levels that fall below and where wisdom is the desired outcome. At the bottom level, everything is abstract, the goal is to get to the wisdom level where the data is being understood and related to other factors and context by the receiver. With wisdom, proper decisions can be made by the recipient. The final visualisation should help runners to get to this level of understanding.

Data, information, knowledge, and wisdom, are the key elements of the data-wisdom pyramid. As Bellinger et al. [11] put it, moving from data to information is all about understanding relations, moving from information to knowledge is about understanding patterns, and moving from knowledge to wisdom is about understanding principles. For the final visualisation, context is a crucial factor in making HR data more understandable. The user of the self-tracking device should be able to understand patterns and principles in their own health data. These principles can subsequently be used for making decisions regarding their running regimen and working towards their running goals.

| Layer | Description |
|---|---|
| Data | The symbols that represent the properties of objects and events [9], [11]–[15], the raw HR information received by the sensors of a self-tracking device. |
| Information | Data that is processed to be useful [11]. |
| Knowledge | The application of data and information and answers “how” questions [9], [11] where experience, expert information and contextual information is of importance [13]. |

| | |
|---|---|
| Wisdom | Deals with values and involves judgment which is all in the human mind [9], [11], [14], actionable moments. |

## 2.2 Current devices

The current devices available for users to track their health data are explored to investigate the state of the art. First, the scope of what the current devices offer regarding health data is researched. Secondly, the way these devices present this data is explored.

### 2.2.1 What data can be measured?

Nowadays, self-tracking devices offer a lot of different data streams to be measured. The possibility of measuring specific data streams differs among the different devices. For the scope of this research, the four best-sold self-tracking devices, Fitbit, Garmin, Apple, and Samsung, in a popular tech store in the Netherlands [16] were analysed to explore the possibilities of data measuring as seen in figure 1. Research was conducted on what these wearables offer regarding HR, sleep, stress level, blood oxygen, blood pressure (BP), and body temperature since these factors have most to do with HR. This analysis resulted in HR, sleep, stress level and blood oxygen being the most common measured data streams among the four wearables. Body temperature and blood pressure (BP) are measured by some brands but not all of them.

| Data streams | Fitbit | Garmin | Samsung | Apple |
|---|---|---|---|---|
| HR | x | x | x | x |
| Sleep | x | x | x | x |
| Body temperature | x | x | | |
| BP | | | x | x |
| Stress, using HRV | x | x | x | x |
| Blood oxygen | x | x | x | x |

*Figure 1: ability of different wearable brands to measure data*

The wearables measure these data in different ways. HR is measured by scanning the blood flow in the wrist by using LEDs to illuminate the blood [17]. This LED is a green light absorbed well by blood because of its red colour. Optical sensors in the device track the amount of reflected light and calculate the HR based on this. However, study shows that most HR monitors do not have 100% accuracy. For example, the study of Nelson et al. [19] showed that the Apple Watch 3 and the Fitbit Charge 2 had an accuracy of 95% and 91% respectively, for measuring HR data. This inaccuracy of wearables can cause errors in the data.

BP also can be measured with a smartwatch or sports watch. However, this is also often done inaccurately. Another downside is that most smartwatches require a first calibration with a dedicated BP cuff [18]. This means that the wearable cannot measure BP on its own. After the first calibration with the BP cuff, the device uses pulse wave analysis to measure the BP. The analysis of the measured HR is used in combination with the calibration reading to determine the BP.

Sleep is measured by all smartwatches analysed. Most wearables use accelerometers to measure sleep quantity and quality. An accelerometer measures the acceleration to determine the body movement during sleep. Some wearables also use HR and respiration to estimate additional sleep stages and to detect REM sleep. However, study shows that sleep trackers are only accurate 78% of the time when differentiating between the status of awake and asleep and only 38% of the time when measuring the amount of time it takes to get asleep [19].

The stress level that the wearables present are based chiefly on HR and HRV, which produces a stress score from 0-100 [20]. A low HRV can be concluded as a high stress level. Since the stress level is based on HR and HRV, the inaccuracy of the HR monitor could also cause inaccuracy in the stress level. In addition, the HRV is hard to measure from the wrist and is measured best when the user is not moving. When the user is moving, this also can cause inaccuracy in the reading of the HRV [20].

The few wearables that measure body temperature do this through a thermistor [21]. thermistor is a resistor whose value changes depending on the body's temperature. The temperature of the skin can be measured through this resistor.

### 2.2.2 How is the data presented?

The different wearables present the data in a different ways. For the scope of this research, only the HR data presentation will be analysed. Fitbit presents the HR data mainly through graphs [Appendix A, figure 1]. Fitbit can measure HR 24 hours a day, so the user can always see its HR data. The Fitbit interface shows HR zones during a workout to help the user to get an idea of how high of a HR they have. The HR zones are marked with colours accommodated with labels that describe the HR zone. In addition, the average RHR in bpm is shown over the day but also during a workout.

Garmin also measures HR 24/7 [22] [23] and HR zones [Appendix A, figure 2]. Also, the average RHR is displayed, and an overview of the average RHR over a week. The HR is displayed in a graph over a day, but the average HR over the week can also be viewed in a graph.

When looking at the interfaces of the Apple watch [Appendix A, figure 3], again, the HR is presented in a graph. However, the graph from Apple differs from the two described earlier in the way that the HR graph is not a continuous line. The current HR and the average RHR are shown on the interface in the same way as the other watches do. The graph shows the HR over a day, no indication of HR zones is present.

When looking at the examples of the Samsung smartwatch [Appendix A, figures 4 and 5], the interface shows the real-time HR as a number. The HR zones are indicated with colours. Samsung offers the option to continuously measure HR [24] for the user to always see the HR. On the phone interface, a graph can be seen that shows the HR accommodated with the HR zones that are indicated with colours.

When looking at the interfaces, all of them use a graph to depict the behaviour of the HR. Most devices use colours to indicate HR zones and graphs to show the HR over time. Some interfaces combine the HR graph with HR zones and indicate at which phase a specific HR zone was present. It is important to mention that not all functions available could have been discovered with this background research. Some of the existing interfaces for a particular brand might not have been found by the researcher or may not exist online to be visible to non-users of that brand.

## 2.3 What insights can be gained from HR data?

The data that this research is about specifically is HR data. To make the HR data more understandable and meaningful, especially for recreational runners, it is important to understand what insights can be gained from HR data. Knowing how HR data can be used to help recreational runners with their running regimen is valuable. To do so, research was performed on the insights that HR data can offer regarding the running regimen of recreational runners.

### 2.3.1 Running goals

Before diving into the insights HR data can give, it is essential to understand what the insights are needed for. Depending on the goal of the recreational runner, different variables can help gain insights into how to achieve this goal. Karahanoğlu et al. [7] performed a study and researched how runners use sports trackers and what their goals are when using these trackers. These goals can help identify user needs for self-tracking devices. After conducting interviews with 22 participants, the participant's goals for running were divided into two categories. (i) achieving a particular performance goal and (ii) keeping running as a habit. Within these two main goals, some sub-goals were defined. For achieving a specific performance goal, the subgoals are:

1. improving running pace
2. completing a particular event
3. improving a running distance
4. maintaining activity level
5. improving overall health

From the paper of Karahanoğlu et al. [7] the five goals recreational runners have for running will be used as a starting point for the final design.

Runners have these goals separately, but most of them interweave between different goals due to the changing factors in life or change of interest. Right now, some sports tracking users switch between different tracking devices because most tracking devices do not support a variety of goals;

they focus on just one or two of them “four participants described switching back and forward between different tools that better met their different goals needs” [7, p. 6]. Apart from this, other studies also show how users switch between tools [25]. The study of Epstein et al. [25] proposes a model that describes how users decide to track, how they select tools, how they track and why they lapse from tracking. The motivations for tracking are all based upon different goals, and the selection of the tools is based upon these motivations, thus the goals. This does not hold for the users who use the tools just out of curiosity. Also, the reasons for transitioning to a new tool are often because they better fit their information needs or offer more benefits. Sometimes the switching of tools was forced for reasons outside of tool selection, like changing phones [25]. The goal of this research is to find a design that enables the tracking and supporting of multiple goals such that users do not have to switch devices when switching goals. To keep the users engaged with the product, they should keep seeing the benefit it holds and be able to use it for all their running goals.

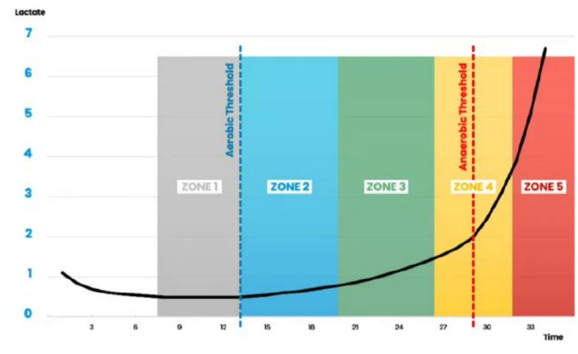
### 2.3.2 Assessing the fitness level

To make the design usable and understandable for all different goals, the data streams needed to assess the success of reaching these goals will be described. The subject's fitness level should be assessed to uncover where improvement lies and whether progression is made in performance. An individual’s fitness level can be estimated by comparing the intensity at which the individual can exercise [26] to the burden on the body. Monitoring HR in combination with the rate of perceived exertion (RPE) and pace will give the best indication of an individual’s overall fitness level and improvement.

The RPE is a 0-10 scale [Appendix B] where an individual grades their perceived exercise intensity. The fitter the individual, the lower the RPE at the same level of exercise or the more intense the exercise at the same level of RPE. The RPE can be measured by training at different exercise levels and monitoring the individual’s perceived intensity. HR can assess an individual’s fitness level by indicating the HR at certain exercise intensity. If the HR decreases for the same intensity or the HR stabilises for increased intensity, this means the individual is getting fitter. The heart rate reserve (HRR) is the range between the resting heart rate (RHR) and maximum heart rate (MHR). Running at different percentages of the MHR is beneficial for different training goals, this is where HR zone training comes in.

Depending on what specifics one wants to train, different HR zones are adequate to train in. With HR zone training, the knowledge of the body’s energy systems is used to improve specified training. If the body needs energy, the molecule ATP gets broken down by the body to provide energy for the human body. Different processes in the body are responsible for refilling the ATP stock once it is broken down. Aerobic and anaerobic combustion are processes the human body uses to convert glucose into ATP [26]. For aerobic combustion oxygen is needed. Once there is a shortage of oxygen the body moves to anaerobic combustion where lactate starts building up in the muscles which causes fatigue.

Each HR zone has its characteristics and functionalities and elicits another energy system. HR zone 1, the warm-up zone, has an intensity of 50-60% of the HRR. Within this zone, the heart is not in much effort; therefore, it is very effective for recovery training or training before a long run. Zone 2, the fat burn zone, is where the HR is between 60-70% of the HRR. Training in HR zone 2 improves endurance and fat burning. Zone 3, the aerobic zone, is at 70-80% of the HRR and is increases aerobic fitness which is useful for improving pace for long distances. Zone 4, the anaerobic zone, is between 80-90% of the HRR and improves the anaerobic capacity which is effective for the pace for shorter distances. Finally, zone 5, the maximum effort zone, is effective for speed and sprints, increases maximum performance and is between 90-100% of the HRR but also not possible and healthy to keep up for long.




| Zone | Percentage of maximum heart rate | Goal of training in this zone |
|---|---|---|
| Zone 1 | 50-60% | Recover from heavy training the day before or to run slowly for a long time |
| Zone 2 | 60-70% | Improves endurance and fat burning |
| Zone 3 | 70-80% | Improve pace for longer distances |
| Zone 4 | 80-90% | Improve pace for shorter distances |
| Zone 5 | 90-100% | Speed and sprints |

*Figure 2: Lactic acid accumulated in muscles measured during exercise [47] and HR as percentages of HRR [26]*

Pace is used as an indicator of exercise intensity [Appendix B]. Pace, in combination with distance, is the external load that influences the internal load, defined as the HR and RPE level and together can determine an individual’s day-to-day and long-term fitness. It is essential to understand that the runner can control the external load and this way can influence the internal load. For the different running goals, the internal load determines the effectiveness of the training for a specific goal.

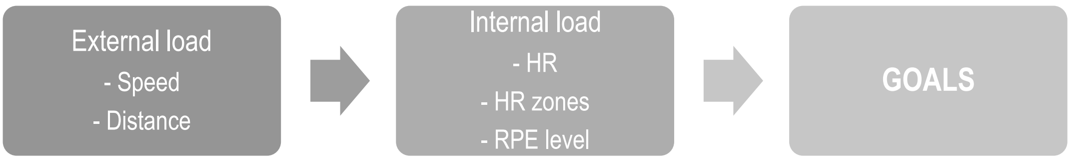



*Figure 3: external- and internal load*

The MHR should be calculated with the following formula to calculate the target HR for a workout

$$HRmax = 208(age * 0.7)$$

Thereafter the HRR can be calculated

$$HRR = HRmax - RHR$$

Lastly, the target HR can be calculated

$$Target\ HR = (HRR * percentage\ of\ intensity) * RHR$$

This equation does not consider the fitness level, gender, or inherited genes of an individual. The fitter a person the lower their MHR. Another way to measure the MHR is to do a test run. The runner should do 4 repeats of 2 minutes at maximum effort with 1 minute rest interval. The highest HR measured is the MHR. The following sections will discuss the variables needed to gain insights into improving the specific goals [Appendix C].

### 2.3.3 Improving running pace

Improving one's running pace means that the athlete wants to run the same distance x km/h faster than one's current record for this distance. To improve the running pace, a person's overall fitness must improve to run at the same pace with a lower HR, showing the body is more efficient [27]. Running at a manageable pace should give the individual a relatively stable HR [28], a running pace that is not manageable for the individual will result in a HR that increases dramatically [28]. One can choose the right pace to run at by identifying the differences. The speed in km/h should be measured using the variables time and distance to assess the current speed.

From a steady state HR an individual can improve the running pace is by training the anaerobic system [29]. However, training using the anaerobic system should be done with caution; one cannot train for long in the anaerobic system and can quickly reach the level of overtraining. To improve pace, the individual needs to train mainly in HR zones 3, 4 and 5, from 70-100% of the HRR. To increase pace on the long distance, the individual should train in HR zone 3, from 70-80% of the HRR. For increasing pace in short distances, HR zone 4 should be trained in from 80-90% of the HRR. For exercising sprints, the individual should train in HR zone 5 from 90-100% of the HRR. It is important to not train too long in HR zone 5 since this causes overtraining.

Besides the external load described earlier, other factors influencing HR are environmental temperature and humidity. It is harder for the body to cool down if there is a high temperature or high humidity, increasing HR. Another factor influencing HR is hydration; if a person is not hydrated well, they have a lower blood volume. Therefore, the heart should work harder and thus creates a higher HR. It is also essential to consider the elevation during exercise. If a person is walking up a hill but maintaining the same pace, it is normal for the HR to go up [30], [31].

### 2.3.4 Improving running distance

Improving the running distance means that the athlete wants to run x km longer than one's longest running distance whilst keeping pace equal. To meet this goal, the aerobic system must be trained. The aerobic system will match the energy needs of muscles during steady-state exercise [26]. By increasing the intensity, the energy need will rise. If this energy need exceeds the aerobic capacity, the blood lactate accumulation will rise exponentially. The level at which the energy need exceeds the aerobic capacity is the lactate threshold. The longer muscles can sustain the aerobic capacity, the longer distance can be run. This means recreational runners who want to improve running distance should train in HR zones 2 and 3. Some factors influence the HR of the runner that can change the insights into the performance. These factors are the same as the ones for improving running pace and include humidity, environmental temperature, cadence, and hydration.

### 2.3.5 Completing a particular event

For completing a particular event, the variables needed differ from what kind of event needs to be completed. When looking at the study from Karahanoğlu et al. [7] it becomes clear that most of the events are a goal that is running distance x in time x. This could be a marathon, half a marathon or a completely random amount of km. A combination of improving running distance and pace is needed to reach this goal.

### 2.3.6 Maintaining activity level

To maintain the activity level, the runner's fitness should stay the same. This means that the RHR should not get higher over time, and the HR during the workouts should also not get higher when performing the same exercise. Secondly, recovery HR is an excellent indicator of health. The recovery HR is the time it takes for the body to return to average HR after exercise. The faster the recovery of HR, the better shape the individual has. These conditions can be monitored using speed, HR, RHR and MHR. Maintaining activity level also means maintaining regular exercise. Here the number of times an individual runs per week/month can be measured. The runner can indicate their preferred training frequency for maintaining activity level.

### 2.3.7 Improving overall health

To improve overall health, one's fitness should be improved. Fitness can be measured by looking at the RHR and the HR recovery time after exercise as mentioned in the previous section. Secondly, fitness can be measured by HR during exercise, as mentioned earlier. The variables HR, MHR, HR rest, age, gender, and speed are needed to improve the overall health. Recreational runners who want to improve overall health should train primarily in HR zone 1 and 2 and by training the anaerobic and aerobic systems. This will result in a well-rounded runner [26].

## 2.4 Mashup system

An example where researchers tried to make data more understandable by combining different data streams and factors is the study of Bentley et al. [32]. Analysing this system might help find effective ways to make data more understandable. Bentley et al. [32] built a "Health Mashup system" that combined weight, sleep, step count, calendar data, location, weather, pain, food intake, and mood to explain the data stream wellbeing. The systems showed participants trade-offs in their everyday lives that they could not see on their own by displaying significant observations about their well-being that were calculated using statistical analysis of the logged data of the participants.

The key to making the data more understandable was to use natural language to express relations, for example, "On days when you sleep more, you get more exercise" [32, p. 6]. This was done since Bentley et al. [32] believed this would be understandable and meaningful for the user. Also, statistic possibilities were simplified with the terms possibly, very likely, etc. (based on the p-value).

A 90-day user test resulted in a situation where participants had a better and deeper understanding, and thus more wisdom, of their well-being and the aspects that affected this well-being. The participants saw actionable moments that they did not see during the control study where they could make decisions to improve their well-being, the participants could see clear relations between different data streams and understood the factors that impacted the different data streams. This correlates to the goal of this research, to make HR data more meaningful and to enable recreational runners to make better decisions to improve their running regimen. The researchers also discovered that it was essential to have consistent data input. With too little data, the system would show contradicting information which would confuse the participants and could result in distrust in the system. Another result from the study was that participants would like the option of getting notifications when new 'insights' were available that would serve as a reminder to look at the system. Bentley et al. [32] explained that participants needed extra encouragement to dig deeper into their data, including those reminders. These reminders would also increase the amount of data available and thus the quality of the insights. "It is clear that a wide variety of contextual variables affect wellbeing and that capturing as many as possible will give users the best and most relevant insights into their own lives" [32, p. 24].

From this study can be learned that statistical correlations are useful for giving insight into how to the effect of different factors on data. Natural language is an effective way to present these correlations and patterns between different data streams to elicit better understanding for the users. Users discover new patterns and use the data to make better decisions which means they get higher into the data-wisdom pyramid. This principle can be used in the final design to make HR more meaningful for recreational runners. The runners goals can be explained in natural language where the users should find the optimum training setting for this by interacting with the data. Secondly, for engagement, it can be essential to include reminders in the system to allow the participants to be reminded to use the system actively. The users need to trust the system, which means it should have as few inaccuracies as possible.

## 2.5 User interviews

To get a better idea of the problems experienced with the current self-tracking devices, interviews were performed to get a qualitative interpretive idea of how runners use and interpret their running data [33]. This was done through a self-reporting approach combined with active interactions with the wearables, the participants will be able to tell what they are doing, what they feel and what their goals are. However, it is important to note participants might overlook or forget actions, feelings, and goals, which is important to keep in mind.

### 2.5.1 Setup and design of the interview

The target participants are recreational runners who run 1-3 times a week and have been doing so for the past six months. The participants should be 18 years or older and have a self-tracking device. Participants who participated in the interviews were recruited via WhatsApp group chats and email. The information brochure was sent once the participant was interested, and a date was planned to perform the interview. The interview consists of four parts [Appendix D, figure 1]. During the first part, questions were asked about participants' goals regarding their self-tracking device. The second part consisted of participants being asked to show different parts of their self-tracking device that they use for running and interacting with it. Afterwards, questions were asked about how the participant experienced the interaction with the device and what their overall experience with the device was. The last part contained questions about what the participants missed in what the current wearable offers and what they would prefer to see, combined with the question if the participant wanted to send screenshots of the interfaces discussed during the interview. The interview is semi-structured, with a list of guideline questions that can be deviated from. After the interviews, the audio recordings were transcribed and coded to find patterns along with the different participants. The received screenshots will link the transcription to interfaces and help depict interesting phenomena within this thesis.

### 2.5.2 Qualitative data analysis

After retrieving the data, it must be prepared before executing a qualitative data analysis consisting of reviewing the transcriptions from the ten interviews and performing a thematic analysis. A first read-through allowed the researcher to get a global idea of the topics of the interview. Afterwards, the interviews were coded using deductive coding, where an initial set of codes was used and complemented with new insights in codes during coding. Overall, 10 participants, five female and five male, participated in the interview. With the analysis, recall bias was considered. Some of the questions require people to recall what they did. It might occur that people cannot recall with 100% accuracy. The emergent themes from the interview were the different motivations people had for buying their wearables, the things people did and looked at during running, how the users reviewed their training after running and how the analysis was used for further training. Also, the lack of understanding of specific interfaces' components and the problem of inaccuracy were frequently occurring themes.

### 2.5.3 Interview results

From the thematic analysis, different themes emerged that were a common thread throughout the interview. Below these different themes are discussed together with their findings.

*Motivations*

The participants had different motivations for buying a wearable. The most mentioned motivations for buying a wearable and requirements for choosing a particular model were the ability of accurate GPS tracking, tracking speed, distance and HR, and the ability to play music from the wearable, which enables the participant to leave their phone at home during running. Two participants mentioned that they wanted a wearable to motivate them to move more, and three mentioned the importance of the aesthetics of the devices.

*During running*

During running, there were different things that the participants would pay attention to that were presented on their sports watch. All participants had time, speed and distance presented on their smartwatch while running. All participants except for two displayed their HR on their sports watch during running. One participant even mentioned having installed different screens for different training activities. When training interval, the participant would have time, speed, and duration on the interface and when training endurance, the participant would mainly have time, distance and HR presented.

Six participants mentioned that they used their HR to check up with real-life. Four participants mentioned adapting their speed based on their HR "when I notice my heart rate is very high, then I think by myself, oh I will run a slower speed to recover a bit" P7. Here P7 reached the level of wisdom where the participant could call out an actionable moment. However, most runners mainly ran based on speed.

*After running*

The things participants looked at after running differed. Almost all participants first looked at the route and the speed they ran. A lot of the users also looked at the HR graph. However, only a few participants did something with this data. Half of the participants mentioned that they try to link the HR to the events in the runs. "I will look and then I think, I understand that the heart rate is this high over there because I had a hard time at that point" P1 and mentioned how they used the heat map that shows the speed in combination with the route [Appendix D, figure 2]. Nevertheless, only a few participants used their HR to adapt their future training, thus, getting to the wisdom level of the data-wisdom pyramid. All participants who used their HR to adapt to future training used their HR zones. These participants knew the most influential HR zones to train in and that the target HR zones could be reached by adapting the training speed. These participants also tend to run based on HR and not on speed.

Three other participants who did not know much about HR and HR zones could indicate what HR was “good” for them by comparing how they felt. Two of them mentioned that if their HR changed over time to a lower value this was an indication that they got into better shape. They use HR to track progression but not to improve their running regimen. Half of the participants did know HR zones but did not know how to use them for their running regimen, or did not have interest in using their HR zones for their running regimen.

The use of speed was widespread to determine the running regimen. Participants used speed as their goal and wanted to increase their speed following a training scheme “the only goal I have is always the fitter I get the higher the pace I can run (…) that is what I am always trying to improve on” P10. About one-third of the participants base their training on how they feel that day.

### *Lack of understanding*

Many data presented by the self-tracking devices were not used by the participants. Only one participant used the body battery and cadence. No participants used %VO2max or stress levels. Three participants used HR zones. Different causes for not using this data were mentioned. Some participants were not interested in some of them, but the more common cause of disuse was that the participants did not know what the number presented meant and how they could change it. This indicates the importance of this research. Also, some participants mentioned that they did not understand the graphs [Appendix D, figure 2]. P10 described that they know a little bit about HR zones but do not know how to train with it “ for example, I have run about a little less than half of the time in a certain HR zone, no idea whether that is good or not so it would be nice if you could click on it directly and that it would give feedback on it” P10. This shows that the lack of context prohibits the user from gaining valuable insights. They referred to the information given in combination with the HR zones. However, this information was minimal [Appendix D, figure 2].

### *Accuracy*

Half of the participants mention the problem of accuracy. It was mentioned that the lack of accuracy creates distrust with the device.. One participant also mentioned that the Apple watch gives very inaccurate values and that there are a lot of datapoints missing. Two of the participants mentioned that it occurs that the GPS of a phone and the tracking-device give different values, this causes confusion with the participants.

### *Type of tracking*

From the interview three main reasons for tracking were found where one participant could have overlap in multiple reasons. Two participants mentioned it was for improving, seven mentioned the reason was for tracking progression and the last reason was just for fun as mentioned by two participants.

### 2.5.4 Interview conclusion

What can be concluded from this interview is that during running, most runners only look at their time, HR, and distance. Most of the participants look at their speed and distance to compare it to their goal and look at the HR to compare it to how they feel. Most participants based their running regimen on speed and perceived intensity. Only a few participants looked at their HR during running to adapt their speed. After running, most participants looked at the route and the speed they ran. Some participants tried to link their HR in a graph to the events during running, but most did not use their HR to adapt their future training. The people who used the analysis of their training for their running regimen also had insights into HR data and HR zones. This could indicate that when understanding HR data, it is easier to use this for the running regimen. Also, the main reason people do not use their health data for the next run is that they do not know how to interpret it or change it. They do not know what the number that represents the data means or how to change this number. This correlates to the idea that a better running regimen will appear with better understanding. Some participants did know what the data meant but did not have the wisdom to act upon the data.

Another interesting conclusion that can be made from the interview is that a lot of the participants subconsciously used the method of measuring RPE to assess their fitness level. As the participants mentioned, they compare their perceived intensity with their HR and find a HR suited a longer running distance. The fact that the participants already use the RPE level makes it an interesting factor to include in the final design.

Lastly, it was noticed that a lot of the participants looked at the route after the training. Also, the participants tried to link real-life events during the training to the graph of HR and speed that were reviewed after the training, thus creating context. The fact that the participants tried to link the real-life events to the data is something to consider for the final design. It would be wise to include the location of the run to help the participant recall particular events and combine these with the data, thus adding context to the data. The addition of context helps convey information into knowledge.

## 2.6 Conclusion

The analysis on what currently available wearable brands offer regarding the tracking of health data showed that all brands analysed can track HR data. There are differences in the presentation of the HR data. However, all brands present HR data in graphs. The graphs are not overlayed with other data, each data stream is assigned to its own interface. Some brands also present the HR zones with colours. It often is not straightforward what service the HR zones offer.

During the background research, insight into what insights HR data can give was gained. In combination with other data streams, HR data can help users improve their running regimen and work towards a specific goal. From the background research into what insights can be gained resulted in that HR, in combination with speed and distance, can give insights into one's fitness level. This also resulted in that HR and RPE levels combined to determine the internal load, whilst speed and distance determine the external load and the external load influences the internal load. The HR zones effectively show how to train for different goals, as the background research and the interviews showed that the participants who used their HR data to adapt their future training also understood the HR zones. These data streams combined should be the base of the final design.

The Mashup system is an excellent example of how simplified statistical correlations can help improve the user's understanding on how to make decisions on improving certain data streams. This information is valuable for the final design, where the goal is to give insight into the correlations between different health-data streams. The mashup system is a small part of the design question of "How can HR data, in combination with other health-data streams, be presented in a way that makes sense to recreational runners and elicits better decision-making regarding their running regimen?".

From the interviews can be concluded that only a small number of recreational runners use their HR data to adapt their running regimen. The main reason for the disuse of the HR data is that the participants did not have an interest in improving their running regimen, or they did not understand the data and did not know how to change it. This highlights the importance of this research. The interview also resulted that most participants linked real-life events to data in graphs in the after-run analysis. They have insight into what happened at what time using their memory and the location map. For the final design, it is important to consider that linking data to real-life events helps gain knowledge.

When comparing the insights that can be gained from HR data regarding running regimen to the insights the participants had, the gap of knowledge becomes apparent. This research needs to fill this gap by answering the question, "What design principles can be employed to improve the understanding of HR data for recreational runners?".

# Chapter 3: Methods and techniques

In this chapter, the Creative Technology Design Process [34] will be described and how this process fits this specific research. In addition to the Creative Technology design process, Kirk et al. [39] 's visualisation workflow will guide the researcher toward a final data visualisation. Each phase has its methods and techniques, and this chapter will give an overview.

## 3.1 Ideation phase

Within the ideation phase, an idea of the final system or design will be generated. In this case, the technology smartwatches and self-tracking devices are the motivation for these ideas. The problem definition, the gathering of relevant information and idea generation occur during this phase. A PACT analysis is performed to understand the people that use the design, the activities that will be performed with the design, and the context in which the design will be placed in. Subsequently, the first user requirements and functional requirements will be formulated. During the ideation phase, the information from the background research is used to create 50 initial ideas for the final design. These 50 ideas are all ideas that contain multiple dimensions to represent the different variables that give insight into the performance of a runner. From these 50 ideas, three ideas were chosen for convergence to ideate further upon.

Finally, a prototype visualisation will be made to see how different data streams relate to each other. This visualisation will be the base for the final design. Here also, the four stages of the visualisation flow by Kirk et al. [35] will be introduced.

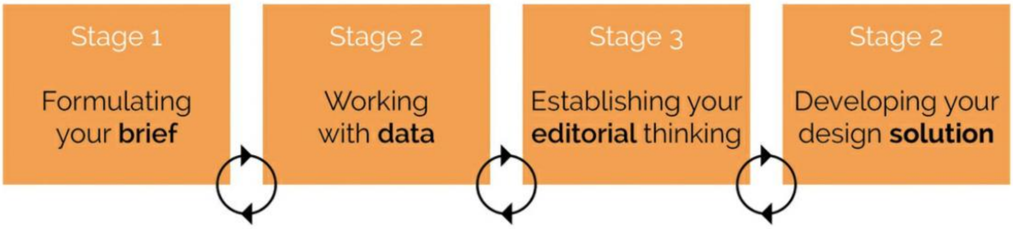



*Figure 4: the four stages of the visualisation workflow* [35]

This process is a workflow generated by Kirk et al. [39] to provide guidelines to reach a final visualisation. The workflow will help reduce the approach's randomness in the data visualisation process. The workflow breaks down activities into a system that helps stay organised. Each stage builds on the stage before and offers information for the next stage. During the ideation phase, the first stage, formulating the brief will be handled. This includes identifying the who, what, why, where, when and how for the final visualisation, which compliments the PACT analysis and helps to understand what kind of visualisation will be made.

## 3.2 Specification phase

The second phase of the Creative Technology design process is the specification phase. Within the specification phase, several different designs will be explored. The designs will be analysed and evaluated and then adapted with feedback, this is an iterative process. The combination of client feedback and data analysis will be used to produce the final functional and non-functional requirements. A precise product specification is present at the end of the specification phase. During the specification phase, the second two stages of the visualisation process will also be tackled: working with data and establishing editorial thinking. Within these two steps, the data used for the final visualisation will be explored and cleaned up. Secondly, the final design's angle, frame and focus will be decided upon. These two steps will help create a clear image of the final visualisation.

## 3.3 Realisation phase

After the specification phase, the realisation phase follows. Within this phase, the specifics of the final actual design will be generated. After the previous phase, it has become clear what works within the design and what does not. Within this phase, this will be brought together and will be realised. The design will not be a mock-up anymore, and care will be given to working out the design in as much detail as possible. During the realisation phase, the last phase of the visualisation workflow of Kirk et al. [35] will be handled, the design solution will be developed. During the development of the prototype, expert opinions will be used to validate and improve the prototype.

## 3.4 Evaluation phase

The last phase within the Creative Technology design process is the evaluation phase. Within this phase, it will be tested whether the earlier set requirements are met. In this phase, user testing will take place with the final design. Also, the final design will be placed in the context of existing work to see where it stands. The evaluation phase also contains the personal and academic reflections of the researcher.

# Chapter 4: Ideation

During the ideation phase, a design concept will be generated. The background research elicits requirements, and feasible concepts will be developed to further shape the design space. A PACT analysis, and sketching will be used to shape this design space. The starting point for the ideation phase is the design question, “How can HR data, in combination with other health-data streams, be presented in a way that makes sense to recreational runners and elicits better decision-making regarding their running regimen?”.

## 4.1 People analysis

To get a better understanding of the people that will use the design and the context where they perform these activities, a PACT (people, activities, contexts, technologies) analysis will be performed [36]. The PACT analysis is used since it is an effective tool for understanding the product users in an interactive system design. It is essential to understand what activities the recreational runners undertake with their sports devices and in what context they do this to provide the best user experience. It is important to note that this PACT analysis will be for a new system/design and not a new technology. Therefore, some of the contents will differ slightly from an average PACT analysis, focusing on new technology.

### 4.1.1 People

This section will give an overview of the psychological and social differences in the target group ‘recreational runners’. Physical differences will not be considered since the technology already exists in form, only the interface should be adapted. The design will be made for people who have normal visibility and audibility.

The target users are recreational runners. A recreational runner is “a person who has been running 1 to 3 weekly sessions for at least six months” [6, p. 3]. However, there are different types of recreational runners [8]. Janssen et al. [8] performed a study where they divided recreational runners into four different types, where each type, from I to IV respectively, was more competitive.

I. Casual individual runners
II. Social competitive runners
III. Individual competitive runners
IV. Devoted runners

Janssen et al. [8] describe that different types exist even within the recreational runners group. When comparing these different categories to the categories of goals runners can have proposed by Karahanoğlu et al. [7] a connection can be seen in the different motivations runners have for running. The categories proposed by Janssen et al. [8] are categorised by the differences in social aspects and performance goals. However, each category has different motivations for running, as seen in the categories from Karahanoğlu et al. [7]. The more performance-based runners want to run longer distances than the less devoted runners. More devoted runners might have stricter goals than the casual runners. For the different types of runners thus might lie different gradations of the goals they have.

When looking at the motivation and ways of using self-tracking apps [Appendix E], it can be seen that these also differ between the different types of recreational runners. Individual competitive runners track HR data the most (72.1 %). However, when looking at what they do with the data, the score was lowest on reviewing the session after the run (75,7%) compared to other types of runners. In contrast, they score highest on monitoring the data over time in the long run (65.3%). This could be explained by the different running goals proposed by Karahanoğlu et al. [7] they might have that have different tracking needs.

When looking at the mental model of recreational runners, different gradations exist. The mental model describes an individual's understanding and knowledge of a particular subject. In this case, this topic is HR data about the running regimen. The mental models of recreational runners will develop by interacting with their sport-tracking device and observing the correlations between different data streams and HR data and their actions. The experience of a recreational runner will play a significant role in this process. Runners who have been using HR data to adapt their running regimen for longer have a better understanding of HR than people with less experience. The fundamental design principle here is to make the interface understandable for the whole spectrum of experience. Sufficient information should be provided in the interface to realise this.

As mentioned before, Karahanoğlu et al. [7] performed a study where they researched how runners use sports trackers and what their goals are when using these trackers. These goals can help identify user needs for self-tracking devices. These goals will also create differences in the types of recreational runners proposed by Janssen et al. [8]. The different goals defined by Karahanoğlu et al. [7] will serve as a framework for the final design since these offer concrete goals that users want to achieve. Different health variables combined with HR will indicate the performance level of the runner and will give them insights on how to achieve a specific goal. The interview also resulted in differing desired data streams per user and goal

### 4.1.2 Activities

This section will cover the most essential activities recreational runners perform with self-tracking devices, considering this research's goal. When considering what data should be displayed, it is important to consider the activities the user wants to perform with the wearable. The user should be able to connect real-life to the data they see on the screen. The activities users perform during running differ from those after running. While running, users do not have much time to look precisely at the interface. The activities performed with the wearable are mainly getting a glance at the current statistics of speed, distance, and HR. After running, the user does have time and more attention for details. The user might take time to evaluate the training analysis, allowing a more complex and inclusive interface to be shown. The final design will be an interface for after running and thus should be inclusive of all the necessary data.

Besides, when looking at complexity, there is a difference between the well-defined tasks and the vaguer tasks a user can perform with self-tracking devices. The well-defined task a user can have is looking at specific data points over time. A user might want to uncover what their HR was at time x, thus reading data and information. The more vague task is understanding patterns and uncovering actionable moments. These vaguer tasks ask the user to get to the knowledge or wisdom level of the pyramid. The vaguer tasks are interpreting the interfaces and making decisions regarding one running regimen upon those interpretations. The goal of the final visualisation is to help the user, especially with the "vaguer" tasks.

### 4.1.3 Context

Understanding the context in which the people perform the activities are valuable. The context where the athletes perform their exercise should be visible in the visualisation to help converting the data to a higher level in the data-wisdom pyramid. The main context is the route and distance ran by the athlete. This determines the visualisation of the interface and the data shown. After running, the user can look at the data analysis with much more attention and rest. This is the moment were the runner links real-life events to the data analysis. When looking at the types of runners from Janssen et al. [8], it can be seen that the runners have different contexts. The visualization should be usable for all contexts which means it should be suitable for both devoted and casual runners, thus allowing different level of wanting to reach a goal. Even without having a goal the visualization should be usable. The visualization should not require social interaction so it is functional in a social and individual context.

### 4.1.4 Technology

The final part of the PACT is technologies. The technology in the domain of this research is the self-tracking device. This can be in the form of a smartwatch or a sensor connected to a mobile application. The input for such devices is via a touchscreen and via sensors. The touchscreen allows users to log data or manually surf through the device. With the sensor, data is tracked automatically. If the runner reviews the run at home, a mobile phone or computer might be used to look at the analysis. This allows a detailed and more interactive visualization since the screen is bigger provides easier user input. Vision is being used as output, and data and information will be presented on the screen. Audio output or physical output should not be an option since this might be interruptive.

## 4.2 Preliminary requirements

From the background research, PACT analysis and interviews, it has become clear what requirements the final design must fulfil. The requirements are categorised into functional and non-functional requirements. The requirements are prioritised using the MoSCoW method [37].

### 4.2.1 Functional requirements

The functional requirements are based upon the activities and context part of the PACT analysis. They present the functionalities the design/system should have and describe what the product should do. This means that the final design should be a design that helps the user with the vague task of getting to the knowledge and wisdom level of how to use HR to adapt a future training to reach their personal running goals. After assessing these data streams, the final visualisation should include all the necessary data streams that allow the user to understand how to train for specific running goals. The user should be able to see actional moments by comparing their current run to the desired run.

| **Requirement** | **Priority** |
|---|---|
| Present HR data | Must have |
| Present HR zones | Should have |
| Present speed | Must have |
| Present location | Must have |
| Provide overviews of correlations between different data streams | Should have |
| Be safety critical | Should have |
| Give suggestions for the users running regimen | Should have |
| Give update notifications | Could have |
| Give warning notifications | Could have |
| Transition between current situation and goal situation | Could have |
| Transition between current situation and next training | Could have |
| Be a fully integrated program | Would have |
| Visualize real-time data | Could have |

### 4.2.2 Non-functional requirements

The user requirements are based upon the people analysis of the PACT analysis. The non-functional requirements show what the user should get out of the visualisation and the reliability of it, it describes how the visualisation realises the functional requirements.

| **Requirements** | **Priority** |
|---|---|
| Give insights into achievements | Should have |
| Give insight into the fitness level of the user | Must have |
| Give insight into the performance level of the user | Should have |

| | |
|---|---|
| Give insight into the ability of completing a particular event | Must have |
| Give suggestions for improving running distance | Could have |
| Give suggestions for improving running pace | Could have |
| Give insight into the activity level of the user | Could have |
| Give insight into the overall health of the user | Could have |
| Enable the user to select what data streams are visible | Could have |
| Help the user make decisions regarding their running regimen | Should have |

## 4.3 Formulating the brief

To get an idea of what the final visualisation should look like. The step "formulating the brief" from the visualisation process by Kirk et al. [35] will be used to get an indication. During this step, the tone of the project will be determined. A decision on what kind of visualisation will be made and what interactions will be needed to deliver the desired experience will be decided upon by keeping the users' needs in mind.

### 4.3.1 The purpose map

The purpose map can be used to create an initial vision of what kind of visualisation should be made. Every existing data visualisation can be placed on the map where the placement is based upon two factors, tone, and experience.

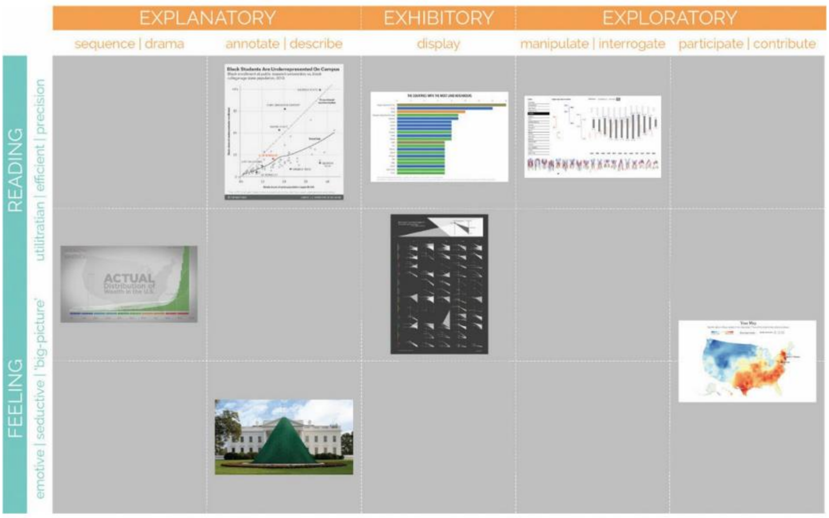



*Figure 5: The purpose map with experience on the x-axis and tone on the y-axis [35]*

The tone, vertical dimension, says something about what tone of voice the design will accomplish the project's purpose, thus helping users understand how to reach their running goals with HR data. The two ultimatums are reading tone, where the users can accurately read off the magnitude of values, the data and information, and the feeling tone, where more emphasis is placed on the "gist of the big" [35, p. 95], thus showing patterns and principles. It is an at-a-glance sense of the relationships that exist within the data.

The experience, the horizontal dimension, says something about how the visualisation operates as a means of communication and through what functional experience the understanding will be achieved by the viewer. Along the experience spectrum, there are the explanatory, the exhibitory and the exploratory states. Explanatory visualisations leave the little prospect of interpreting the meaning of the information to the user. The visualisation tries to help the users process of understanding as much as possible. Exploratory visualisations are more focused on helping the user find their insights. Most of the exploratory visualisations are digital and interactive. Exhibitory visualisations are neither explanatory nor exploratory, they are just a display of data.

The design may have multiple layers where each layer has a different position on the map. The beginning layer might be very exploratory, but a more explanatory design might appear when the user interacts with the design. The final design is both explanatory as well as exploratory. The user can explore their HR data in relation to their running regimen. Exploratory visualisations are focused on helping the user "finding their own insights" [35, p. 90] which is the exact purpose of this study. The exploratory designs are interactive in their nature, the user can change parameters or shift between different interfaces, which will be done in the final design where the external load can be changed. The visualisation's explanatory part is where the user will be shown to which extent a particular training is effective for a specific goal. The different visualisation layers thus have different dimensions on the horizontal axis of the purpose map.

For the vertical dimension of the purpose map, tone, the final design will have a more feeling-like tone. The user may be unable to precisely count all the values but have an overview of the relationships between them.

To conclude, the final design will be an exploratory and explanatory visualisation with a feeling tone. This means that the design will be on the bottom right of the purpose map but sometimes shifts a little to the left. To ensure this position, it is important to show patterns and relationships between data rather than the real specific value of each data point and to make it interactive to allow an explorative data visualisation. Some of the information shown is preordained to help the user to get meaning out of the data shown.

## 4.4 50 Idea generation

After combining all the information retrieved from the different phases, now the first idea generation can take place. This will take place during divergence and a convergence phase. These phases are necessary to elicit all possible ideas and then choose the best ones. This way, as many possibilities as possible will be explored.

### 4.4.1 50 ideas

From the variables defined earlier that are needed to gain insights, 50 ideas were generated [Appendix F, figure 1] on how to analogise these variables. During this divergence phase, as many ideas as possible should be generated. This was done through brainstorming, every idea that came to mind was written down on paper. Nothing was wrong, and it was not obligatory to include all preliminary requirements in every idea, different ideas could be later combined to fit all requirements. From this brainstorming, 50 initial ideas emerged. With these analogies, different dimensions represent different variables. From these 50 ideas, three ideas were chosen to ideate further upon.

i. Running person
ii. The volcano
iii. Heart

### 4.4.2 Convergence

The first idea is the running person. The running person represents the user that is running during their training. As the user starts the running exercise, a real-life version of this run is projected on the watch's display. Before starting the exercise, the runner chooses their goal. This goal includes a pace and a distance. The goal pace will be projected as a second runner. The running person should run at the same pace as the guidance runner. The progress of the distance will be visualised using a bar at the bottom of the interface.

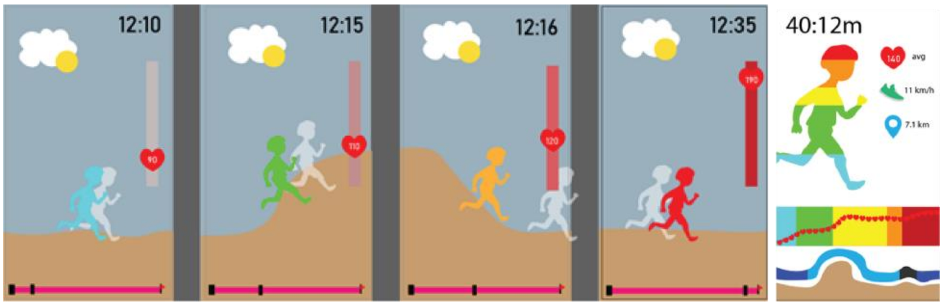



*Figure 6: running man visualisation during and after running*

Where,
Color = HR zone,
Path = cadence,
Cloud = humidity + temperature,
Ghost = desired pace,
Pink bar = desired distance,
Bar with heart = current HR compared to MHR and RHR,

Air = color can be changed for extra variable

After the exercise, the runner can review the .The elevation in combination with HR, speed and HR zones is presented. Suggestions for improved performance are not yet present within this design.

The second idea is the volcano visualisation. The volcano visualisation is a visualisation of the data analysis after the run. The idea of the volcano is to capture multiple dimensions at once, where the interaction between the dimensions is visible. Each data stream is dedicated to its own dimension and influences the other dimensions.

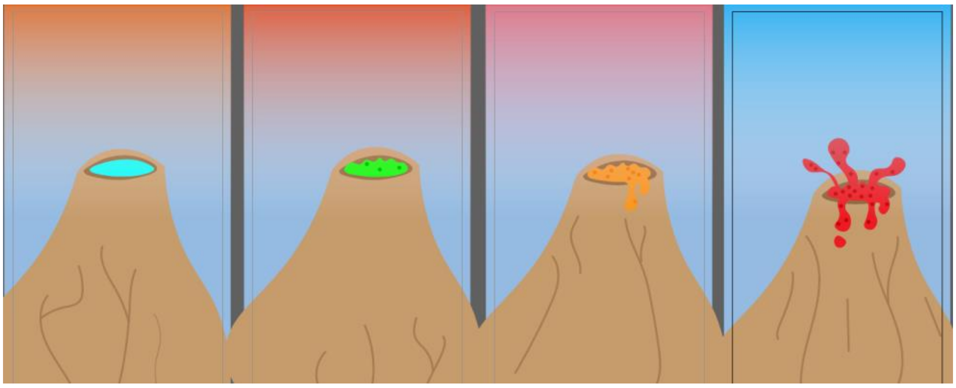


*Figure 7: volcano visualisation after running*

Where,
the amount of bubbling = HR,
color of lava = HR zone,
color of air = environmental temperature,
density of dots in the lava = SV,
and arteries = running speed

What is nice about this visualisation is that it gives a clear overview of all the different data streams related to each other. The data streams are integrated into each other, which helps gain insights into their correlations by clearly showing their influences on each other. The shape of one stream of lava is the product of multiple data streams. A difference in the shape of one stream of lava thus can be explained by multiple data streams. This visualisation is a nice at-a-glance visualisation where the user can see differences in relations quickly.

The last visualisation is the heart visualisation. This is an interactive prototype made in Processing [38] based upon the sketches [Appendix F, figure 2] of a dot that changes form and colour. The dot represents the heart and beats in the frequency of the actual HR. The sliders represent the RPE level and the user’s speed. The user can influence HR by moving the sliders, which should be one of the key elements of the final visualisation. The visualisation is an analysis of the exercise the runner did. If the RPE level increases, the HR increases, if the speed increases, the HR also increases. The %VO2max represents the number of smaller dots within the big dot.

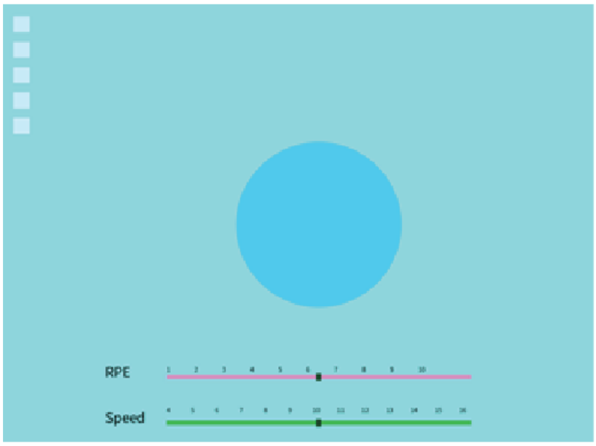



*Figure 8: the interactive dot visualisation*

After meeting with the supervisors, it became clear that the dataset used should be narrowed down for the scope of the research. Also, the visualisations in this divergence phase are not what the final visualisation should look like. The final visualisation should be in 3D to show clear relationships between different data streams. In 3D, it is easier to show how the different factors influence each other.

## 4.5 Conceptual framework

From the ideation phase, a clear conceptual framework can be sketched. Different visualisations have been explored to understand the best way to visualise HR, HR zones, RPE level, speed, and distance to make them meaningful for the running regimen of recreational runners. Preliminary requirements emerged by understanding the future users of the visualisation and the context they will be using it in. With these preliminary requirements, the design space was defined, and within this design space, initial ideas for the final design emerged. The preliminary requirements, in combination with the idea of what kind of visualisation should be made from the purpose map and the initial design ideas, will serve as a basis for the specification phase. During the specification phase, an exploratory and explanatory design with a feeling-like tone should be developed that allows the user to gain insights into achieving specific running goals by interacting with their data. The visualization should be interactive, where the user is able to change the external load, which are the factors they have control over in real-life, to uncover its influence on the internal load.

From the interviews, it became clear that many people use their GPS to link real-life events to the data shown. The speed map from Strava is a great example of creating knowledge because the user can link their location, which is easy to recall, to their speed. Such a location map will also be present in the final design. The interviews also showed that the users who understand HR zones have the most insight into how to use HR to change their running regimen. Therefore, the HR zones were chosen by the researcher as a basis of the final visualization, they are relatively easy to explain and are applicable to every run and especially insightful for reaching different goals. The background research showed that HR, in combination with HR zones, speed, distance and RPE level, gives the best insights. Therefore, the RPE level should be a dimension in the final visualisation. The first idea was to include the variable %VO2max. However, due to time constraints and the amount of insight it adds, this will not be included in the final visualisation.

When discussing the visualisations from the divergence phase with the supervisors, the conclusion was made that the final visualisation should be in 3D to help the user better understand how the different data behave in relation to each other. The visualisation should give insight in the first sense when looking at it. The user should not immediately see all the specific data points but understand their relationships to uncover patterns and principles. Keeping the exploratory characteristic in mind, the visualisation ideas from the convergence phase are not a good fit for the final design.

# Chapter 5: Specification

During the ideation phase, a conceptual idea of what the final design should be like was retrieved. This conceptual idea is a visualisation in which HR, HR zones, speed, distance and the RPE level will be visualised in 3D. It will be an interactive exploratory and explanatory visualisation where the user can adapt the external load to see its influence on the internal load. This idea will be used in the specification phase, where the idea will be evaluated and iterated on. The final design will be specified during this phase.

## 5.1 Working with data

The next step in the visualisation workflow from Kirk et al. [39] will be followed to get a grasp on the data that should be visualised. This dataset had to be gathered, identified, modified, and explored. During this step, different measures will be taken to understand the underlying patterns and principles of the data and how these can be best portrayed in the final visualisation. The data used is sample data from different runs measured with a sports watch.

### 5.1.1 Acquisition

For the final visualisation, data from a run that includes HR, speed, distance, and time is needed. The data was gathered through one of the supervisors who provided the data of the personal Garmin sports watch for four independent runs. The data was measured with a Garmin device and downloaded from the Garmin Desktop app. For the final visualisation, this sample data is the basis. Based upon this sample data, alterations are made with an educated guess of the researcher.

### 5.1.2 Examination

After the acquisition, the data was scanned by the research to get a grasp on the volume and the first relations visible. The data set contained four different runs from different lengths. For each run, index, time, leg distance, leg time, elevation, leg course, position, temperature, and HR were measured. The data streams of interest were speed, distance, and HR over time. All these data streams are numerical, continuous data streams. The condition of the data was good. The other data streams were excluded because they did not have as many contribution to giving insights into reaching specific goals as the ones chosen.

### 5.1.3 Transformation

To make the data ready for its purpose, the data was modified in the excel file. During the modification, unnecessary data streams were removed, and the quantities (km/h, m etc.) in each cell were removed to be left with only numbers. Subsequently, the data was sorted from small to large values. All values for speed were rounded off to whole numbers. During the transformation was chosen which run would be used as sample data for the final visualisation and up to what time. The data goes on for 1130 data points, whilst only 100-150 data points are needed for the final visualisation. The rest was unused.

### 5.1.4 Exploration

The last step is to explore the data. The data was plotted and interpolated to uncover the relationships between the different data streams. What can be seen is that over time the HR increased [Appendix G, figure 1 and 2]. This increase can be explained by the increase in speed over time [Appendix G, figures 1 and 2], which is an increase in workload. For three runs, the HR was plotted against speed and elevation. When looking at the relation between HR and elevation [Appendix G, figure 3], one can see that as elevation increases, HR increases. However, not all plots are statistically significant (p-value). When looking at the relation between HR and speed [Appendix G, figure 4], one can see that HR goes up as speed goes up. Once again, the plots are not statistically significant. This means that HR is not only influenced by speed and elevation, which is what was also found during the background research.

To better understand how the different factors relate to each other, a scheme was made [Appendix H]. Within this scheme, all the factors that influence each other are included. The speed and distance define the external load. The internal load is defined by HR and RPE level. The external load influences the internal load. For the final visualisation, the external load will be visualised using speed and distance, and for the internal load, HR and RPE level. Elevation is left out because this has a slight variation in the sample data, %VO2max was left out since it was not present in the data set and does not contribute to the goals as much as the data chosen. RPE level was included because from the interviews resulted that this was an easy and accessible way for users to add context to the data and that a lot of the participants already used their own made RPE levels. It will help the participants to familiarise themselves with the data, which is important for reaching the wisdom level.

## 5.2 Editorial thinking

Within this section, the overall picture will be sketched of what will be shown to the users. It is important to consider the focus of the visualisation and how this can be best portrayed. One must think about how to convey the goal of the visualisation best. Depending on the perspective, there are several legitimate ways of portraying a particular situation. This section will focus on the angle, framing and focus of the data [35]. The angle determines what will be measured and by which dimensions, framing determines what variables will be left out and what not, and focus determines the most important variables and insights and how these will be highlighted.

### 5.2.1 Angle

To determine the angle, information is needed about what the intended users want and need to know and how the visualisation can be relevant to their context [35]. For this, the PACT analysis and the interviews should be used. One should consider choosing as few angles as possible since more angles will not create richer insights [35].

Considering the previously gathered information, this project's angle will combine HR data, RPE, speed and distance over time to indicate the runner's fitness level, as concluded in the previous exploration. This is relevant because understanding the different factors that influence the HR and RPE can change these factors to get to the desired HR and RPE to reach the specific running goal and fitness level [Appendix H]. Other data that could be included but is not is the stroke volume (SV), blood pressure (BP) an oxygen level (SPo2) because they would make the model too complicated and do not give that much insight into how to achieve a specific goal. Other influencing data streams such as elevation and body temperature were excluded because of the lack of information on their influence or because of the lack of the significance of their influence. A distinction that is of importance for this design is whether the data is controllable by a runner. A runner can change speed, but it is harder to change environmental factors. The uncontrollable factors such as temperature and humidity, do not help the runner with their running regimen because they cannot easily change these factors.

Secondly, HR zones will be visualised to give insights into how one can improve on a specific running goal. Understanding HR zones is relevant for users since running in different HR zones contributes to different running goals, using the body's energy systems is very useful to train the body in specific areas. HR zones are an accessible way of understanding how to get to most out of the body. Also, from the interviews resulted that HR zones were used most by the participants to get insights into how to change their running regimen based on HR data. Thus, it is a very accessible way to learn how to use HR data. When reviewing a training review, one can see which percentage of the run has been run in which HR zone. This is a great way to see where the runner should improve. If the runner has run most of the run in HR zone 5, for example, it should be clear to the runner that next run, the pace should be lowered to stay in HR zone 4. If, after multiple trainings, the HR zone lowers to 3 for the same intensity, it has become clear that the runner improved and that the pace can be increased again.

The most relevant aspect of HR is to see whether it increases, decreases, or stabilizes, this gives an indication of the fitness level of an athlete. This feature of HR will therefore be highlighted in the final visualisation. For RPE, it is important to show that speed influences it in combination with one's fitness level. For the HR zones, it is important to highlight the qualities of the different zones and for what goal they are effective. For the speed, it is important to show that it influences the intensity of the training and, therefore, the HR and the RPE.

### 5.2.2 Framing

To determine the frame the final visualisation is going to be in, one should make decisions on which data to include and exclude. Which category values will be depicted, are all quantities values going to be shown or just those over a certain threshold?

For HR data, the magnitude will be visualised and how this value changes based on the value before. No threshold is chosen because every value of HR is insightful, from the lowest HR to the highest. The HR zones will be represented as distinct values based on the HR data. All HR zones from one to five will be visualized, since the user does not necessarily understand what each zone is good for, the zones will be accompanied with the effectiveness it has for a certain running goal. RPE levels are also distinct values, all RPE levels from 1-10 will be visualised. Speed is a continuous variable and will be visualised for all values. All the values will be visualised over time and based upon location. For the final design, establishing what relationships will be visualised is important.

- As speed goes up, HR goes up
- HR zones are based on HR
- The higher the fitness level the faster the HR will stabilize for the same speed
- The higher the fitness level the lower the HR will be for the same speed
- The higher the HR zone the higher the RPE level
- The lower the fitness level the higher the HR for the same speed
- The lower the fitness level the higher RPE level for the same speed

Where HR will be in bpm ranging from HR rest to MHR. RPE will be on a scale from 1 to 10. HR zones will be from zone 1 to 5 based upon a percentage of MHR. MHR will be in bpm and derived from age and/or from practice. Workload, the external load, will be defined by speed and distance.

### 5.2.3 Focus

The focus of the visualisation will be on how to reach different running goals. These running goals can best be explained by the influence of the external load on the internal load. HR zones are essential in explaining how to reach a specific running goal and therefore will be the main focus of the visualization. In addition HR, and the HR change over time will be shown to give an indication of the fitness level. The user should understand that by controlling the external load, the internal load can be influenced and that the internal load determines the effectiveness of the training.

## 5.3 Iteration on conceptual framework.

The first design included the idea of making suggestions to users for their running regimen. However, this is not how the desired wisdom level will be reached. The wisdom should be created by giving the user knowledge on how HR, HR zones, speed, distance and RPE level correlate and how this can be used to help increase the performance level of the runner instead of telling them what to do. The user should investigate the relationships between the different variables themselves and, with this knowledge, create wisdom. The final design will be an interactive data visualisation where the user will explore instead of being told what to do.

## 5.4 Functional and non-functional requirements

The requirements formulated in the ideation phase will be reformulated and refined into the final requirements for the visualisation. These functional and non-functional requirements will be the basis of the final visualisation. The final visualisation will be evaluated and tested upon these requirements. The functional requirements describe what the product does, and the non-functional requirements describe how it does it. The requirements are prioritised using the MoSCoW method [37].

### 5.4.1 Functional requirements

| **Requirement name** | **Explanation** | **Priority** |
|---|---|---|
| Present the fitness level | The visualisation should be able to present the fitness level of an imaginary runner | Must have |
| Present HR zones | The visualisation should be able to present the HR zones based upon the MHR of the imaginary runner | Must have |
| Give personalized visualisations | The visualisation should show a different shape for every other person | Could have |
| Check | The visualisation should be able to indicate if the health metrics of the runner are out of bound | Could have |
| Give insight in specific goal | The visualisation should give insight into how to achieve a specific running goal | Should have |
| Present HR data | The visualisation presents HR data | Must have |
| Present speed | The visualisation presents the speed | Must have |
| Present location | The visualisation presents the location where the run took place | Must have |
| Give suggestions for the users running regimen | The visualisation will give text-based suggestions for the next training | Would have |
| Have 3 dimensions | The visualisation is a 3-dimensional visualisation where at least 2 dimensions are different data streams | Must have |
| Be a fully integrated program | The visualisations are embedded in a system where switching | Would have |

| | | |
|---|---|---|
| | between the different visualisations will be enabled | |
| Transition between current situation and goal situation | The visualisation shows a transition between the training and the goal | Should have |
| Transition between current situation and next training | The visualisation shows a transition between the training and the next training based on the goal | Should have |

### 5.4.2 Non-functional requirements

| **Requirement name** | **Explanation** | **Priority** |
|---|---|---|
| Stage based | The visualisation should be extended step by step, where each step is based upon the ones before to create wisdom | Must have |
| Use colours | The visualisation should use colours to differentiate between different variable quantities | Must have |
| Use shapes | The visualisation should use shapes to differentiate between different variable quantities | Must have |
| Fitness level | The fitness level should be based upon the HR, workload and RPE. | Must have |
| HR zones | The HR zones should be based upon the MHR from the user | Must have |
| Out of bound values | The out of bound values should be based upon the MHR from the user | Could have |
| Personalized visualisation | The visualisation should be personalized based upon the goal and the fitness level of the user | Should have |
| Give insight | The visualisation should give insight into how to achieve a specific running goal by using | Should have |

| | | |
|---|---|---|
| | the relationships between the different variables | |
| Use sample data | The visualisation is based upon sample data and altered with an educated guess of the researcher | Must have |
| Use real-time data | The visualisation is based upon real-time data | Would have |
| Enable adaptivity of visible data streams | The user can select what data streams are visible | Could have |

## 5.5 Mental visualisation

To specify the final visualisation further, his section will explore and capture an initial vision of the mind's first idea when thinking about the specific topic. This way, a more specific view will be created on how the final visualization might look. This includes colours, shapes and patterns that come to mind when thinking about the topic, which might lead to initial sketches of the final design. Besides, the language that comes to mind should be considered when thinking about the topic. Instinctive keywords reflect the type of language that might be suitable for the visualisation. Both things might help in the final visualisation. They might all be used, or none, but they help iterate towards the final visualisation. When thinking about HR data in relation to recreational runners' running regimen, the first colour that comes to mind is red because of the HR data and influencing factors such as BP. When thinking about recreational runners, health comes up, related to health are clear and clean colours. Finally, HR zones are very important in understanding HR data. The currently available visualisations mostly use the colours of the rainbow to distinguish the different HR zones.

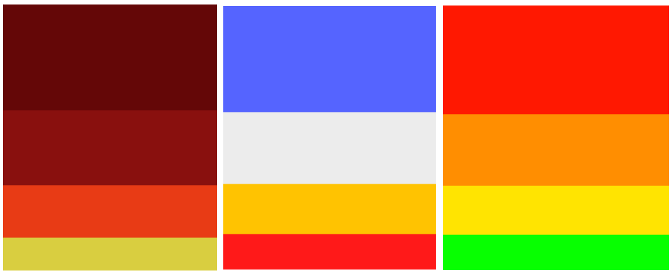


*Figure 9: colours for the mental visualisation*

When thinking about the topic, the patterns and shapes that come to mind are primarily fluent and rounded shapes. The heart is something natural, and the shapes associated with it also. Another important image in the mental visualisation is the image of location. Location is the feature that brings all the data streams together and helps the user recall particular events.

## 5.6 First visualisations

From these requirements, the first visualisations were made. The final visualisation will be made with Maya. Maya [39] is a professional 3D software for creating objects, scenes, and animations. Using the requirements, different sketches were made to explore the design space [Appendix I]. The most important requirement was to make the shape 3D, where different data streams were related to each other. These visualisations were also made in Maya. However, only one of the visualisations included the location, which is another crucial requirement for the final visualisation.

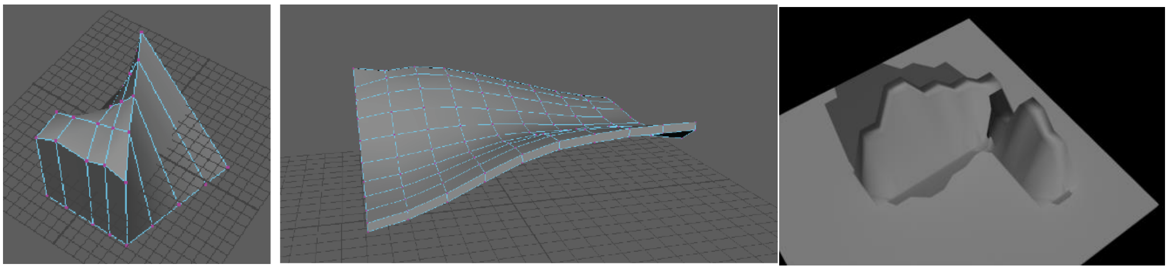


*Figure 10 : first 3D visualisations where each axis represents a different data stream in Maya*

The visualisation that offered the best options and met most requirements was chosen to iterate further upon. This is the location-based visualisation where the height and broadness of "mountain" parts will correlate to different data streams and create a path that describes the route and distance run. Based on this basic visualisation, new things are added. The chosen design was elaborated further upon and will be used as the basis for the realisation phase.

# Chapter 6: Realisation

The final concept from the specification phase will be realised during the realisation phase. The final prototypes is made for the user tests in the evaluation phase. Within this section, the process of making the final prototype is described. Also, all the features that the final prototype has will be described here. The process is influenced by client feedback and expert opinions to make a final prototype that is of the best quality and matches the client's requirements. When looking at what must be realised, the requirements specified in the specification phase should be considered together with their priority.

## 6.1 Lo-fi prototype

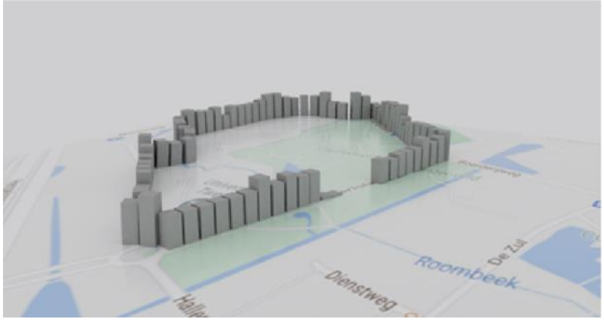
To realise the location-based visualisation, the map from the university was downloaded since this is a place most people know. On this map, a route was made. The route does not correspond to the route of the original sample data, this is because of privacy reasons. The addition of the different data streams will be described in the following sections.

### 6.1.1 Speed

After the route was set up, each bar on the route was linked to one data row in the original dataset. Bar number one corresponds to index one in the excel file. To visualise the speed, the height of the bar was adapted to match the speed.

### 6.1.2 HR

Secondly, each bar got a specific transparency of red colour corresponding to the HR at that moment. The problem, however, was that the difference of one bpm was not visible using only transparency. Therefore, another dimension should be added to get the desired result. The choice to add different shades of red to indicate the HR, as seen in figure 8, did distinguish the different HR levels better but the slight differences between HRs of one bpm were still hard to see.



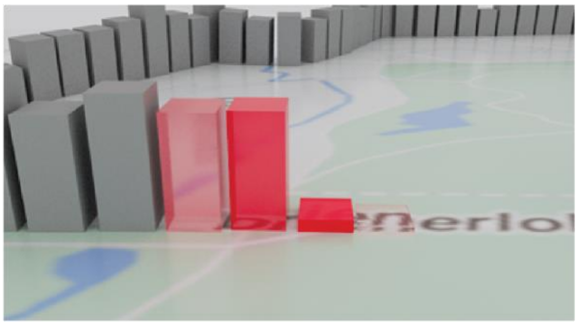


*Figure 11: the route, speed, and HR*

A new approach for adding HR was adding an entirely new object to the visualization in the form of a dot that gets bigger if the HR increases. However, it is hard to see if a dot gets bigger or smaller. Colours were added to clarify the HR behaviour. If the HR for sec t2 is bigger than sec t1, the dot's colour is red. If the HR for sec t2 is smaller than sec t1, the dot's colour is green. If the HR for sec t1 and t2 are similar, the dot's colour is blue. For the user, the goal should be to have as many blue and green dots as possible in the middle and ending of the run, this represents a stable HR which corresponds to a higher fitness level. One can see that at the beginning of the run, the HR rises and that towards the end of the run, the HR remains stable, this is an indication of a good run.

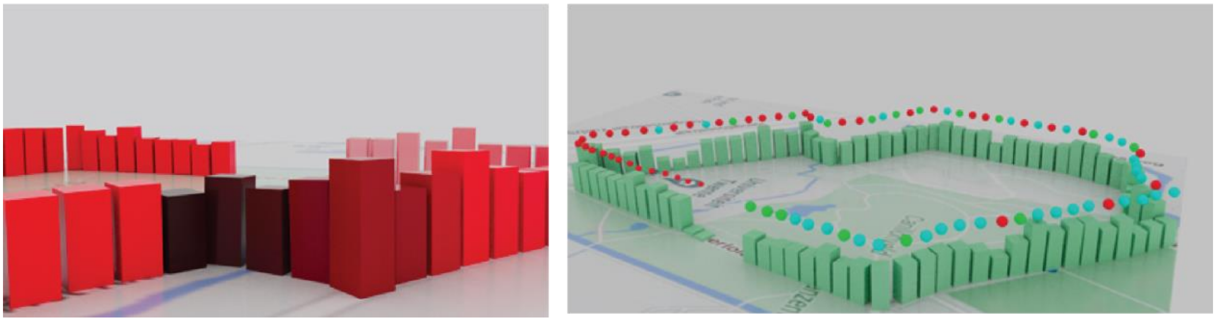


*Figure 12: different tries on HR visualisation*

The HR for the untrained individual has a bigger increase, this can be seen in the number of red dots. The trained individual has a steadier HR which results in more green and blue dots. When comparing the two runs, one can also see that the size of the dots for the untrained individual is larger than the ones from the trained individual. The untrained individual has an overall higher HR.

### 6.1.3 HR zones

The next step was to add HR zones in a way that they can give insights to the user. To get an idea of how the HR zones relate to the speed, the HR zones were visualised through colours. The first run calculated was for a trained person with the age of 40, the HR zones were be calculated with the following equation:

$$Target\ HR\ =\ (HRR\ x\ percentage\ of\ intensity)\ +\ RHR$$

Where $HRR\ =\ MHR - RHR$

HRR = 180 – 50 = 130 bpm
HR zone 1 = 50 bpm - 127 bpm
HR zone 2 = 128 bpm – 140 bpm
HR zone 3 = 141 bpm – 153 bpm
HR zone 4 = 154 bpm – 166 bpm
HR zone 5 = 167

The second visualisation is for an untrained person with the age of 40:

HRR = 200 – 70 = 110
HR zone 1 = 70 bpm – 135 bpm
HR zone 2 = 136 bpm – 146 bpm

HR zone 3 = 147 bpm – 157 bpm

HR zone 4 = 158 bpm – 168 bpm

HR zone 5 = 169 bpm – 200 bpm

For both individuals, the HR zones were be added to the visualisation. This created two different prototypes for two different fitness levels. However, for the less trained person the HR went up higher at the same speed. This increase was estimated through an educated guess of the researcher. A slower speed will help the individual to train in the same HR zones as the trained individual.

*Figure 13: HR zones for two different persons*

### 6.1.4 RPE level

After visualising the HR zones, the RPE level should be visualised. The RPE should be visualised in relation to the speed, HR, and HR zones. The RPE is a distinct number from 1 to 10. Therefore a scale should be present to show the difference between 1, 2, 3 etc. The visualisation of the RPE level was done with the same bar representing the speed and HR zone. This way, for each bar, a 3-dimensional shape occurred for each data point where the height represents the speed, the colour represents the HR zone, and the extension of one side represents the RPE level.

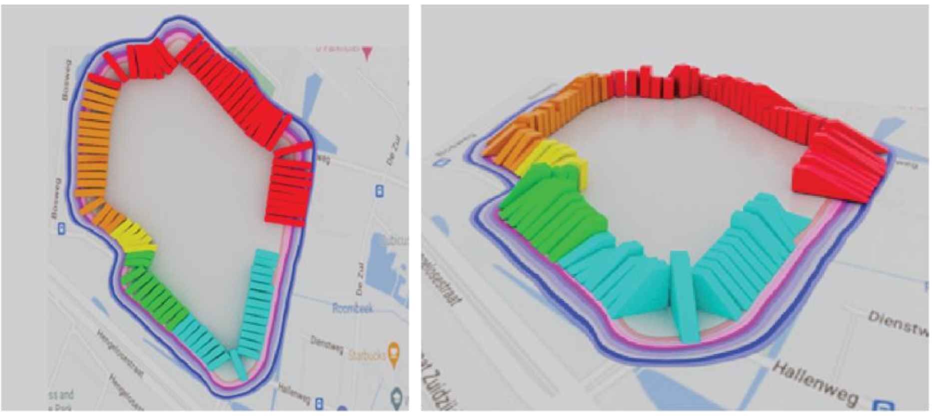



*Figure 14: RPE level*

## 6.2 Expert opinion

To validate and improve the lo-fi prototype, expert opinions were used to see where the improvement for the design lies. The visualisations were shown to the experts on which they gave their opinion. The goal was to uncover what the opinions were on the looks of the visualisation and how the experts would interact with it. There was interaction with four experts who all gave their opinion on the visualisation. E1 and E4 are experts in sports-data visualisation. E2 has expertise in the HCI field and experience design of personal health technologies and wearable computers. E3 is an expert in the field of HCI as well and focuses on designing and developing tools that support the health and wellbeing of users. E1 and E2 were explained what each component in the visualisation meant immediately and afterwards asked which insights they got out of it. E3 and E4 were asked to try to interpret it themselves first and then asked to share their insights.

All experts mentioned the lack of clarity. No numbers were shown within the visualisation to indicate quantities. With the current visualisation, an individual cannot see the specific statistics of one data point. However, the vision of the researcher is to make an explorative visualization, which is abstract and does not necessarily need specific data points to be visible. With this in mind, the choice was made not to implement this expert opinion. What should be implemented is the mention that a legend is missing to explain what the different colours and shapes mean. Another trouble with the design was that the colours used for HR and the HR zones were similar, which could confuse the user. Therefore, other colours should be used. After discussion on the RPE level it was concluded that the variable is hard to understand and therefore should be visualized very simplistic. The RPE levels should be accommodated with a table of all the ten different levels and how these levels relate and can be recognised in real-life.

The expert opinions of E3 and E4 showed that the design was useful in giving an at-a-glance view of the relations and patterns in the data. E3 was very successful in providing insights with the use of the prototype where E4 had more trouble. This trouble was explained by the lack of a legend and the viewpoint of the visualization.

The way E3 would use the visualisation was to get a grasp on patterns and that the visualisation was of explorative nature. E3 thought the visualisation was novel and could help potential recreational runners gain insights into their running regimen. The visualisation is nice and useful to uncover trends; however, as mentioned earlier, it is hard to see specific data points.

E4 pointed out that the currently used route that is used could be extended to a longer round. They said that this should not be a priority but could be something to think of when having time left.

### 6.2.1 Client feedback

From talking to the client, the supervisor and the critical observer, the idea to divide the different data streams into internal and external loads occurred. The internal loads are the RPE level and the HR of the runner. The external loads are the speed and distance of the run. The final visualisation should give insight into how these two loads influence each other. This should be done by allowing the user to change the external load to see its influence on the internal load, thus being able to change speed and distance.

### 6.2.2 Feedback conclusion

From this section can be concluded that the visualisation is successful at giving an at-a-glance view of the data and their relationships. The visualisation needs clarification which will be done through a legend and different use of colours. The legend should allow the user to get a grasp on what they are seeing, the colours should help better distinguish different data and data streams. The visualisation of the RPE level should be reconsidered. If the RPE level should be kept in the visualisation, it should be visualised in a different, more simple way. Also, the interaction should change, right now, the user can change speed only. Also, the distance dimension should be added to allow the user to change every factor in the external load.

## 6.3 Framework of layered understanding

The navigation through the different visualisations is important for the generation of wisdom with the user. The user should understand the basics before proceeding with a more complicated visualisation. To retrieve this wisdom, the visualisation starts at the basic level of speed and location.

After the user understands that the speed differs in the location, the user can go to the second layer to add HR. the user sees HR in combination with speed and should understand that the speed influences the HR. When the user understands the relation between HR and speed and can correlate this to the real-life event that happened using the location. After adding the layer of HR, the layer of HR zones will be added. The user understands HR in relation to speed and can now relate this to HR zones. The final layer will be the RPE level. However, the expert opinions resulted in the RPE level being too complicated to add to the visualisation. The user tests will show if the RPE level is of added value.

Another navigation structure is the navigation through different visualisations, thus the different distances. The main goal of the visualisation is to give insight into the runner’s fitness level and how to improve this fitness level. However, if the time also allows, the insights into the other running goals should be added to the final visualisation. The navigation through these different goals [Appendix J] should have a clear structure where the user can select their goal and will get insights into how to achieve this goal and how to track progress when trying to achieve the goal.

## 6.4 Mid-fi prototype

The mid-fi prototype was reached by integrating the scenes of the lo-fi prototype, thus the different visualisations for each speed level. Instead of having separate static scenes, the scenes now transitioned into each other to see how the different data streams relate to each other. This way, the user can have a better interaction with the visualisation. Secondly, the influence of the external load on the internal load should be added to the visualisation, and the feedback from the expert interviews should be integrated into the visualisations.

### 6.4.1 Integrating expert feedback

The expert feedback showed that the HR dots' colours should be altered. This resulted in the colour blue that will be used for the HR. The colour is light if the HR decreases, medium if the HR remains stable and darker blue if the HR increases. The colours used for the HR zones remained the same. Also, it should be apparent where the runner started running, in which direction the runner ran, and where the runner finished, this was done using arrows and a finish line.

The lo-fi prototype lacked a legend, this legend is placed in Maya to allow the user to always see it. A legend was made for the colour of the HR and HR zones and the RPE level.

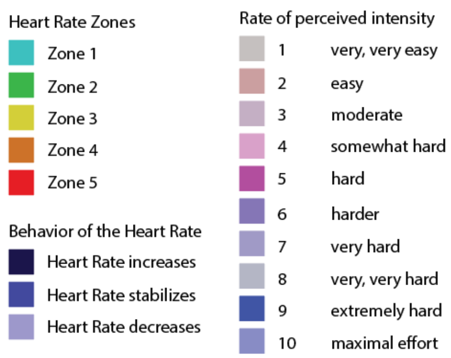



*Figure 15: legend*

The RPE level should also be visualised differently. It was unclear what each level is since it was only indicated with colours. To simplify the RPE level, it is presented with just a number. This number represents the number that the user gave to the run after running. By changing speed, this number changes since the speed influence the internal load, which is the HR and the RPE level. The user should recognise that overall a higher speed and distance corresponds with a higher HR and thus a higher RPE level.

### 6.4.2 Other iterations on the prototype

Besides the expert opinions and the client feedback, the researcher also gained a new perspective on how to visualise the different variables. This caused a shift in the visualisation. First of all, the extension of the bars is now no longer dedicated to the RPE level. Therefore HR could take this place. Instead of the dots that grow bigger, the HR is now presented as the extension of the bars. The higher the HR, the larger the extension. The visualisation is layer based. The first layer only shows the HR in relation to speed and distance. Within this visualisation, the colour of the bars represents the behaviour of the HR. These are the same colours of blue as the dots originally were. For the second layer, the HR zones were added. The shape of the bars still represents speed and HR, but the colours of the bars are now the HR zones, the same way described earlier. In the last layer, the RPE level was added in the form of numbers. By deleting the dots above the bars and implementing them in the shape of the bars, a fully integrated 3D visualisation is the result.

### 6.4.3 Integrating scenes

To make the visualisation interactive and explorative. The user should be able to change the external loads. The external load consists of speed and direction. Speed is the most essential factor of the external load and, therefore, is implemented in a slider with which the user can play. The user can move from a low speed to a higher speed and see the HR changing accordingly. Three different visualisations are made to mimic the influence of distance, each with a different distance; 5K, 10K and 15K. The idea is that the longer one runs, the higher the HR will be in the end. When comparing the different distances, the user can see that for 5K with maximum speed, HR zone 5 is hardly reached, whilst for the 15K, not maximum speed it is. The user can change the speed slider at all different distances. This way, the combined effect of distance and speed on the HR and HR zones can be explored.

### 6.4.4 Adding the running goals

The final goal of the visualisation is to give the user insights into how to train to achieve specific or a combination of running goals. The running goals are to improve distance, improve pace for the short distance and improve pace for the long distance. Another goal is to improve the overall fitness level. This, however, is a combination of the three other goals and, therefore, will not be highlighted in the visualisation. The different running goals are visualised by adding a legend with the three running goals. After each goal, a bar is placed that can be filled up. The more filled up the bar, the more effectively one is training for that specific goal. By adjusting the speed, the bars move, and the bar has different settings through the different distances. The user should be able to identify a combination of speed and distance that matches their goal or a combination of goals.

## 6.5 Final prototype

After the realisation process, the final prototype was ready. The final prototype is a series of interactive explorative data visualisations. The series consists of three layers. The first layer is HR in relation to speed and distance, the second layer is HR zones and HR in relation to speed and distance together with the goals, and the last layer is RPE level, HR zones and HR in relation to speed and distance together with the goals. Each layer visualises each distance (5K, 10K and 15K), where the speed is adjustable with a slider. With the change of the external load, the internal load changes, and the bars that show the training effectiveness for a specific running goal. This allows the user to explore how the different data streams relate and help reaching specific running goals

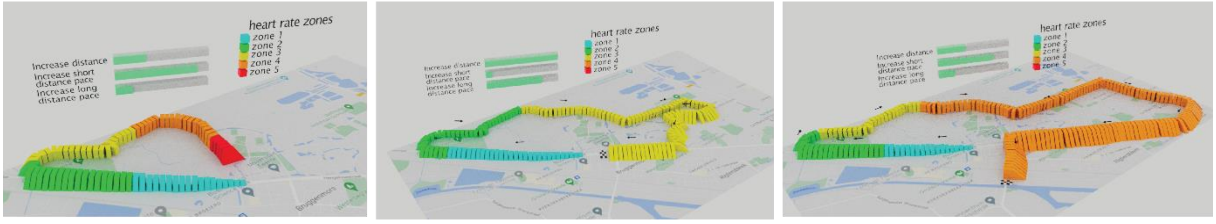



*Figure 16: 5K, 10K and 15K visualisations at different speeds showing the HR zones and HR*

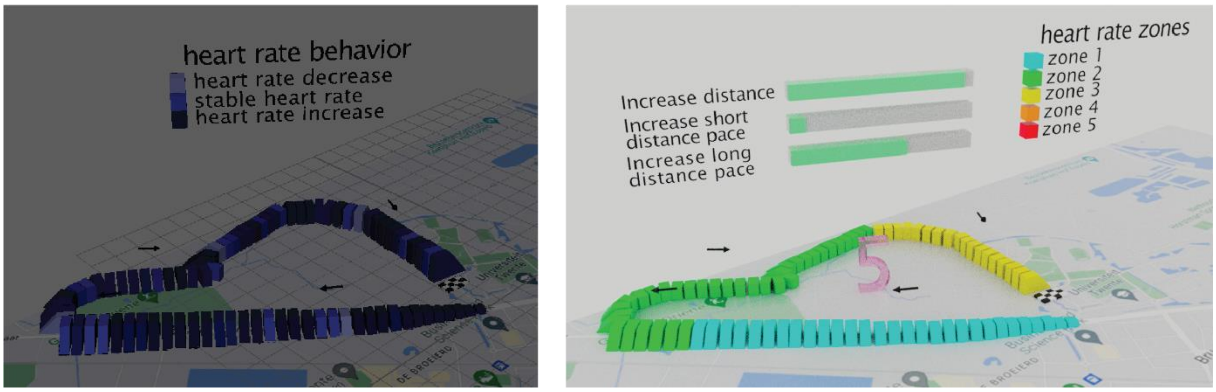



*Figure 17: 5K visualisations showing HR and RPE level and HR zones*

# Chapter 7: Evaluation

During the realisation phase, a final prototype was produced. During the evaluation phase, the question of how well the users can learn and use the prototype to achieve their goals will be answered. Also, the non-functional requirements will be evaluated. The goal is to uncover how well the users can use the prototype, thus the visualisation, to achieve their goals. The goals, in this case, are to meaningfully change the running regimen to train effectively for the desired running goals. It thus has to be investigated if there is an increase in insights in the HR data and especially if there is an increase in the wisdom level of the users. An increase in wisdom means an increase in the ability to understand how to reach specific running goals.

## 7.1 Setup and design of user evaluation

To measure the effectiveness of the visualisation, user tests were performed to see how users interact with the final visualisation and what insights were obtained from it. For the zero measurements, eight participants were asked to interact with HR data presented in the traditional way. The researcher measured the number of statements made at each level of the wisdom pyramid. Eight participants were asked to interact with the researcher's visualisation to uncover if the design adds extra understandability. Again, the number of statements made at each level of the data-wisdom pyramid was measured. The difference in the number of statements made at the knowledge and wisdom level will show if and to what extent the new design improves the understandability of the users. The questions the researcher asked [Appendix K] were the same for the zero measurements and the user test. The researcher could not give extra information about the interfaces since this would bias the statements of the participants. In total, 16 participants participated in the study. Four women and four men participated in the zero measurements, and five women and three men participated in the user test. The participants were reached through text message and email.

## 7.2 Results

After the testing, the results from the zero measurements Z1-8 were collected, and the results from the user-test with the prototype P1-8. The testing resulted in the researcher's visualisation, increasing the wisdom and knowledge the participants got from the data. There are differences when looking at the percentages relative to the number of statements made during the test. In total, 13% of all statements in the zero measurements were data statements, with the prototype, this number was reduced to 7%, 36% of the information statements were reduced to 28%, and 12% of wisdom statements increased to 29% of the total statements. Even though the number of knowledge statements went up from 72 to 83, the relative amount of knowledge statements decreased from 39% to 36%. There thus were more statements, but this increase was caused by an increase in the total statements made. The number of wisdom statements increased, and the participants could call out more actionable moments that showed they had insights into the principles of the HR zones and how to use these to reach specific running goals. This means that the goal was met to increase the number of meaningful insights.

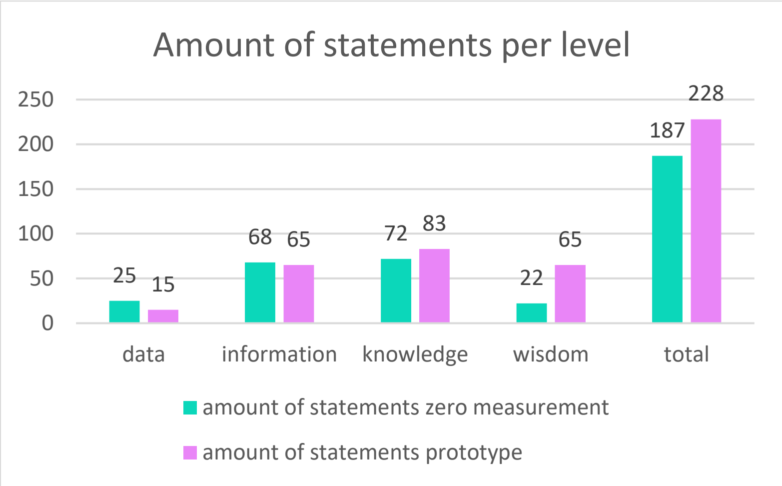



*Figure 18: results of the user test*

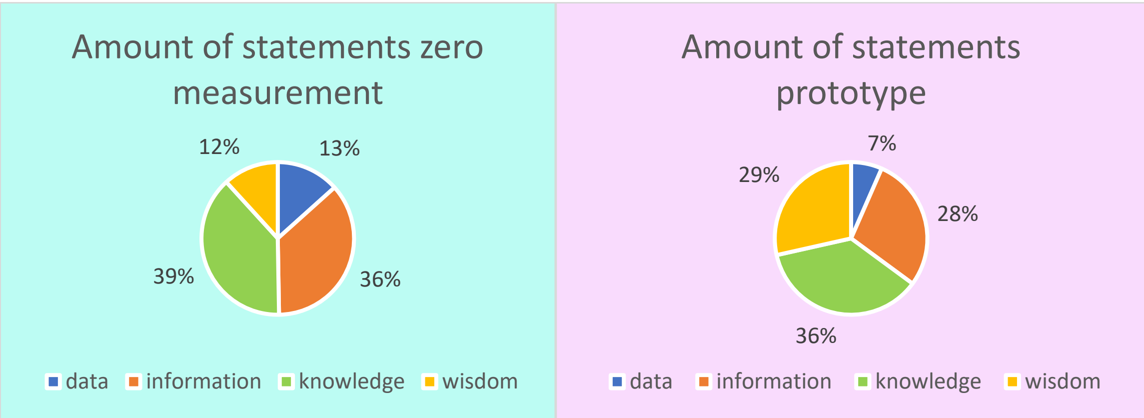



*Figure 19: amount of statements made relative to the total amount of statements*

When looking at the different visualisations separately, a difference in effectiveness can be found. The first visualisation, showing HR in relation to speed and distance, was sometimes hard to understand for users. The first thing that became clear was that the angle of the visualisation was important. A top view enabled the users to see the increase in HR more clearly than a side view. All eight participants got the insight that HR increases as speed increases. However, only five participants mentioned that they used the information on the different shades of blue of the blocks for this. Four participants understood that a permanent light blue block could indicate that the spot of the route influenced the HR, there was a connection between location, HR, and speed. The knowledge the participants got from the first visualisation was mainly because of the shapes and not the colours. Four participants specifically mentioned that they preferred the visualisation with the HR zones over the visualisation with only the HR. During the zero measurements, the course of speed over time was mentioned by all participants. The relation that the participants saw was that when the speed dipped, the HR dipped as well. However, they did not mention that when the speed increases, the HR increases explicitly as a clear relation

When looking at the second visualisation, where the HR zones were added, from the statements made it can be concluded that the understandability increased. The users, even when not familiar with HR zones, were able to understand that the speed influenced the HR and thus the HR zones. Also, when asked if the users noticed differences between the different distances, all could mention that as distance increases, the HR increases. “If you walk at this pace until here, then you will not reach this HR zone, but if you keep walking, you will” P8. For the zero measurements, four of the participants mentioned that with a different distance, the HR and speed deviated more during the run, some of them did not mention a clear relation between distance and HR. Z3 mentioned that “the HR builds up more in the other distance” and that “a tempo might be too high for a distance”, which shows that they understand the influence of distance also, Z6 mentioned that for a different distance, the HR was lower. One participant did not mention any relations at all.

When looking at the understanding of goals. All participants in the prototype test managed to understand that combined speed and distance would determine the HR zones one will run in and interact with the visualisation until an optimum speed and distance were found for a specific goal. The participants were also able to apply different methodologies for the different goals.

The last visualisation which had the addition of the RPE levels resulted that six participants did not think the number would provide additional insightful information. The participants mentioned that it was a nice way to measure improvement but that it did not add anything other than that. Especially since a lot of different factors can have influence on the perceived intensity that might not be measured

## 7.3 Reflection and discussion on the setup and design of user evaluation

The selected evaluation method and techniques should be evaluated to conclude on the user evaluations. The different aspects of the evaluation will be discussed in the following sections.

### 7.3.1 Participants

For the user test, a total of 16 participants were recruited. Eight participants performed the zero measurements, and eight participants performed the user test with the visualisation. The inclusion criteria for the participants was to be a recreational runner in possession of a wearable. However, this was not an exclusion criterion, and due to time constraints, only five of the 16 participants met both criteria. Secondly, the participant group were all students. This means that the education level was not representative of the whole community of recreational runners. Also, students have a thinking level which enables them to read off graphs better. This could cause them to interpret the graphs presented in the zero measurements more easily than most people. It could also cause the participants not to mention all “obvious” observations made because the participants might feel like it is logical for them to understand it. This could cause a reduction in statements made. These factors could cause bias in the results. It is recommended to perform a user study with a more generalisable participant group and with the specific target group.

### 7.3.2 Procedure

The zero measurements and the user-test data were presented to the participants. The way of presenting differed during the two measurements. The difference in these ways of presentation was measured. However, the data that was presented did also differ from each other. The data presented in the traditional way of data presentation was actual data provided by the supervisor. The data presented in the visualisation was dummy data that was based on data provided by the supervisor and altered with an educated guess of the researcher. This means that besides the effect of a different presentation of the data, the difference in data could also influence the change in the statement amount. Secondly, for the zero measurements, an interface of Garmin was used. This is not generalising to all current existing interfaces. In future research, the insights gained from the interfaces should also be researched with other wearable brands. Overall, when reflecting on the user evaluation, a few things could increase the validity and reliability of the results.

## 7.4 Evaluating non-functional requirements

Besides the user evaluation, the non-functional requirements should be evaluated as well. All the must-have requirements have been met. The visualisation is stage based, the user can first look at only the HR data, then add HR zones and in the final stage, and then add the RPE level. The visualisation uses colours and shapes to differentiate between different variables and changes by adapting the external loads. The visualisation presents the user's fitness level based on the user's HR, workload and RPE level. This is the final stage of the visualisation, where the HR is presented in the broadness of the blocks, the workload is presented in the number of blocks (distance), the height of the blocks (speed) and the RPE level is presented as a number. The visualisation visualises HR zones. The prototype does not yet use personal data for this, but the HR zones are based upon the MHR of the imaginary user, and the visualisation uses sample data that was altered with an educated guess of the researcher.

The should have that has been reached is to give insights. The visualisation gives insights into how to achieve a specific running goal by showing how effective the combination of the external loads is for a specific training goal. This is done through bars that change relative to the effectiveness of the specific distance and speed settings. The should have requirement that the visualisation should be personalised based upon the goal and fitness level of the user is partly met. The visualisation is personalised to be used for all three different running goals. However, the visualisation is not yet personalised using different fitness levels and based on real data.

The could have requirements have not been met. The visualisation does not show out-of-bound values, and the user cannot select what data streams are visible. The user can go through the different stages, which influence the data shown. The user is not able to change the data shown within each stage. The second stage, for example, that shows HR data, speed, distance, and HR zones, does not enable the user to remove the colours to be left with only HR data, speed, and distance. Overall, it can be stated that all the necessary non-functional requirements have been met.

# Chapter 8: Discussion and future work

The overall results seem very promising. The results show that the visualisation increases the number of statements made in the wisdom level from 12% relatively, to 29%. The increase in wisdom statements could explain the relative decrease in knowledge statements. Wisdom must have been knowledge before it can convert into wisdom. This can be explained by the data-wisdom pyramid that states that without knowledge, wisdom cannot be reached. If there was a decrease in knowledge and a decrease in wisdom, then there were less meaningful insights. However, because there was an increase in wisdom, the insights retrieved from the visualisation were more meaningful, and the number of knowledge statements decreased because they were converted into wisdom. When looking at the percentage of knowledge combined, one can see that this went from 51% (12% wisdom and 39% knowledge) to 65% (29% wisdom and 36% knowledge). This means that although there was a decrease in knowledge statements, overall, there was an increase.

The number of data statements went down from 13% to 7%. This makes sense since the visualisation is an interactive explorative visualisation. Hard data values are not present in the visualisation, which can explain the reduction in data statements, the users are not able to read off specific data values. Specific data values were present in the Garmin interface; the users could read these specific values. The goal of the visualisation was to help people understand how to reach different running goals. Most of the wisdom statements that resulted from the test with the visualisation were statements on how to reach a specific goal (91.52%). This can be explained by the focus of the visualisation, which is to give insights into how to achieve specific goals. The increase in wisdom statements from 12% to 29% can thus be explained by the focus of the prototype. The zero measurement interface was not focused on showing how to reach specific running goals and, therefore, has fewer wisdom statements. The zero measurements were more effective in giving specific data values than the visualisation. If the Garmin interface would explicitly state what HR zones to train in, for example, this might already improve the wisdom statements since the participants might then use that information to call out actionable moments.

The difference in insight in the relation between HR and speed could be that the interfaces from the visualisations did not show this relation as clearly as the prototype. With the prototype, one can actively change speed to see its influence on HR. Besides the data after a run, the user thus has extra data to uncover this relation by shifting in speed which is not present in the zero measurements. This seems to be very effective since it increased the insights into the relation between speed and HR. The same goes for the relation between speed and distance. The participants in the zero measurements could see the data for the two different distances. However, the speed was equal. By allowing the participants to change both speed and distance in the prototype, it was easier for them to uncover the relationship between distance and HR. When looking at how the final prototype relates to the current state of the art, it is evident that this solution is effective and novel in helping users uncover patterns and principles of HR data. The traditional data presentation consists of graphs and numbers, and some applications offer maps. However, the integration of all data streams is mostly missing in these presentations. The traditional way of presenting data enables the user to uncover specific data values over time. However, the lack of the ability to show overall patterns for non-data-experts, this is where the prototype comes in.

Future work should make the visualisation usable and personal for all users. This means that the visualisation should be able to process real data gathered from wearables and visualise these the same way it is now. The user should be able to go through the visualisation in 3D and view the visualisation from all different viewpoints to enable them to see the shapes in complete form. It is also important to add a legend that shows what the shape of a single block means. This can be done by adding a block in the legend and showing that height is speed, and broadness represents HR. In the future, the feature that enables the user to choose the visible data streams should be added. This way, no unnecessary data streams will be shown to the user. Also, another software should be chosen to visualise the data. The program used was Maya. Maya is an excellent tool for making 3D visualisations. However, it is hard to visualise data since there is no option to import data files and changing the visualisation accordingly. Another limitation is the lack of data available. The data used for the prototype was sample date that was altered with an educated guess of the researcher. In addition, the researcher is no data expert and gained the knowledge from literature research. This is not a problem since the goal was to uncover how design practices could be used to make HR data meaningful rather than to uncover how to process data. But the accuracy would be improved in the future if real-life data were used. It could be of value to research the effect different data streams have on HR to make the visualization more accurate. Right now, the prototype enables the user to change speed with a slider and choose between three different distances. In the future, it would be an improvement if, within one visualisation, the user can change speed as well as the distance with the slider. This allows for more smooth and detailed data exploration and makes it easier to find an optimum, and offers a wider variety of distances. The user then could also look at 7 km or 12 km, for example. Besides the data streams used within this visualisation there are other factors that have an influence on the internal load such as elevation and temperature. In future work these factors could be added. Currently, existing brands might want to include the focus on specific running goals if interested. They right now offer as a great means for providing data specifics, but by adding the context of how to achieve specific running goals, they might offer the users more insight into how to change their external load to get to the internal load needed to reach specific goals.

The strength of the prototype is the level where the HR zones in combination with HR, speed, distance, and different goals are visible. From the user evaluation resulted that the most insights into achieving specific goals were gained from this visualisation. The colours of the HR zones, in combination with the broadness of the bars, give insight into the behaviour of the HR. The bars that present the effectiveness for every goal help the users to see how they change and differentiate between the combination of speed and distance to find an optimum for their goals. Also, by enabling the users to choose between different distances, they can find a setting that works the best for them. A beginner might not want to run 15 km for the first run and choose to run 5 km. By adjusting the speed in the 5 km run, this person still can find the optimum way of training for their goals. A more experienced runner could go through all different distances and find the optimum combination between speed and distance. The strength of the overall prototype is that it is a powerful tool for showing patterns. Instead of individual data points, the visualisation shows the overall relations between data and causes the user to uncover actionable insights. By using shapes and colours instead of numbers, the user gets an abstract idea of how the different variables relate and allows the user to see differences in the glimpse of an eye.

# Chapter 9: Conclusion

To conclude, there is a lot of data that wearables can track. However, the way that this data currently is presented in the interfaces sometimes prohibits the user from getting meaningful insights out of this data. For running especially, HR data contains a lot of valuable insights that can help with the running regimen. The goal was to uncover how design practices could be used to increase the understanding of HR data for the running regimen of recreational runners. The research question "What design principles can be employed to improve the understanding of HR data for recreational runners?" was researched. To tackle this problem, background research was performed to see the state of the art and get insights into how HR data can be used to give insights. From the background research resulted that HR, in combination with HR zones, speed and distance, can give rich insights into how to achieve specific running goals. Also, the data-wisdom pyramid was evaluated to uncover how to convey data into wisdom. From this was concluded that the use of context was a significant factor for this. In combination with the interviews, the idea occurred to use location as context. The users could use this as context and link real-life events to the data analysis.  During the ideation phase, different design spaces were explored. What became clear was that the final design should be a 3D design to be able to visualise the different data streams in relation to each other in one 3D space and shape. In the final design, this can be seen in the blocks where height represents speed, broadness represents HR, colour represents the HR zones, the number of blocks represents distance, and the placement of the blocks represents the location.

After testing, it became clear that the purpose of the study was met. By providing context through a location-based and 3D visualisation, the users could get to a higher level in the data-wisdom pyramid. Also, the addition of the different running goals contributed to the insights the users got from the visualisation. It can be concluded that the prototype is a novel way of helping recreational runners explore their HR data in correlation to their running regimen.

The final visualisation successfully increased the participants' knowledge and wisdom, especially the visualisation with the HR zones and bars for goals. The visualisation with only the HR was not as effective. When looking at the research question "What design principles can be employed to improve the understanding of HR data for recreational runners?" it can be concluded that by using HR zones to indicate how to reach specific goals, the insights that the users gain improve. Working in 3D helps to understand patterns and principles, and using a map gives context, which helps move up in the data-wisdom pyramid. The bars representing the effectiveness of training for a specific goal are an easy means to help the user understand how the HR zones and HR relate to improving a specific goal. It is easy for the users to interact and explore the data by changing the external load with the sliders, and the goal bars serve as a means of context and an indication of what the data could mean and what a change in the external load could do. The users could easily implement this in their training.

In the future, this design could be implemented in different apps or interfaces of currently existing brands. This will help recreational runners with their running regimen. With the increased understanding of HR data, recreational runners can take their running into their own hands. Overall this would make it easier for recreational runners to reach their running goals without professional help or a lot of reading. It provides a nice way of interactive data exploration that enables the users to get a better grasp on how their body reacts to the external load. In the future this visualisation might be extended to an overall comprehensive visualization that is personal for every runner.

# Appendix

## Appendix A


Figure 1: Fitbit interfaces for HR [40]


Figure 2: Interfaces of Garmin of HR [22]


Figure 3: Health interface of the mobile phone of Apple [41] [42] [43]

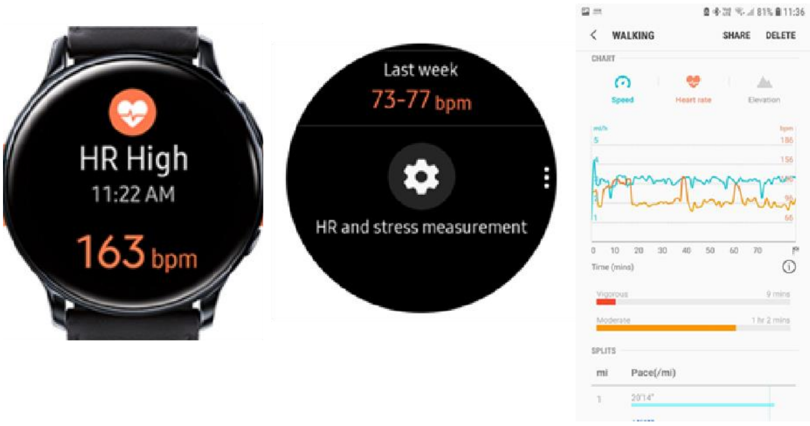



Figure 4: Interfaces of the Samsung Smartwatch [24], [44]


Figure 5: Interfaces of HR zones of the Samsung smartwatch [45]

# Appendix B

**Pace calculator**

| | BEGINNER | IMPROVING RUNNER | ADVANCED RUNNER | ELITE RUNNER |
|---|---|---|---|---|
| MARATHON GOAL TIME | 04:30:00 | 03:45:00 | 03:00:00 | *WORLD RECORD* 02:01:39 |
| Marathon pace | 6:24/km | 5:20/km | 4:16/km | 2:53/km |
| Half marathon pace | 6:05/km | 5:04/km | 4:03/km | 2:44/km |
| Lactate threshold pace | 5:46/km | 4:53/km | 3:58/km | 2:45/km |
| 10-km pace | 5:45/km | 4:47/km | 3:49/km | 2:35/km |
| 5-km pace | 5:32/km | 4:37/km | 3:41/km | 2:29/km |
| 3-km pace | 5:15/km | 4:22/km | 3:30/km | 2:22/km |
| 1500-m pace | 4:55/km | 4:06/km | 3:16/km | 2:12/km |
| 800-m pace | 4:28/km | 3:43/km | 2:59/km | 2:01/km |

**RPE–pace equivalents**

| RPE | DESCRIPTOR | PACE/EFFORT |
|---|---|---|
| 0 | No effort | Sedentary |
| 1 | Very, very easy | Walking |
| 2 | Easy | Easy pace |
| 3 | Moderate | Marathon pace/half marathon pace (recreational) |
| 4 | Somewhat hard | Half marathon pace (elite)/lactate threshold pace/10-km pace (recreational) |
| 5 | Hard | 10-km pace (elite) |
| 6 | Harder | 5-km pace |
| 7 | Very hard | 3-km pace |
| 8 | Very, very hard | 1500-m pace |
| 9 | Extremely hard | 800-m pace |
| 10 | Maximal effort | Sprinting/final exertion at the end of a race |

Figure 1: Pace calculator and the RPE equivalents [26]

# Appendix C

| **Goal** | **Variables** | **Insight** |
|---|---|---|
| **Improving running pace** | | |
| | HR | The lower the HR at the same pace the better trained the individual is |
| | MHR | Used for calculating HR zone |
| | Time | Used for calculating speed |

| | | |
|---|---|---|
| | Distance | Used for calculating speed |
| | Speed | A higher speed with the same HR indicates a higher running pace |
| | HR zone | Running in zone 3 and 5 to increase the pace |
| | BMI | Increase in HR correlates with increased BMI |
| | Age | MHR = 207 – 0.7 x age |
| | Gender | Women have a higher average HR than men, men have 10%-15% higher VO2max levels than women |
| | Humidity | The higher the humidity level the higher the HR |
| | Temperature | The higher the temperature the higher the HR |
| | Elevation | More elevation increases workload and thus increases HR |
| | hydration | Dehydration increases HR |
| | VO2max | Indicates workload and discipline of runner |
| | RPE | Indicates perceived intensity of exercise |
| | fatigue score | Indicates whether a person is overtraining |
| **Improving running distance** | | |
| | HR | The lower the HR for the same distance the better trained the individual is |
| | MHR | Used for calculating HR zone |
| | time | Used for calculating speed |
| | distance | Used for calculating speed |
| | speed | A higher speed with the same HR indicates a higher running pace |
| | HR zone | Running in zone 2 and 4 for increasing distance |
| | BMI | Increased HR correlates with increased BMI |
| | Gender | Women have a higher average HR than men, men have 10%-15% higher VO2max levels than women |
| | Age | MHR = 207 – 0.7 x age |
| | Humidity | The higher the humidity level the higher the HR |
| | temperature | The higher the temperature the higher the HR |
| | elevation | more elevation increases workload and thus increases HR |
| | hydration | Dehydration increases HR |
| | Lactate threshold | Indicates at which level the energy needs exceed the aerobic capacity |
| | VO2max | The higher the VO2max the higher the exercise intensity for the body |
| | RPE | Can be used to indicate lactate threshold and perceived exercise intensity |
| | fatigue score | Indicates whether a person is overtraining |
| **Completing a particular event** | | |
| | HR | The lower the HR at a specific workload (increased distance and/or increased speed) the higher the fitness |
| | MHR | Needed to calculate HR zones |
| | time | Needed to calculate speed and goal for the event |
| | distance | Needed to calculate speed and goal for the event |
| | speed | Insight in performance |
| | HR zone | Different HR zones need to be trained for different goals, both aerobic and anaerobic zones must be trained |

| | | |
|---|---|---|
| | BMI | Increased HR correlates with increased BMI |
| | Gender | Women have a higher average HR than men, men have 10%-15% higher VO2max levels than women |
| | Age | MHR = 207 – 0.7 x age |
| | Humidity | The higher the humidity level the higher the HR |
| | temperature | The higher the temperature the higher the HR |
| | elevation | more elevation increases workload and thus increases HR |
| | hydration | Dehydration increases HR |
| | goal | The goal gives indications of how the other variables should look like |
| **Maintaining activity level** | | |
| | HR | |
| | MHR | For calculating HR zones |
| | time | For calculating speed |
| | distance | Insight into how much one runs per week and for calculating speed |
| | speed | Insight into how fast one runs per week |
| | BMI | Increased HR correlates with increased BMI |
| | Gender | Women have a higher average HR than men, men have 10%-15% higher VO2max levels than women |
| | Age | MHR = 207 – 0.7 x age |
| | Humidity | The higher the humidity level the higher the HR |
| | temperature | The higher the temperature the higher the HR |
| | elevation | more elevation increases workload and thus increases HR |
| | hydration | Dehydration increases HR |
| | RHR | The lower the RHR the fitter the person |
| | HR recovery time | The shorter the HR recovery time the fitter the individual |
| | VO2max | Indication of the physical fitness level |
| | frequency | frequency of exercise indicates activity level |
| **Improving overall health** | | |
| | HR | The lower the HR during certain exercises the fitter the person |
| | time | For calculating speed |
| | distance | Insight into how much one runs per week and for calculating speed |
| | speed | Insight into how fast one runs per week |
| | BMI | Increased HR correlates with increased BMI, BMI indicates the health status of individual |
| | Gender | Women have a higher average HR than men, men have 10%-15% higher VO2max levels than women |
| | Age | MHR = 207 – 0.7 x age |
| | Humidity | The higher the humidity level the higher the HR |
| | temperature | The higher the temperature the higher the HR |
| | elevation | more elevation increases workload and thus increases HR |
| | hydration | Dehydration increases HR |
| | RHR | The lower RHR the higher the fitness level of the individual |
| | HR recovery time | The lower the HR recovery time the higher the fitness level of the individual |

| | | |
|---|---|---|
| | VO2max | Indication of the physical fitness level |

Figure 1: Different variables needed for gaining insights into specific running goal

## Appendix D

| **Phase** | **Question nr.** | Question |
|---|---|---|
| Pre-questions | 1 | What kind of wearable do you have? |
| | 2 | Why did you buy the wearable? |
| | 3 | How do you use your wearable for your running regimen? |
| | 4 | Could you grab the interfaces that you use? |
| Interface questions | 5 | Which interfaces do you use during running? |
| | 6 | What insight do you get out of it? |
| | 7 | What are the interfaces that you use most frequently after running? |
| | 8 | Could you go to a training and go through it step by step like you normally would after a training and mention the insights you get out of it? |
| | 9 | Do you use this analysis to adapt your future training? |
| | 10 | What don’t you use? |
| | 11 | Why don't you use these interfaces? |
| Experience questions | 12 | How do you experience the interfaces? |
| | 13 | What do you like most and why? |
| | 14 | What do you like the least and why? |
| | 15 | Is the current design missing something? |
| Closing questions | 16 | Do you have any final questions? |
| | 17 | Could you send me the screenshots/photos of the interfaces discussed during this interview? |
| | | |

Figure 1: questions of the semi-structured interview

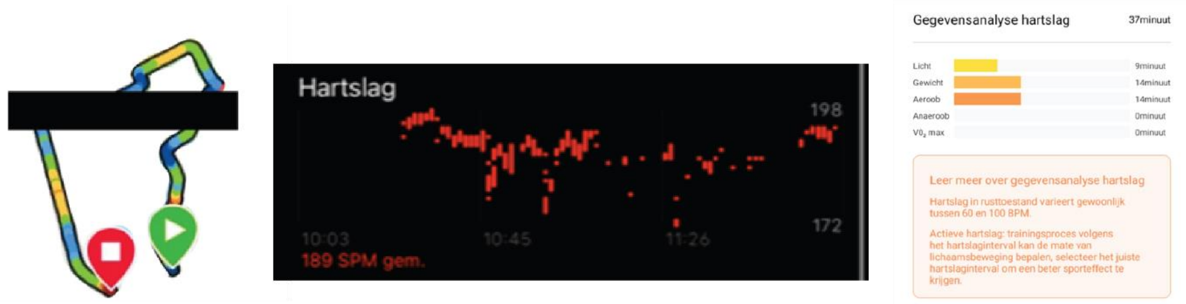



Figure 2: particpants’ screenshots from interview mentions

## Appendix E

| Variable | Measurement | Casual Individual | Social Competitive | Individual Competitive | Devoted | Average |
|---|---|---|---|---|---|---|
| What do you monitor? | Distance | 87.4 [a] | 88.0 [a,b] | 92.3 [b] | 91.3 [a,b] | 90.0 |
| | Time | 96.5 | 95.2 | 96.2 | 96.4 | 96.0 |
| | Speed [1] | 85.9 [a] | 87.3 [a,b] | 91.0 [b] | 88.4 [a,b] | 85.5 |
| | Heart rate | 68.8 [a,b] | 65.2 [b] | 72.1 [a] | 66.1 [a,b] | 68.2 |
| | Other (cadence, kcal) | 8.6 | 6.7 | 10.6 | 8.9 | 8.8 |
| What do you do with the data? | Nothing [2] | 6.8 [a] | 7.4 [a] | 4.2 [b] | 4.9 [b] | 5.7 |
| | Review the session after the run | 77.1 | 78.2 | 75.7 | 78.6 | 77.3 |
| | Monitor data over time | 54.2 [a] | 52.0 [a] | 65.3 [b] | 52.1 [a] | 56.6 |
| | Use data to adapt training | 20.4 [a,b] | 15.1 [b] | 29.7 [c] | 22.0 [a] | 22.3 |

Figure 1: sport watch users related to types of runners in percentages [8, p. 10]

## Appendix F

1. Car dashboard; different meters for different variables
2. Volcano; bubbling, expanding, different streams
3. Sea; waves, fish, water level
4. Tree; leaves, winter/summer, wind
5. Heart; beat, blood flow; colour
6. Animal/figure; mood, jumping, growing
7. Running person; speed of running; distance, resistance
8. Waterfall; amount of water, speed of falling
9. Growing plant; speed of growing, size of leaves, dies when overtraining
10. Weather; thunder, rain, sun
11. Highway; cars, trucks, speed, amount, colours of cars
12. Ants; amount, size, colour, speed
13. Speed; not as a number but a puppet that must follow another puppet and they have to walk the same pace
14. Mountain climber; zoomed out mountain for process
15. Surfer; at the end zoomed out version for process
16. View of location where different animals pass; kind of animal for HR zone, speed of animal for HR etc.
17. Train; speed, amount of people, colour
18. Glass of tea; heat, colour amount
19. Factory; amount of working people, speed of work, number of products made
20. Bird; altitude of flying, speed of flying, colour, amount
21. Boiling soup; temperature, colour, ingredients, speed of stirring
22. Inside a race car; speed, number of cars in front, position
23. Fire; heat, size of fire, colour of fire
24. Bus; speed, colour, amount of people in it
25. Aquarium; colour of the water, level of the water, amount, and type of animals in it
26. Body; heart beating, blood flowing, colour of the blood
27. Restaurant kitchen; number of cooks, heat; amount of food, speed of cooking
28. Restaurant; amount of people, amount of food, speed of people arriving and leaving
29. Forest; number of trees, number of animals, state of trees, activeness of animals
30. Air; colour, things floating around, size of clouds, speed of clouds
31. Water puddle; height of water, colour of water, water grass, ducks

32. Choose a character that runs; the environment depicts the different variables, colour, speed, obstacles, height
33. Butterfly garden; number of butterflies, colour of butterflies, speed of butterflies
34. Fuels; depiction of different fuels that have different levels and colours
35. Dancing crowd; amount of people dancing, style of dancing
36. Flowers; number of flowers, speed of flowers growing, bees, colour of flowers
37. Two footsteps; brightness, colour, flickering
38. Tamagotchi; performance determines mood and wellbeing
39. Coral; colour, speed of growing, amount of coral, wellbeing of coral
40. Running track; icons depict different variables and speed is visible on track
41. Bubbles flowing (screensaver); colour of bubbles, size of bubbles, amount of bubbles
42. Infographic; more extended explanation of the exercise
43. Map; different locations represent different variables with lines showing connections
44. Game like situation; puppet running, different goals can be reached, wellbeing of puppet represents performance of runner
45. Nature from above; the more trees the more variable x, the more water the more variable y
46. Bubbles; each variable is a different “bubble”, and the size is the value of the data, size differs over time you can see this in a timeline
47. Each exercise is a different stack
48. Lava lamp; colour, size of lava, speed of lava, amount of lava
49. ‘guitar hero’ idea; setting specific goals and while running trying to target these goals
50. Space; planet and stars, size of flying objects, speed of flying objects, type of flying objects

Figure 1: 50 ideas

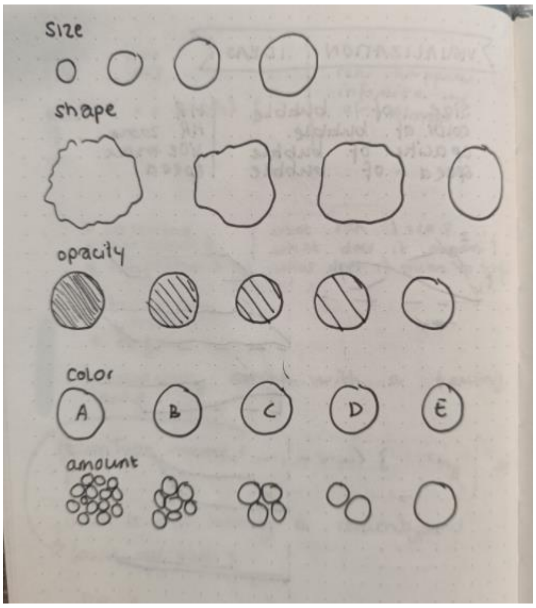



Figure 2: inspiration for processing example

# Appendix G

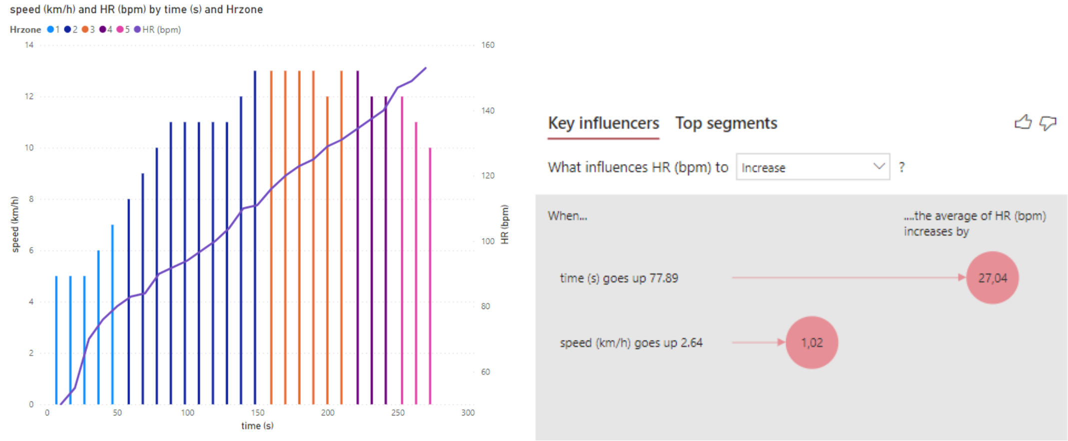



Figure 1: speed, HR, and HR zones over time and the key influencers

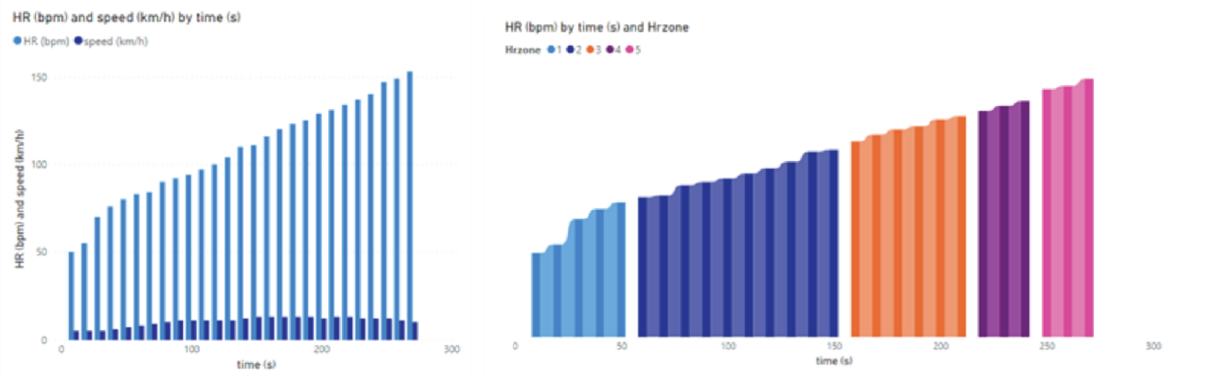
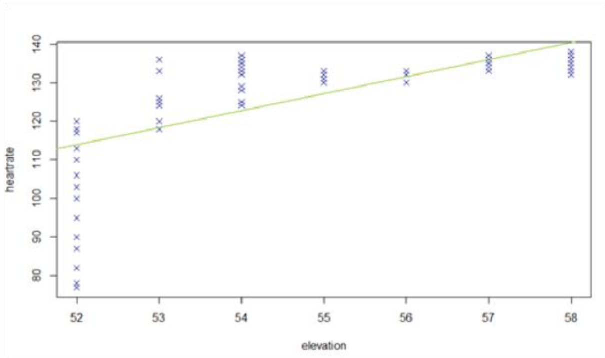
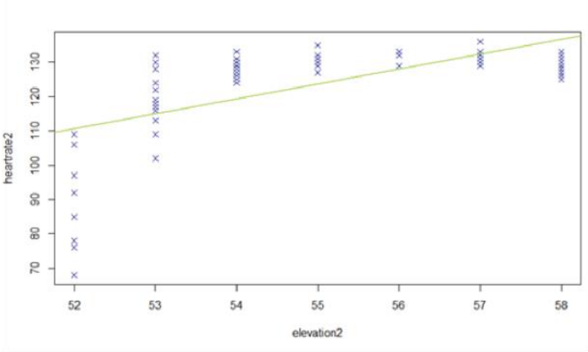



Figure 2: HR and speed over time vs HR and HR zones over time



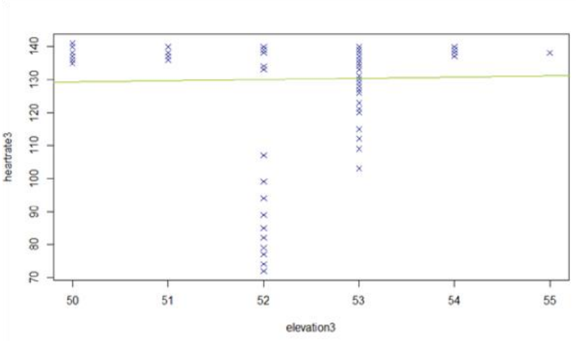

```
Call:
lm(formula = heartrate ~ elevation)

Residuals:
    Min      1Q  Median      3Q     Max
-36.991  -3.412  -0.009   5.903  17.605

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -114.9898    28.6563  -4.013 0.000125 ***
elevation      4.4035     0.5197   8.473 4.62e-13 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 10.34 on 89 degrees of freedom
Multiple R-squared:  0.4465,	Adjusted R-squared:  0.4403
F-statistic: 71.79 on 1 and 89 DF,  p-value: 4.621e-13
```

Run 1




```
Call:
lm(formula = heartrate2 ~ elevation2)

Residuals:
    Min      1Q  Median      3Q     Max
-42.729  -4.740   0.923   7.260  16.934

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -114.7904    30.7769  -3.730 0.000323 ***
elevation2     4.3369     0.5566   7.792 7.39e-12 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 11.04 on 97 degrees of freedom
Multiple R-squared:  0.385,	Adjusted R-squared:  0.3786
F-statistic: 60.72 on 1 and 97 DF,  p-value: 7.392e-12
```

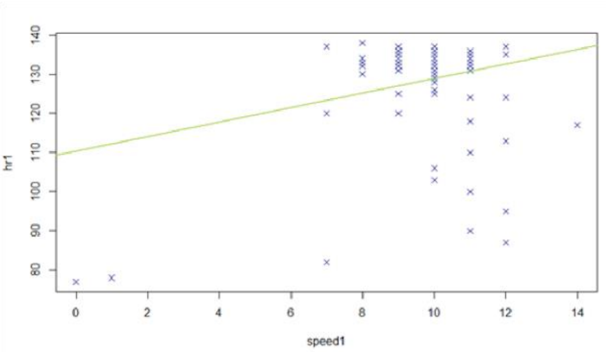
Run 2




```
Call:
lm(formula = heartrate3 ~ elevation3)

Residuals:
    Min      1Q  Median      3Q     Max
-57.972   1.667   6.667   8.528  11.751

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 111.1855    73.5126   1.512    0.134
elevation3    0.3613     1.4022   0.258    0.797

Residual standard error: 16.83 on 97 degrees of freedom
Multiple R-squared:  0.0006839,	Adjusted R-squared:  -0.009618
F-statistic: 0.06638 on 1 and 97 DF,  p-value: 0.7972
```

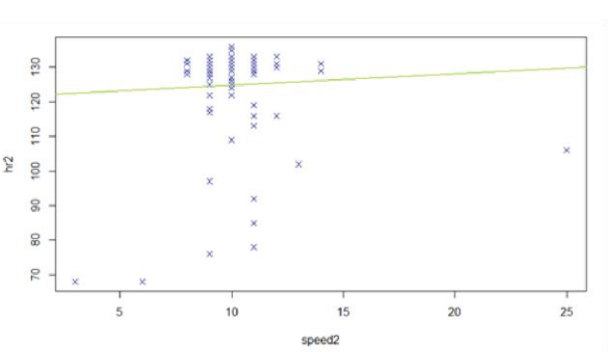
Run 3

Figure 3: HR plotted against elevation for 3 different runs



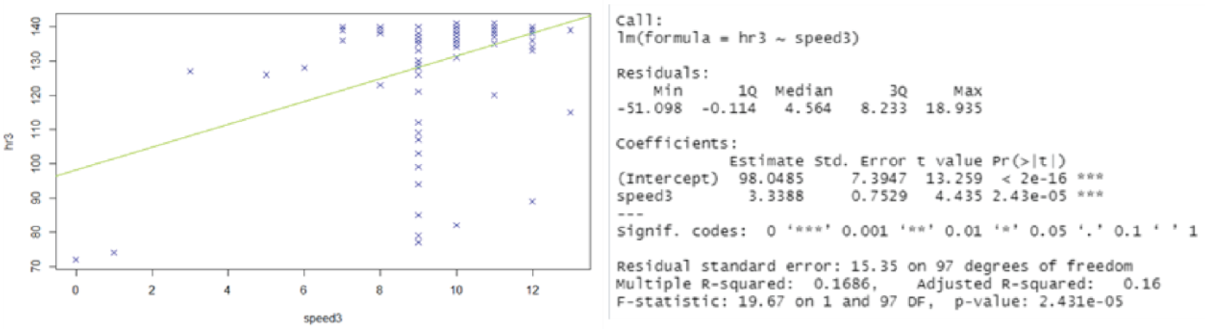

```
Call:
lm(formula = hr1 ~ speed1)

Residuals:
    Min      1Q  Median      3Q     Max
-45.612   0.671   4.954   6.954  13.665

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 110.3455     7.1457  15.442   <2e-16 ***
speed1        1.8556     0.7321   2.535   0.0129 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 13.01 on 97 degrees of freedom
Multiple R-squared:  0.06212,	Adjusted R-squared:  0.05245
F-statistic: 6.424 on 1 and 97 DF,  p-value: 0.01286
```

Run 1




```
Call:
lm(formula = hr2 ~ speed2)

Residuals:
    Min      1Q  Median      3Q     Max
-55.545   1.628   5.128   7.128  11.128

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 121.5555     6.8313  17.794   <2e-16 ***
speed2        0.3317     0.6670   0.497     0.62
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 14.05 on 97 degrees of freedom
Multiple R-squared:  0.002542,	Adjusted R-squared:  -0.007741
F-statistic: 0.2472 on 1 and 97 DF,  p-value: 0.6202
```

Run 2




Run3

Figure 4: HR plotted against speed for 3 different runs

# Appendix H

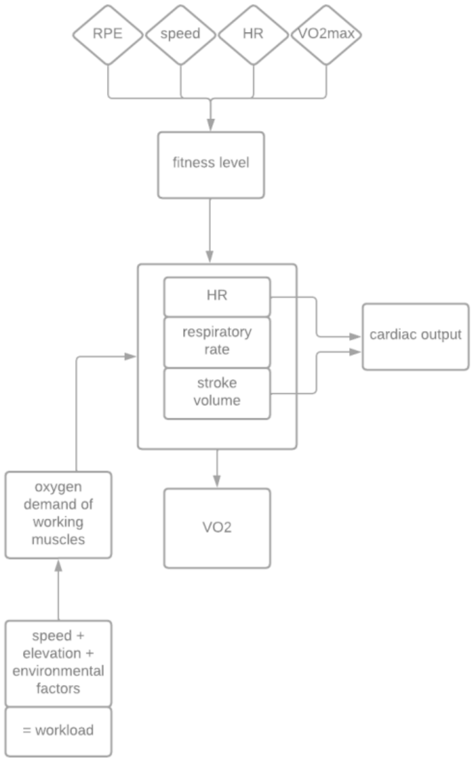



Figure 1: relationships between the different data stream where RPE, speed, HR and VO2max are indicators of the fitness level

## Appendix I

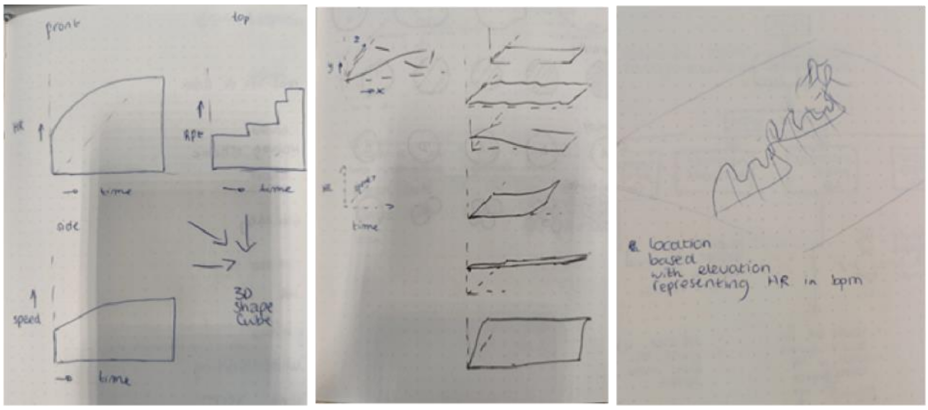
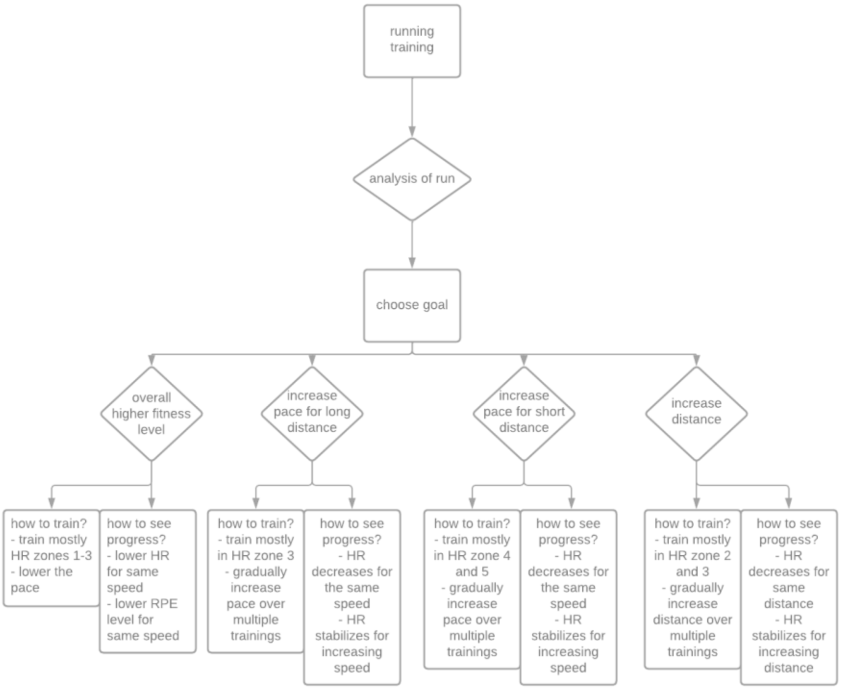



Figure 1: Sketches of 3D visualisations

## Appendix J




## Appendix K

| Action | Zero measurement | User-test |
|---|---|---|
| Introduction | Explain what is being researched and why this is important and how this specific interview/test contributes to the research. | Explain what is being researched and why this is important and how this specific interview/test contributes to the research. |
| 1. Show interface | This is a run done measured with a Garmin device | This is a visualisation of the data after a run |

| | | |
|---|---|---|
| 2. Ask them what they see | You can now go through it and I am wondering what things you see. | You can now slide the speed bar and I am wondering what you see |
| 3. Speed and HR | Do you think there a relation exists between speed and HR? If yes, how would you describe this relation? | Do you think there a relation exists between speed and HR? If yes, how would you describe this relation? |
| 4. HR and HR zones | Do you think the HR and HR zones are related? If yes, how would you describe this relation? | Do you think the HR and HR zones are related? If yes, how would you describe this relation? |
| 5. Show other interface for different distance | This is another run from the same person but with another distance | This is another run but then with a different distance. |
| 6. Ask the differences | Do you see differences and if yes what are those differences? | Do you see differences and if yes what are those differences? |
| 7. Distance and HR | Do you think there a relation exists between distance and HR? If yes, how would you describe this relation? | Do you think there a relation exists between distance and HR? If yes, how would you describe this relation? |
| 8. Goals | Runners have different goals. These goals can be increase distance, increase pace for the short distance or increase pace for the long distance. Could you make a top 3 of these goals? | Runners have different goals. These goals can be increase distance, increase pace for the short distance or increase pace for the long distance. Could you make a top 3 of these goals? |
| 9. How to reach the goals | With these goals in mind, could you tell from this visualisation how to achieve those goals by adapting a next training? If yes, how? | With these goals in mind, could you tell from this visualisation how to achieve those goals by adapting a next training? If yes, how? |
| 10. Go through the whole | When looking at this interface, how would you interact with it in real life? | When looking at this interface, how would you interact with it in real life? |
| 11. Next training | Would you use this for your next training? If yes, how? If not, why not? | How would you use this for your next training? If yes, how? If not, why not? |

Figure 1: setup of the user test

# References

[1] M. Pobiruchin, J. Suleder, R. Zowalla, and M. Wiesner, “Accuracy and adoption of wearable technology used by active citizens: A marathon event field study,” *JMIR Mhealth Uhealth*, vol. 5, no. 2, Feb. 2017, doi: 10.2196/mhealth.6395.

[2] S. Lomborg, H. Langstrup, and T. O. Andersen, “Interpretation as luxury: Heart patients living with data doubt, hope, and anxiety,” *Big Data and Society*, vol. 7, no. 1, Jan. 2020, doi: 10.1177/2053951720924436.

[3] M. Galesic and R. Garcia-Retamero, “Graph literacy: A cross-cultural comparison,” *Medical Decision Making*, vol. 31, no. 3, pp. 444–457, May 2011, doi: 10.1177/0272989X10373805.

[4] M. Schield, “Information Literacy, Statistical Literacy and Data Literacy.”

[5] A. Wolff, J. Moore, Z. Zdrahal, M. Hlosta, and J. Kuzilek, “Data literacy for learning analytics,” in *Proceedings of the Sixth International Conference on Learning Analytics & Knowledge - LAK ’16*, 2016, pp. 500–501. doi: 10.1145/2883851.2883864.

[6] B. Mulvad, R. O. Nielsen, M. Lind, and D. Ramskov, “Diagnoses and time to recovery among injured recreational runners in the RUN CLEVER trial,” *PLoS ONE*, vol. 13, no. 10, Oct. 2018, doi: 10.1371/journal.pone.0204742.

[7] A. Karahanoğlu, R. Gouveia, J. Reenalda, and G. Ludden, “How are sports-trackers used by runners? Running-related data, personal goals, and self-tracking in running,” *Sensors*, vol. 21, no. 11, Jun. 2021, doi: 10.3390/s21113687.

[8] M. Janssen, R. Walravens, E. Thibaut, J. Scheerder, A. Brombacher, and S. Vos, “Understanding different types of recreational runners and how they use running-related technology,” *International Journal of Environmental Research and Public Health*, vol. 17, no. 7, Apr. 2020, doi: 10.3390/ijerph17072276.

[9] R. Ackoff, “From Data to Wisdom.”

[10] I. Li, A. K. Dey, and J. Forlizzi, “Understanding my data, myself: : supporting self-reflection with ubicomp technologies,” in *Proceedings of the 13th international conference on Ubiquitous computing - UbiComp ’11*, 2011, p. 405. doi: 10.1145/2030112.2030166.

[11] G. Bellinger, D. Castro, and A. Mills, “Data, Information, Knowledge, and Wisdom,” *The Ways of Systems*, 2004.

[12] M. Zeleny, “Management support systems: Towards integrated knowledge management,” 1987, Accessed: Apr. 14, 2022. [Online]. Available: https://content.iospress.com/articles/human-systems-management/hsm7-1-08

[13] D. Snowden, “Complex acts of knowing: Paradox and descriptive self-awareness,” *Journal of Knowledge Management*, vol. 6, no. 2, pp. 100–111, May 2002, doi: 10.1108/13673270210424639.

[14] D. Chaffey and S. Wood, “What is information? How do we improve information quality? How do we develop strategies for Information Management? How much do we invest in Information Systems? What are the risks of introducing a new system? How is this change managed? What are the legal constraints on Information Management?” [Online]. Available: www.booksites.net/chaffey

[15] P. Bocij, A. Greasley, and S. Hickie, “Business Information Systems.”

[16] Coolblue, "Top 10 best verkochte smartwatches." https://www.coolblue.nl/smartwatches/top-10 (accessed Apr. 17, 2022).

[17] J. O'Donoghue, "I 'heart' my smartwatch," Jan. 18, 2021. https://edu.rsc.org/feature/the-science-of-smartwatches/4013008.article#:~:text=The%20newest%20generation%20of%20smartwatches,absorption%20taken%20from%20your%20wrist. (accessed May 11, 2022).

[18] M. Sawh, "How to take blood pressure on Samsung Galaxy smartwatches," Mar. 04, 2021. https://www.wareable.com/samsung/how-to-take-blood-pressure-on-samsung-galaxy-watch-active-2-8321 (accessed Jun. 12, 2022).

[19] S. Conley *et al.*, "Agreement between actigraphic and polysomnographic measures of sleep in adults with and without chronic conditions: A systematic review and meta-analysis," *Sleep Medicine Reviews*, vol. 46, pp. 151–160, Aug. 2019, doi: 10.1016/j.smrv.2019.05.001.

[20] M. Sawh, "Stress wearables: best devices that monitor stress and how they work," Apr. 01, 2022. https://www.wareable.com/health-and-wellbeing/stress-monitoring-wearables-explained-7969 (accessed Jun. 12, 2022).

[21] Intelligent Data: Experts in technological dreams, "State of the art: Body temperature measurement in wearables," Sep. 24, 2021. https://www.intelligentdata.es/en/estado-arte-medida-temperatura-corporal-wearables/#:~:text=Today%2C%20the%20technology%20used%20to,the%20skin%20on%20the%20wrist. (accessed Jun. 12, 2022).

[22] Garmin, "Heart Rate Monitoring." https://www.garmin.com/en-US/garmin-technology/health-science/heart-rate-monitoring/ (accessed Apr. 17, 2022).

[23] M. Sawh, "Garmin Connect guide: Unleash the full power of this incredible app," Nov. 16, 2021. https://www.wareable.com/garmin/how-to-run-better-with-garmin-connect (accessed Apr. 17, 2022).

[24] Samsung, "Monitor your heart rate on your Samsung smartwatch." https://www.samsung.com/us/support/answer/ANS00083511/ (accessed Apr. 17, 2022).

[25] D. A. Epstein, A. Ping, J. Fogarty, and S. A. Munson, "A lived informatics model of personal informatics," in *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing - UbiComp '15*, 2015, pp. 731–742. doi: 10.1145/2750858.2804250.

[26] C. Napier, "Science of Running".

[27] C. Luff, "22 Tips to Improve Running Speed and Endurance," Apr. 15, 2021. https://www.verywellfit.com/how-to-run-faster-and-improve-race-times-2911291 (accessed May 04, 2022).

[28] B. Hambleton, "Heart rate and pace: how to compare these metrics to improve performance," Mar. 02, 2022. https://runningmagazine.ca/sections/training/heart-rate-and-pace-how-to-compare-these-metrics-to-improve-performance/ (accessed May 04, 2022).

[29] K. Carter, "Want to Know How to Increase Your Running Speed? All You Need Are These 4 Tips," May 12, 2021. https://www.runnersworld.com/training/a20845443/improving-speed-and-endurance/ (accessed May 03, 2022).

[30] S. K. (Scott K. Powers and E. T. Howley, *Exercise physiology : theory and application to fitness and performance*.

[31] J. P. Porcari, C. X. Bryant, and F. Comana, *Exercise physiology*.

[32] F. Bentley *et al.*, "Health Mashups," *ACM Transactions on Computer-Human Interaction*, vol. 20, no. 5, pp. 1–27, Nov. 2013, doi: 10.1145/2503823.

[33] R. Gouveia, "Design for Experience Lecture 2: Defining experiences: Methods for Asking & Observing ." University of Twente, Enschede.

[34] A. Mader and W. Eggink, "A DESIGN PROCESS FOR CREATIVE TECHNOLOGY."

[35] A. Kirk, "Data Visualisation: A Handbook for Data Driven Design."

[36] D. Benyon, "Designing User Experience A guide to HCI, UX and Interaction Design." [Online]. Available: www.pearson.com/uk

[37] ProductPlan, "MoSCoW Prioritization." https://www.productplan.com/glossary/moscow-prioritization/ (accessed Jun. 12, 2022).

[38] "Processing." https://processing.org/ (accessed May 21, 2022).

[39] Autodesk, "Maya Autodesk." https://www.autodesk.com/products/maya/free-trial (accessed Jun. 04, 2022).

[40] A. Oglethorpe, "6 Ways Continuous Heart Rate Tracking Gets You Closer to Your Goals," Sep. 06, 2018. https://blog.fitbit.com/heart-rate-tracking/ (accessed Apr. 17, 2022).

[41] Apple, "Monitor your heart rate with Apple Watch." https://support.apple.com/en-us/HT204666 (accessed Apr. 20, 2022).

[42] Apple, "Je hartslag bekijken op je Apple Watch." https://support.apple.com/nl-nl/guide/watch/apda88aefe4c/watchos#:~:text=Open%20the%20Settings%20app%20on,then%20turn%20on%20Heart%20Rate (accessed Apr. 21, 2022).

[43] M. Sawh, "Apple Health guide: The powerful fitness app explained," Apr. 14, 2022. https://www.wareable.com/health-and-wellbeing/apple-health-guide-apps-wearables-8016 (accessed Apr. 21, 2022).

[44] The Smartwatch, "How Accurate Is The Heart Rate Monitor On The Samsung Galaxy Watch." https://thesmart.watch/how-accurate-is-the-heart-rate-monitor-on-the-samsung-galaxy-watch/ (accessed Jul. 06, 2022).

[45] O. Radke, "Samsung Wearables," Feb. 2022. https://support.mapmyfitness.com/hc/en-us/articles/1500009117242-Samsung-Wearables/ (accessed Apr. 21, 2022).

[46] The Athlete Blog, "Heart Rate Training Zones – Complete Guide To Endurance Gains", Accessed: May 04, 2022. [Online]. Available: https://theathleteblog.com/heart-rate-training-zones/