At-a-glance feedback during cycling: improving cycling performance of patients with CVA

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Date: 03-07-2020

Abstract

For patients with a cerebrovascular accident (CVA), better known as stroke patients, there is currently no system that gives feedback on cycling behavior that is understandable at a glance. Patients with CVA have to maintain an active lifestyle after rehabilitation and can do so by cycling. However, due to motor, cognitive and visual impairment riding a bike is often a difficult task in itself for patients with CVA, and using existing cycling apps can be distracting. This research aims to design a form of feedback on cycling performance during the ride that is understandable at a glance and asks: *What is the best way to communicate at-a-glance feedback about cycling performance to patients with CVA during cycling?*

Based on literature research and a state of the art review, several designs for data visualizations were made and tested via a questionnaire and semi-structured interview in a qualitative lo-fi test on preference between 5 participants. Each design showed a goal in distance and the progress toward that goal. The 2 best designs, according to the lo-fi test were improved based on feedback from the participants and were made into final prototypes. These prototypes were then tested via a questoinnaire in a quantitative hi-fi test with 65 participants on how well each visualization was understood at a glance. Analysis of the test shows that the design of a circular progress bar scored best overall. From this research can therefore be concluded that the specific design made in this research with a circular progress bar as its main feature, works best for giving at-a-glance feedback on cycling behavior during the ride. Further research is needed to troubleshoot the used method and validate the results.

Acknowledgements

I would like to thank my supervisors Monique Tabak and Roos Bulthuis for guiding me through the process of this thesis and for all the new knowledge that I have gained from them on doing a big research such as this one. Thank you for the constructive feedback and for thinking along when the COVID-19 virus caused drastic changes in (academic) life, bringing new challenges along with it.

In addition, I would like to thank my friend Benedetta for proof reading my report multiple times and giving me some useful tips and advice troughout the whole process, along with some laughs during my breaks.

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1 Introduction

Over the last couple of years, it has become more and more apparent how important it is to be active and exercise in a culture where most people sit on a chair all day long [1]. To stay fit and healthy, it is necessary to have an active lifestyle, especially for those who are suffering from a disease or the consequences thereof. A large group that suffers from a chronic condition are patients with a cerebrovascular accident (CVA), also known as stroke patients. To reduce the chance of a second CVA and to maintain their health they need to follow an active lifestyle. Even though most patients with CVA go through a rehabilitation process during the first six months after the accident, afterwards they are expected to maintain a healthy lifestyle on their own, which includes, but is not limited to, maintaining stamina, mobility and balance. Maintaining such a lifestyle, is easiest if it fits in with everyday life.

An example of an activity that both helps maintain health and activity and commonly finds its place in daily life is cycling. Cycling is an accessible way of exercising, especially in The Netherlands where it is also a very popular and relatively cheap means of transportation. Furthermore, mobility, balance and stamina can be trained by riding a bike. Other than that, a study of Greenhalgh et al. [2] on the perception of stroke survivors on cycling, shows that cycling not only helps for physical improvement, but also has valuable emotional aspects to it, such as an improved mood due to getting out of the house and being part of a community. However, the same study also shows that some patients with CVA are hesitant to use a bike due to safety concerns in traffic and they worry about falling. Even adaptations specifically made to help them, such as straps to keep the feet on the pedals, were seen as a hazard because they would obstruct getting feet off of the pedals when needed.

As the study shows, riding a bike is not necessarily easy for everyone, especially when suffering from the results of a stroke. That is why Van Raam[1] manufactures specially made bicycles and tricycles for people who have a hard time operating a regular bike.

Van Raam is a manufacturer that makes a variety of bicycles and tricycles that are adjusted to the user. The clients that they work with are people that are not able to operate a regular bicycle anymore and need assistance in cycling. This can entail electrical assistance from a battery, assistance in balance and assistance from another person cycling with them. Some examples of the products they make are mobility scooters, tandems, duo bikes, wheelchair bikes, low entry bikes and (electrical) tricycles. [3] A very popular type of adapted bicycle that Van Raam manufactures is the 'Easy Rider'. The Easy Rider is a tricycle with a chair rather than a saddle and it is powered by a battery. Because of the placement of the seat, the paddle movement is in a more forward direction than on a regular bicycle, which gives more comfort for the user. Furthermore, because of the three wheels it provides a very stable ride. [4]

Figure 1: Van Raam's Easy Rider tricycle [4]

[1] Van Raam's website: https://www.vanraam.com/nl-nl?gclid=CjwKCAjwi_b3BRAGEiwAemPNU7U6WTjROcCAkKGqUs3WhZ78e3IxYnpy1_qrvNJM1OPd71mKfy6lARoCSDwQAvD_BwE

1.1 Problem statement

1.1.1 Problem

The Easy Rider can be a safe alternative for patients with CVA who have a fear of falling with a regular bike, because three wheels give more stability. However, to properly train for and manage a healthy lifestyle, performance feedback could be helpful. Van Raam already has a mobile app that shows user data of the trike ride after the ride is done, but during the ride the performance feedback via the current app might be distracting, which could lead to dangerous situations in traffic. It would therefore be useful to have a feedback system that helps the user monitor their own cycling behavior during the ride, without it being distracting.

1.1.2 Objective

The objective of this thesis is therefore to design a form of feedback on cycling performance during the ride that is understandable at a glance.

This research will be done in the assignment of adjusted bicycle manufacturer Van Raam and in close collaboration with Roessingh Research & Development (RRD). This research will target the user group of the Easy Rider that consists of patients with CVA that are finished with rehabilitation and need to maintain an active lifestyle.

1.2 Research question

The main research question of this thesis is defined as follows:

What is the best way to communicate at-a-glance feedback about cycling performance to patients with CVA during cycling?

Before answering this question, the report will look into a couple of sub-questions to gain a better understanding of several aspects that have to be taken into account. These sub-questions are as follows:

Sub-question 1: What is the current recovery procedure for patients with CVA?

Sub-question 2: How can cycling behavior of patients with CVA be measured?

Sub-question 3: How can complex user data be presented to the user in an understandable way?

Sub-question 4: What form of data feedback is the most effective at a glance to improve cycling behavior of patients with CVA?

1.3 Study outline

This report consists of 9 chapters, that will all contribute to answering the research question. An overview of all chapters is given below with a brief description of the contect of each chapter and, in some cases, the purpose of the chapter.

- Chapter 1: Gives an introduction to the subject of this research and a description of the problem statement and the goal of the research.
- Chapter 2: Contains a literature research and a state of the art review; for acuiring prior knowledge on the subject of this thesis.
- Chapter 3: Describes all the steps in the design workflow; functions as a guide for the design process.
- Chapter 4: Contains a context analysis, stakeholder analysis, persona and scenario sketch; functions as a base for the design.
- Chapter 5: Contains an expansion of the design base, including a description of the initial designs; is meant as a specification of the context and as a start of the product development.
- Chapter 6: Describes the lo-fi test and its results and the development of the final prototype; is meant to filter out the best designs and for further development of the product idea.
- Chapter 7: Describes the hi-fi test and its results; functions as the main experiment of this research.
- Chapter 8: Gives a conclusion to the research and discusses the outcome.
- Chapter 9: Gives suggestions for possible future work.

2 Theoretical framework

Before diving straight into new research, it is important to gather already existing theories and any other relevant information on the topic from existing literature. This chapter first gives more information on what a CVA entails and on the rehabilitation process that usually follows. It then moves on to explaining how using sensors can help with maintaining a healthy lifestyle and how the output of these sensors can be visualized in an understandable way. Then, the way this data can be used to motivate someone towards leading a healthier and more active lifestyle is highlighted and finally, some examples of already existing applications and hardware in this field are considered.

This section will also provide answers to the following sub-questions:

Sub-question 1: What is the current recovery procedure for patients with CVA?

Sub-question 2: How can cycling behavior of patients with CVA be measured?

Sub-question 3: How can complex user data be presented to the user in an understandable way?

2.1 CVA

Every year about 97,200 people in the Netherlands alone suffer from a cerebrovascular accident [5]. A CVA is an overarching name for the better-known Transient Ischemic Attack (TIA), cerebral infarction and cerebral hemorrhage. All three of these conditions are caused by a malfunction in the veins in the brain. In case of a TIA or a cerebral infarction a blood clot blocks a vein in the brain, causing a lack of oxygen in a part of the brain. In case of a TIA this clot will disappear relatively quickly but with an infarction the clot is permanent. A cerebral hemorrhage is when a vein tears open, spreading blood throughout (parts of) the brain.[6] In all three cases a quick medical intervention is of the utmost necessity and the severity of the consequences rely on how fast the situation can be handled [7].

2.1.1 Medical treatment

With a TIA the symptoms usually disappear by themselves. Still, medical research is needed because the chance of having another TIA or a cerebral infarction will have increased a lot, especially during the first couple of days after the TIA. To prevent a second CVA, doctors can prescribe blood thinners, cholesterol-lowering drugs or antihypertensives. Furthermore, after a TIA a healthy lifestyle is important to decrease the chance of having another CVA. If the TIA is a result of a narrow carotid artery or a heart problem, then further medical research and appropriate treatment is needed.[8] In case of a cerebral infarction, treatment can include either the use of blood thinners or surgery with a catheter, where they remove the blood clot [5]. In case of a cerebral hemorrhage, the most common approach is to wait until the bleeding has stopped, whilst monitoring the patient closely. If any intervention is needed, the doctor can prescribe drugs to solidify the blood or, if that does not help, a surgery can be done to drain some of the bleeding. The latter is usually only done if the bleeding is on the outside of the brain, because in that case the chance of damaging brain tissue during the surgery is significantly smaller than when the bleeding is located more towards the center of the brain.[9]

With any form of a CVA, motor impairment is a common result, amongst which also a (semi)sided stroke (hemiparesis) is possible. Furthermore, cognitive impairment can be an issue after suffering from a stroke, with attention being one of the biggest problem areas [10]. Next to that, patients with CVA often suffer from a decrease in their visual skills. According to a study of Smith et al. [11] CVA survivors and their caregivers often notice visual impairment as well as a decrease in balance. Out of these three regions of impairment, motor impairment is the most common issue with patients with CVA, with about 85% of patients suffering from hemiparesis, where half of their body is weak [12].

2.1.2 Rehabilitation

For patients with CVA the chance of improvement is highest within the first six months after the accident. Therefore, most patients go through a rehabilitation process during this period. This rehabilitation is usually led by occupational therapists, physiotherapists and a speech therapist if needed. Most patients with CVA tend to recover to some degree but about 1 in every 5 patients needs permanent help in everyday living and will have to stay in a nursing home permanently. [13]

Several studies have been done on the importance of rehabilitation for patients with CVA and what aspects of this rehabilitation are most important to focus on for a higher chance of recovery. For example, Lee et al. [14] have shown in their studies that with rehabilitation based on improving motor skills, balance also gets improved for patients who suffer from hemiparesis. In addition, Smith et al. [11] claim that visual impairments can influence the rehabilitation process and should thus be the focus in such a setting. Furthermore, Tatemichi et al. [10] suggest that apart from mobility tests, cognition should also be a focus point of rehabilitation of patients with CVA.

2.2 Sensors

To be able to give feedback to a user, it is important to know what kind of data can be worked with. Over the years the measurement equipment used to track physical activity has developed rapidly, causing a both a significant increase in the variety of data that can be collected, and measurement precision [15]. There are a lot of different devices to monitor different kinds of physical activity and one should therefore be aware of how the different devices work and what they actually measure. For example, pedometers are used as a way to measure displacement in walking, however, they would not work for measuring displacement in cycling. This is because pedometers measure a vertical displacement that happens in the hips when walking. When cycling, the threshold would not be reached and thus the device would not measure any displacement. [16] This paper focusses only on sensors that are relevant to cycling and wether or not they are applicable to measuring cycling performance in patients with CVA.

Firstly, a widely used sensor for measuring displacement in cycling is an accelerometer as it measures the physical activity of a person [17]. They do this by measuring forces of acceleration in three axes. This does not depend on a specific body movement like a pedometer does and is thus suitable for multiple fields of sports, including cycling [18]. This is affirmed by the fact that accelerometers are already often used as a means of measurement in (professional) cycling races [19].

Secondly, another sensor used in cycling races and also in private use of bicylces is a GPS tracker [19]. GPS trackers send out a signal to several sattelites and in return receive information about their own location based on how close to these sattelites the tracker is [20]. These devices are widely used in tracking vehicles and are even a standard feature on cell phones nowadays. Furthermore, they can be connected to the internet or can work on their own. On the one hand, GPS trackers can be used in cycling on a larger scale to find popular routes or monitor how busy certain roads are. On the other hand, they can be used privately and give the user feedback on the route they have cycled.

Thirdly, force sensors can be used in cycling. Force sensors are sensors that measure the force applied in one direction only. Depending on their size, they can be used for large objects and humans as well as for smaller forces. However, for the latter they might be less precise [21]. They can be integrated in different parts of the bike such as the handle bars and the saddle, to measure the pressure of the user on those parts. This can give insight into their posture on the bicycle, which can be of interest in patients with CVA with hemiparesis. [22]

Lastly, to measure movement of the handlebar or the rotation of the wheels, Hall sensors can be used. Hall sensors measure magnetic fields and can thus be used to percieve the movement of a magnet [23]. For example, the movement of the wheels on a bike can be measured with magnets on the spokes of the wheels and Hall sensors on the wheel forks. Furthermore, if two Hall sensors are placed on the same fork next to each other, the rotational direction of the wheel can be measured too, because then either sensor one or sensor two “sees” the magnet first, depending on the rotational direction. [24]

All of these sensors can be used individually, but there are also systems that combine some of them. Smartphones, for example, usually have an accelerometer and a GPS tracker in them, along with several other sensors. This would be a relatively accessible option to give feedback with, considering the widespread usage of these high-tech devices nowadays. The same goes for smartwatches, which are becoming more and more popular and also contain different types of sensors, including accelerometers. However, since both of these devices also carry a lot of personal information about the user, privacy becomes a very important aspect to take into account when using them to gather data.

2.3 Data visualization in cycling

The above mentioned examples of sensors can be applied to a bicycles to measure cycling behavior. However, having a sensor in itself is not enough. Sensors generally output a large sequence of numbers and, without context, they have no significant meaning. Therefore, to communicate the data to a cyclist, a user interface should be made which orders the output of the sensors and puts it into context. One of the ways to do this is by visualizing the data. [25]

2.3.1 Graphing data

When working with quantitative data, often the use of graphs as a data visualization methodology comes to mind. Graphs can give a rather simple overview of the numbers without showing the whole list and they can show differences or relations between different sets of data. Visualizing numbers like this can often even help low-numeracy people understand numerical data [26]. However, this depends on the style of the graph. Graphs can come in a wide variety of shapes, colors and styles, but the main design principle that always applies when designing a graph is that all the elements in it should be helpful at conveying the message. Anything other than that should be taken out because it could be counterproductive. [27]

To make an insightful graph, there are some general guidelines to consider such as being consistent in the way data is presented and choosing the right visualization [28]. Each type of chart has their own characteristics and application and some of the most commonly used charts will be explained below:

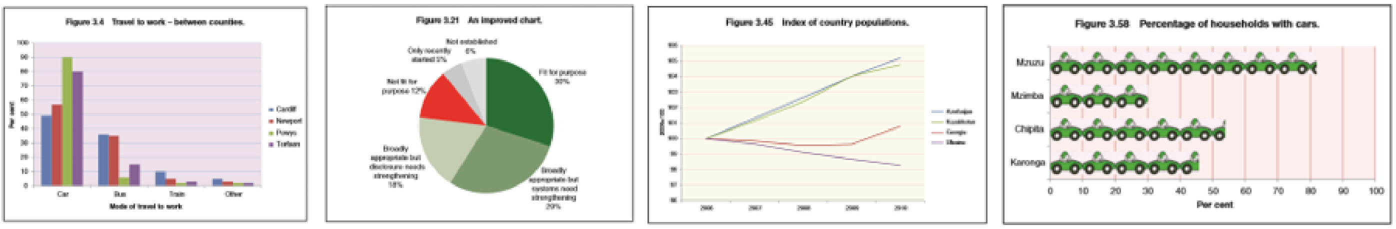


Figure 2: fLTR Example of a bar chart, a pie chart, a line graph and a pictogram [28]

- *Bar chart:*
    - Displays categorical data
    - Can show either real or relative numbers.
    - **Point of attention:** overlapping data can be hard to interpret correctly
- *Pie chart:*
    - Displays categorical data
    - All segments together add up to 100%
    - **Point of attention:** estimating the actual size of an individual segment can be hard
- *Line graph:*
    - Displays relationship between two or more variables
    - Can show either real or relative numbers
    - **Point of attention:** the scale of all axes should be intuitive and clear
- *Pictogram:*
    - Displays categorical data
    - Can show either real or relative numbers
    - **Point of attention:** the right images should be chosen as those themselves represent data as well

Although these charts are used quite often, there is a whole range of kinds of charts that can be used and with the right creativity even new ones can still be thought of. However, with any type of chart, the message that is conveyed needs to be the main focus point and in addition to that the data needs to be correct, the presentation must be clear, and all should be consistent. [28]

Charts are often used on smartwatches such as Fitbit and find a common use in the field of sports and exercising [29]. However, even though there is such a broad choice in ways of giving data feedback to a user, not all are fit for cycling. Because cyclists participate in traffic, it is important that the data feedback does not distract the user. In a sports journal article about feedback in running, Van Hooren et al. [30] state that it has been proven that visual feedback can distract the user from their environment if they have to look at it for a relatively long time. However, when the feedback does not require long looks and the interval between the feedback moments is long, the distraction is minimal, and it can thus be an effective tool.

A study of Blascheck et al. [29] gives more insight into data visualizations fitting for brief looks and it has shown that bar and donut charts can be understood in a shorter glance than radial charts. Hence, the use of a bar or donut chart could minimize the time that the user has to look at the data visualization and could be a good option for data feedback in cycling.

On the other hand, Van Hooren et al. [30] mention that auditory feedback has shown to be non-distracting when used appropriately and has been proven effective as well. Furthermore, auditory feedback prevents the user from having to look to a screen and thus lose the overview of their environment [2]. However, when participating in traffic this option might be less viable. Firstly, there is a lot of background noise from the traffic itself which could cause the user to not be able to hear the feedback properly. Secondly, the opposite is true: to participate in traffic it is important to hear your surroundings and having auditory feedback might interfere with hearing the traffic properly. For this reason, this research has opted for visual feedback.

2.3.2 Visual hierarchy

When giving visual feedback, it is important that the user focusses on the right information. This can be done by filtering out any irrelevant information and creating visual hierarchy. Visual hierarchy is the order in which the user absorbs information and this aspect can be influenced by using guide points for the eye. In general, the viewing pattern of a user starts with a searching phase, in which they try to find an entry point into the visualization. Using different sizes, colors, locations, images and text styles for different aspects of the visualization can influence where the entry point is. [31] For example, a larger item attracts more attention than a smaller one and a higher saturation grabs more attention than a lower one. These strategies should thus be used for the aspects of the visualization that are most important. Furthermore, medium saturations should be used for contextual data and finally, a low saturation should be used for background data. [32]

After an entry point has been found, a scanning phase begins where the user takes in data located mostly around the entry point. Using different spacing or putting aspects in a different order can influence the scanning phase as aspects closer to the entry point are more likely to be seen. Furthermore, people interpret a smaller distance between two aspects as a relation between the two. [31]

Making the right choices in these variables can greatly influence the users view of a visualization and can help them interpret the information as intened.

2.4 Persuasive data

Giving visual feedback to a cyclist is not only useful for informational purposes, but can also be a means to make the user change their behavior. The aim of giving feedback to patients with CVA during cycling is that they can use it to adapt their behavior in such a way that they are exercising as is needed for them. In this case, the feedback should be presented such that it causes some form of behavioral change. To achieve this, Fogg's theory on persuasive design can consulted [33]. By a 'persuasive design' is understood a design that urges the user to perform a target behavior.

According to Fogg's research done at Stanford University, any persuasive design must meet the following three requirements: (1) the user must be sufficiently motivated, (2) the user must have the ability to perform the required task and (3) the user must be triggered to perform said task. Fogg's model, which is the FMB model, relies on these three pillars and figure 3 shows that the higher these pillars are, the more likely it becomes for the user to reach the target behavior.

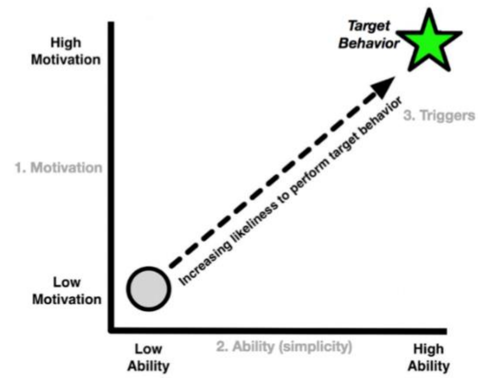


Figure 3: Visualization of Fogg's FMB model [33]

Although the FMB is used often, there are also models describing persuasive technology that are more focused on cycling in rehabilitation. For example, Geurts et al.[34] describe that for their application to help cardiac patients with cycling, the application is succesful if it adheres to three pillars: (1) simplicity and ease of use, (2) reduce fear and anxiety and (3) direct and indirect motivation. Their research is focused on secondary prevention, which entails preventing a second incident, which is also a focus point for patients with CVA.

With the first pillar, simplicity and ease of use, is meant that the user should be able to use the system after a short instruction. For any further use, no further research should be needed for the user as this could cause frustration and a lack of motivation to continue usage. Furthermore, any informative visualization should be easy to understand and interpret and during the ride any interaction with the system should be minimal and easy. This also causes the user to focus more on the ongoing traffic, rather than the system. This can be achieved by showing the user data in small segments, rather than filling the whole screen with a bunch of different data sets. By showing these segments one by one, the user can focus on one visualization at a time, which is easier to interpret at a short glance.[34]

The second pillar, reduce fear and anxiety, entails that the user should have trust in the system. This can be achieved by sharing collected data with medical staff. This could for example mean that they are part of the design process or that they recommend it to the user. Furthermore, the system becomes more trustworthy if the feedback is personal to the user. Showing this feedback regularly can give the user a sense of support and thus can reduce their fear of using the product.[34] In the case of patients with CVA, this pillar is especially important because, as mentioned in the introduction of this paper, stepping on a bike can be daunting for them [2].

The third pillar, direct and indirect motivation, suggests that there are different ways of motivating the user. The indirect approach focuses on external factors such as the company that the user cycles with or the environment they do it in. [34] The direct approach, on the other hand, is focused on the use of the system, by for example using nudges: strategies that guide people in a specific direction with indirect suggestions. One example that could be useful in a cycling application could be the principle of goal-setting. In a summary by E.A. Locke and G.P. Latham of 35 years of research done on goal setting and taks motivaiton [35], the importance of goal setting is affirmed. Multiple researches show that when someone has a goal to work towards, their performance generally improves. Furthermore, when people set these goals personally, their performance seems to be even higher than when the goal is given to them by someone else. Furthermore, giving feedback when that goal is reached also functions as a nudge because the feedback is seen as a symbolic reward and is likely to increase the possibility of the users repeating their actions. However, the latter can lose its impact over time and should thus not be used too often. [36]

2.5 State of the Art

2.5.1 Applications

The use of data feedback in sports and the visualization thereof is already a widespread concept that has grown over the years. With the emergence of smartphones and smartwatches, many different types of applications became available to monitor physical behavior. In the Google Play Store [37] for smartphones, with a simple search term such as "health tracker" immediately a huge list of activity and calorie tracking applications pop up, where 9 out of the top 10[2] of the best rated apps all have been downloaded over a million times each[3]. In table 6 (Appendix 1), this top 10 is shown with their individual characteristics. Although these applications are not necessarily focused on cycling, their method for data feedback and visualization can be an inspiration to this research and can show insight into customers' preferences.

The table shows that a number of visualizations are common between different apps in this top 10. This indicates that visualizations such as regular numbers in combination with icons, maps, line graphs, bar graphs, area graphs, progress bars and a calendar aspect are popular amongst users of these types of apps. The same can be said about motivational stategies that can be found in multiple apps in this top 10, such as easy usage, personal goal setting, an overview of the user's history, challenges in combination with badges and connection with friends.

According to 4 different sources [38][39][40][41], all listing the best fitness tracking apps for Android in 2020, the following apps are considered among the best:

- Google Fit (4 votes)
- Runkeeper (3 votes)
- Adidas Runtastic (3 votes)
- Jefit (3 votes)
- MyFitnessPal (3 votes)

In table 7 (Appedix 2), this top 5 is shown with their individual characteristics, found in the Google Play Store.

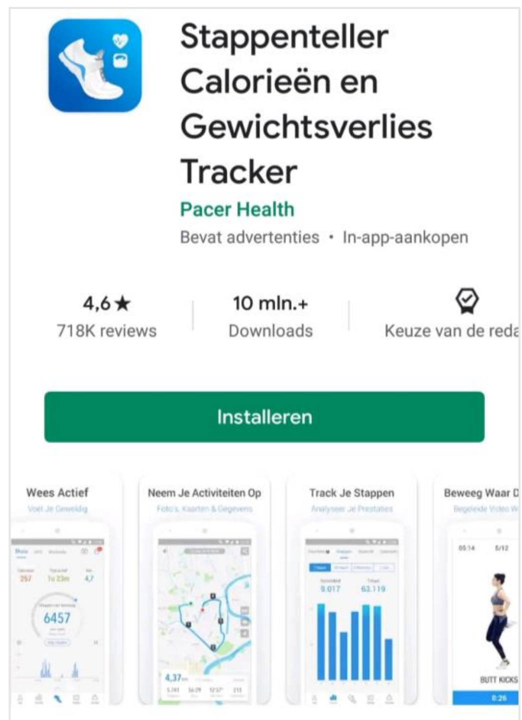


Figure 4: Screenshot of a health tracking app with some of the most popular visualizations [56]

[2] Disclaimer: This search was made on a smartphone registered in The Netherlands. Repeating this search in another country might give a different outcome based on geographical location.

[3] Disclaimer: This data was gathered on 19-04-2020, whilst most countries are placed in lock-down due to the COVID-19 virus and normal gyms are closed. This could cause an increased usage of fitness and health applications compared to normal.

It is interesting to see that the top 5 that is most recommended online, for the most part does not resemble the most recommended ones in the Google Play Store, which might have to do with the personal preference of the voters of the top 5 list, but it could also have to do with the way Google prioritizes the apps in the Play Store. However, they are relatively similar in their motivational strategies and visualizations.

Other than these rather simple mobile apps, there are bigger players such as Strava, Garmin and Fitbit. All three of these apps need to be connected to wearables and are therefore less accessible and more advertised towards motivated sportsmen.

Strava does not have their own wearable, but the app is compatible with most wearables on the market [47]. Their most important characteristic is that the company is built by sportsmen and designed with the athlete in mind. They use a clean visualization with only the essentials such as heart rate, time, distance and speed. The visualizations used, as seen in figure 5, are mostly maps and bargraphs to compare current data to personal history. Furthermore, Strava has the option to share live data with friends an family so they can support you during your run or bike ride.

Figure 5: Example of the Strava app [63]

Figure 6: Example of the Garmin App for fitness [64]

Garmin, on the other hand, have their own wearables which are designed with a specific activity in mind. For example, Garmin has smartwatches especially made for golfing but also activity trackers for playing kids. [48] Simillarly, Garming has a variety of apps, each with their own specific application such as working out in the gym as well as tracking of outdoor activities. In the latter, the visualizations are mostly maps to show the routes taken, area graphs to show the difference in height along the way and additional information on personal goals in numbers in combination with a calendar. An example can be found in figure 6. The fitness app, on the other hand, has a more sleek design with progress bars, bar graphs, area graphs and some text to give a quick overview of personal progress. Some examples of the data shown here is heart rate, number of steps and workout time.

Fitbit also has their own wearables, but they have more general ones compared to Garmin. Fitbit focusses on overall health with a wide variety of information monitored and with the goal to motivate the user to stay healthy. For the latter, they use collectable badges. Apart from tracking specific exercise, they also track everyday activity such as walking up a flight of stairs and they even monitor sleeping paterns. Fitbit uses a range of different visualizations such as incons with numbers, bar graphs, timelines, line graphs, color coding, maps and calendars, all in different designs to give the user a quick overview with limited text but still a lot of information. [49]

Figure 7: Example of Fitbit app [65]

2.5.2 Sport equipment

Finally, data feedback is also applied in equipment that has been made specifically for working out. Quite often in gyms electrical equipment such as rowing machines, treadmills or spinning bikes are equipped with a display showing the user's statistics. This can come in any form or shape and some common uses are images, two-dimensional graphs and even animations. The data that is displayed could for example be distance, speed, power, the number of calories burned or change in heart rate. The exact outputted data depends on the type of equipment [50]. The same type of systems can be found in cyclocomputers, which are specifically made for cycling and are attatched to the handlebar. They are simple informational systems that display information about the bike ride on the go [51].

Figure 8: Examples of data feedback in sport equipment [50]

Figure 9: Cyclocomputer [51]

2.6 Conclusion & discussion

All in all, this chapter has shown that there is a huge variety of ways to give data feedback to cyclists during the ride and there are already different options on the market for private use. However, none of them are specifically focused on giving feedback at a glance, which is what makes this research unique and more applicable to patients with CVA.

Furthermore, with the information from this theoretical framework, some of the sub-questions of this research can already be answered.

Firstly, the current recovery procedure of patients with CVA generally consists of a rehabilitation process for about 6 months after the accident. The patients receive help from occupational therapists, physio therapists and psychologists and mostly train in improving their motor skills, cognitive skills and visual skills. Furthermore, they are guided into living independently and participating in society again. However, in some cases help is needed permanently.

Secondly, cycling behavior can be measured in the following ways: with accelerometers, GPS trackers, force sensors and Hall sensors. Other than that, smartphones and smartwatches can be used as easy access to a variety of sensors packed together.

Lastly, complex data can be presented during cycling to improve cycling performance of patients with CVA by considering the following:

- The feedback is non-distracting
    - Visual feedback
    - It is understandable at a glance (e.g. bar or donut chart)
    - The presentation is simple and visual hierarchy guides the user
- The goal and the feedback are specific and personal
- The system could be connected to family, friends and medical staff

However, user testing will be done as well on this topic, for a more specific answer that is applicable to patients with CVA.

3 Design workflow

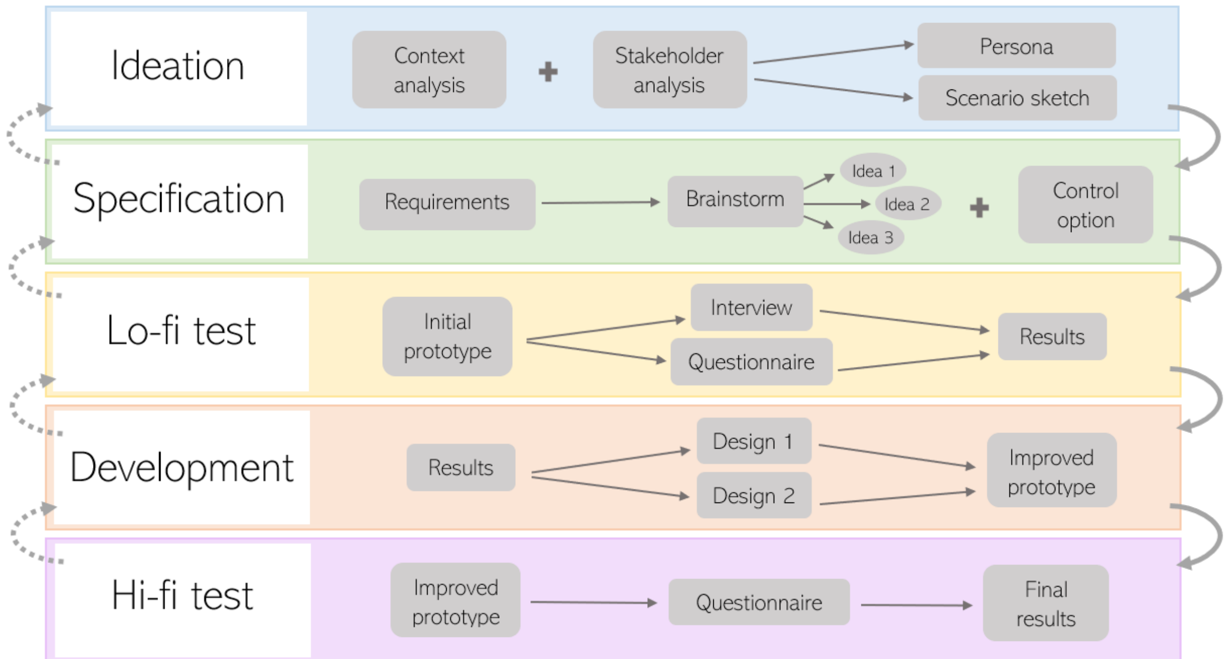


Figure 10: Design workflow

In figure 10 above, the workflow that will be used for the design part of this research can be found. The chronological order is from top to bottom and in principle a new phase cannot be started before the current one is finished. However, it is always possible to go back to a previous phase for evaluation and, if neccessary, adjustment of that phase. This iteration is encouraged to keep track of the requirements and stay focussed on the end goal.

The design process starts with an ideation phase, in which the initial context is defined. This is followed by a specification phase, in which the intital product idea is created. For this research, two test will be done: a low fidelity (lo-fi) test and a high fidelity (hi-fi) test. The lo-fi test is used to get some initial feedback on a prototype and the outcome of this test is the base for the hi-fi prototype. After the lo-fi test, a development phase takes place in which the results of the lo-fi test are used to create an improved prototype. This prototype is then testen in the hi-fi test, which is the main experiment for this research. Each phase seen in figure 10 is further explained in their own chapter.

4 Ideation

The ideation phase is the first phase of the design process and provides a reference on which the actual product can be based. This phase starts with a context analysis, which is followed by a stakeholder analysis and finally, a persona ans scenario sketch.

4.1 Method

4.1.1 Context analysis

The context analysis was based on the theoretical framework and additional sources that were provided by RRD. They have done several interviews with occupational therapists, physio therapists and clients of Van Raam, in which patients with CVA and/or the Easy Rider were topic of discussion. These were shared by RRD for this research and were delivered in the form of written files: the interviews were transcribed and the results of the questionnaire were presented in an Excel sheet. The interviews and questionnaire done with clients of Van Raam were held previously, whereas the interviews with two occupational therapists and one physio therapist were held the same time as this research. However, all of these interviews were held separately from this research and were only shared because they contain information that could be relevant to this research.

Other than that, Van Raam's website also functioned as a source for this research [52]. On the website, there is a page with user experiences and reviews of the Easy Rider, which give a clear insight into the added value of the Easy Rider for people who cannot ride a normal bike. Some of these users are indeed patients with CVA, but not all of them.

The context was analyzed by summarizing these sources separately and stating who the person of interest was, what type of source it is, a short description and the date on which it was conducted.

4.1.2 Stakeholder analysis

Once the context was set, the parties that are involved in this research and the product that could come out of it were defined. These could be any relevant group or person involved from the design and production until the final use. To determine who these stakeholders are, the context analysis and the theoretical framework were consulted. These stakeholders are presented in an overview along with their relevant characteristics, their expectations, their deficiencies and potentials and their implications and possible solutions for them.

4.1.3 Persona & Scenario sketch

Next, a persona and scenario sketch were made, as an example of the target user and how the product might be used. They are both imaginary but based on theoretical research from the theoretical framework, the sources provided by RRD and the user experiences on Van Raam's website.

The persona is mostly based on the information about CVA from the theoretical framework and on the interviews with occupational and physio therapists where frequent behavior and characteristics of patients with CVA were discussed. These sources formed the base of the character and made it specific for the target group and any additional background information such as hobbies, his name etc. were made up from imagination. Furthermore, next to personal information, a set of needs and wishes of the character were specified, which are relevant to the product. These are mostly based on the interviews and questionnaire with Van Raam's clients and the user experiences on Van Raam's website. This information shows the need for the new product and is key in the design process.

Once this persona was created, a scenario sketch was made which describes a novel product that meets the persona's needs and wishes. The scenario is mostly based on the persona and on imagination about the interaction of the user with the product.

4.2 Results

4.2.1 Context analysis

The context is analyzed using the sources listed in table 1. A summary of each source and how it defines the context is presented.

Table 1: Overview of sources provided by RRD

Person(s) of interest	Type of source	Short description	Date
Clients of Van Raam	Questionnaire done by RRD	34 clients of Van Raam tell about how often they use the Van Raam app and what their experiences are with it.	01 November 2018 until 15 November 2018
Clients of Van Raam	Interview done by RRD	Four users of several adapted e-bikes of Van Raam share their experiences with the vehicles.	January 2019
Clients of Van Raam	Online reviews	Users of the Easy Rider share their experiences with the product on Van Raam's website.	Consulted: 22 May 2020
Occupational and physio therapists	Interview done by RRD	Two occupational therapists and a physio therapist tell about their jobs and more specifically, their experiences in helping patients with CVA.	22 April 2020 29 April 2020 15 May 2020

<u>Summary questionnaire with clients of Van Raam</u>

Not all people interviewed are patients with CVA or users of the Easy Rider, but they do talk about their experiences with adjusted bikes from Van Raam. The survey shows that the most occurring reason for choosing a tricycle is bad balance and all participants indicate that cycling for recreation plays a big role for them. Furthermore, almost all participants mention their vehicle gives them more physical activity, mobility, social interaction, confidence, independence and less disability. From this group, approximately two out of three use the current Van Raam app, but not every time they use the bike. Reasons for not using the app are mostly inconvenience, either from the app or from Van Raam.

<u>Summary interview with clients of Van Raam</u>

Although the people interviewed are not patients with CVA, two out of the four use the Easy Rider and the other two use other electrical tricycles. All participants mention they use pedal assistance depending on how tired they are and would like to use Van Raam's app to gain insight into their cycling behavior during their ride, such as speed, distance and routes. However, all of them mention difficulties that they have had with the app so far and thus do not use it very often. Furthermore, all participants think that a competitive aspect with other users would be fun, but they also fear that it is not fair if people with different bikes or different capabilities are paired up.

Summary online reviews of clients of Van Raam

In the user experiences of the Easy Rider on Van Raam's website, a reoccurring theme is that it gives the user independence and freedom to go wherever they want. They find that the e-trike helps them with their balance and that the motor is a big support for when they find cycling too heavy. However, again the inconvenience of the Van Raam app is mentioned. Furthermore, some users explain that the Easy Rider is provided to them through the Wet Maatschappelijke Ondersteuning (WMO), which is a Dutch law that helps people stay independent for as long as possible. However, such a product is only provided in special cases.

Summary interviews with occupational and physio therapists

Interviews from RRD with two occupational therapists and a physio therapist show the other side of rehabilitation. Most patients with CVA receive holistic inpatient care in a rehabilitation center from occupational therapists, physio therapists and psychologists during the first phase of their rehabilitation. The goal of this phase is to have the patient be independent in the chronic phase. Informal caretakers, however, can be in the picture for a longer time. Furthermore, the interviews highlight that the mental aspect plays a big role in physical performance, and the other way around. For instance, if a patient has been cycling for a long time and gets tired, their attention for traffic decreases and that can cause dangerous situations. The other way around, a patient could have set certain goals, but if they have a bad day, they might not be able to achieve those goals. Moreover, because there is a large variety in types of patients and their cases, a therapist's assessment should be tailored to the patient.

The therapists were asked about their opinion on giving feedback of cycling behavior directly to the user, and one current issue that came up is that most users of the Easy Rider use the motor assistance to ride very fast, instead of using it as support of their own strength. This does not help them in training their stamina and muscles. A possible solution for that would be to inform the user better on what motor settings to use so that they can train appropriately instead of choosing the easy way out. Furthermore, informing the patients better and giving them feedback could help create an environment in which the user can train and recover on their own, with limited help from therapists. A physio therapist could help them make a training plan and only intervene if necessary. However, especially the aspect of direct feedback to the user without any intervention from therapists would be a great added value. This could help the patient to have an independent and active lifestyle in the long run, even outside of rehabilitation.

4.2.2 Stakeholder analysis

Based on the context analysis and theoretical framework, the following stakeholders are defined:

Table 2: Overview of stakeholders

Stakeholder	Characteristics	Expectations	Deficiencies and potentials	Implications and solutions
Patient	- Has had a CVA - Can have cognitive, visual and/or motor impairment - Is currently in the chronical recovery phase - Uses the Easy Rider	- Regaining independence - Going back to a "normal" lifestyle as much as possible	- Is willing to be trial candidate for new product - Might have difficulties focusing on multiple things at once, due to cognitive impairment	- Gets own use out of the product - Can have different types of chronical impairment - It is difficult to find a common solution
Informal caregiver	- Provides (daily) home care to patient - Motivates patient to exercise	- Easy handling of the product - Decrease of the work load	- Sees patient regularly in personal environment - Has a busy schedule	- Gets no own use out of the product - Is essential for the user
Occupational therapist	- Helps patient to integrate into normal life again - Focusses on patient's independence	- Gaining information on the patient's progress in independency - Getting the patient motivated to have an active lifestyle	- Has limited time with the product - Has professional knowledge on the patient's health	- Gets own use out of the product - Is essential in making good use out of the product
Physio therapist	- Helps patient to integrate into normal life again - Focusses on patient's movement	- Gaining information on the patient's progress in mobility - Getting the patient motivated to have an active lifestyle	- Has limited time with the product - Has professional knowledge on the patient's health	- Gets own use out of the product - Is essential in making good use out of the product

Psychologist	- Helps patient to integrate into normal life again - Focusses on patient's mental state	- Gaining information on the patient's mental state	- Has limited time with the product - Has professional knowledge on the patient's health	- Is essential in tracking the mental effect of the product
Van Raam	- Manufactures the Easy Rider - Wants to provide customization to help the patient	- Gaining feedback on the use, efficiency and operation of the product	- Has limited knowledge on the patient - Knows the physical restrictions and possibilities of the product	- Gets own use out of the product - Is essential in estimating the validity of the product
Municipality	- Helps people to be independent as long as possible with the WMO	- Providing more independence for the patient	- Has limited knowledge on the patient - Has a high profile	- Gets no own use out of the product - Can make the accessibility to the product better

4.2.3 Persona

Ben

64 years old
Patient of CVA

Job

- Primary school principal
- Works 32 hours per week
- Is free on Wednesday
- Retires next year

Hobbies

- Gardening
- Babysitting his grandchildren
- Watching tennis on tv

Living situation

- Lives in Enschede
- Lives together with his wife
- Lives in a semidetached house with a small garden
- Owns an allotment

Excercise

- Rides on Easy Rider every day:
  - As recreation
  - For transport
- Uses the Van Raam app on his phone
- Works in his garden regularly

Medical conditions

- Had a cerebral infarction 8 months ago
- Is still recovering at home
- Has low stamina
- Has a hard time concentrating
- Goes to physio therapist every other week

Goals

- Babysitting grandchildren every Wednesday
- Going there independently by trike
- Training his stamina to do so
- Following his progress along the way

4.2.4 Scenario sketch

It is morning and Ben wants to go for a ride on his Easy Rider, so he can get a bit of fresh air and train his cycling performance. He opens the Van Raam app on his phone and navigates to the 'at-a-glance cycling guide' where he finds the start screen. He chooses his goal of a distance of 10km, according to the training plan that he and his physio therapist came up with, and he presses start. He then mounts his smartphone to the handlebar of the electric trike and takes off. The route to his grandchildren is 15km, but he is currently training for 10km as he has to build up his stamina and muscles first. He starts off with a low support from the motor and follows his progress as he goes. On his screen he sees his traveled distance and how far still to go to reach his goal, his speed, the time that has passed and at what rate he is paddling. Seeing his progress build up gives Ben a satisfying feeling as he paddles along.

Around 8km in, Ben gets tired and wants to stop. However, he looks at the app in front of him and sees how close he is to reaching his goal. He decides to opt for a slightly higher support from the motor and pushes through to finish the 10km. He comes home a little tired, but he is proud that he made it and cannot wait to eventually reach the 15km and visit his grandchildren.

4.3 Conclusion & Discussion

To summarize, almost all stakeholders are focused on having the patient regain their independency. One way to do so would be to have the patient recover with limited external help by informing them properly on how to have an active lifestyle. This could be done by giving feedback on, for example, their cycling behavior, which is also what many current clients of Van Raam are interested in.

5 Specification

In the specification phase, a more specific product idea is formed, with the principles from the ideation phase in mind. This chapter consists of an overview of all the requirements that the product should meet and a brainstorm in which several options for the product are considered, until a limited number is selected to be worked out further. In this phase, important design choices are made on which the testing in the next phase greatly depends.

5.1 Method

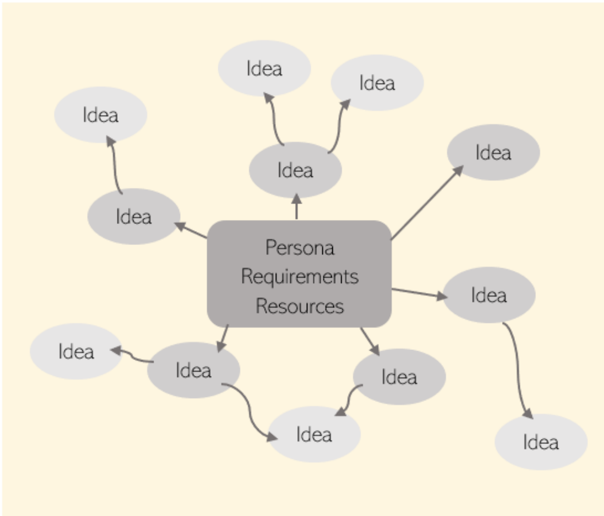
5.1.1 Requirements: MoSCoW

For the first step of the specification phase, a set of requirements was set up for the product. These requirements are based on the persona and scenario sketch, the stakeholder analysis and any information gathered from RRD, Van Raam's website and the theoretical framework. The requirements follow the so called 'MoSCoW principle' [53]. MoSCoW stands for 'must have, should have, could have, won't have' and implicates the priority of the requirements. These four categories can be described as follows:

- **Must haves:** critical requirements without which the project would be considered unsuccessful. These requirements must be implemented within the time span of the project.
- **Should haves:** important requirements that do not necessarily have to be executed within the time span of the project but can also be added later.
- **Could haves:** nice improvements on the project that are only added if the time and resources allow it.
- **Won't haves:** requirements with the lowest priority. These usually do not get scheduled within the current time slot. They might be added in a later stage but are not taken into account in the current one.

What priority each of the requirements should have is also based on the sources mentioned before, where especially the persona plays a significant role as that is the end user example of this research. Other than that, the time span and resources that are available for this research influence the priority in the sense of achievability. For the final product, at least all the 'must have' requirements must be met. [53]

5.1.2 Brainstorm



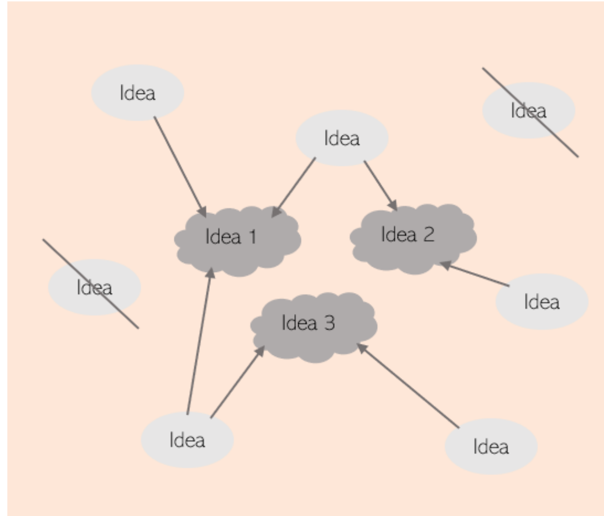


Figure 11: Concept of a diverging brainstorm (left) and a converging brainstorm (right)

Once the requirements were clear, a brainstorm session was held, which had a base containing the persona, the scenario sketch and the requirements. The session started with a diverging brainstorm, in which a word cloud was made with ideas that built upon each other. Secondly, a converging brainstorm was held in which the ideas in the word cloud were combined until three final ideas were made. To decide which ideas should be the final ones, the theoretical framework, the requirements and the context analysis were consulted. An explanatory visualization of the brainstorm process can be found in figure 11, although these two parts were combined into one word cloud. The brainstorm was done digitally, using Notability.

Next, the final ideas were made into visualizations using Adobe Illustrator, along with a fourth design. This design was made as a control visualization, to test whether intricate visualizations are even needed or, for example, some simple numbers would suffice. This design is therefore a rather simple one.

Of each option, four different variations were made with varying coloring and either with or without added numerical data.

Finally, all visualizations were exported to a PNG file.

5.2 Results

5.2.1 Requirements

In the tables below, all requirements are listed, along with the source they are based on, the reasoning behind them and their priority according to the MoSCoW principle. The sources are:

- The theoretical framework in chapter 2 of this report
- Sources provided by RRD:
    - The questionnaire with clients of Van Raam
    - The interviews with clients of Van Raam
    - The interviews with occupational and physio therapists

- The user experiences of clients of Van Raam
- The stakeholder analysis in chapter 3 of this report
- Personal reasoning

Table 3: Overview of requirements

ID:	1
Requirement:	All visualizations must at least represent the cycled distance
Source:	- Interviews with clients of Van Raam - Personal reasoning
Rationale:	Because aspects such as time and speed can vary greatly due to traffic (lights) or any other breaks, distance is the most reliable aspect to train for and should thus be the focus point of the visualizations. Any other aspects that might be interesting can be added as an extra feature with less emphasis.
Priority:	Must

ID	2
Requirement:	The user must be able to set their own goals
Source:	- Theoretical framework: §2.4 (Locke & Latham [35]) and §2.5 - Interview with occupational therapist
Rationale:	Users are more motivated if they can set their own goals
Priority:	Must

ID	3
Requirement:	The product must be non-distracting (i.e. no distracting images and only limited interactions)
Source:	- Theoretical framework: §2.2 and §2.4 (Geurts et al. [34]) - Personal reasoning
Rationale:	The product will be used in traffic and should thus not distract the user because that could lead to dangerous situations.
Priority:	Must

ID	4
Requirement:	The user must be able to track their personal cycling behavior on the go
Source:	- Theoretical framework: §2.4 (Geurts et al. [34]) and §2.5 - Interviews with clients of Van Raam - Interviews with therapists
Rationale:	Users are more motivated if they can follow their own live progress and it contributes to them having faith in the system.
Priority:	Must

ID	5

Requirement:	The data feedback must be understandable at a glance
Source:	- Stakeholder analysis - Theoretical framework: §2.1 - Interviews with therapists - Personal reasoning
Rationale:	Because the user will be participating in traffic during the use of the product, and already has difficulties focussing on everything going on around them as it is (due to cognitive impairment), the user can only spend limited time looking at the feedback and must be able to understand it within those limited time spans.
Priority:	Must

ID	6
Requirement:	The product should be integratable with the current Van Raam app
Source:	- Stakeholder analysis
Rationale:	Since there is already an app by Van Raam that can be used for the Easy Rider, having the outcome of this research integrated on that app would be an easy development and sharing setup.
Priority:	Should

ID	7
Requirement:	The product should be easy to use
Source:	- Theoretical framework: §2.4 (Geurts et al. [34]) and §2.5 - Questionnaire with clients of Van Raam - Interviews with clients of Van Raam - User experiences of clients of Van Raam
Rationale:	The current Van Raam app is a hassle to use, according to their clients and as a result they do not use it anymore. Making a product easy and intuitive to use, makes the threshold to use it lower and can motivate the user to use it.
Priority:	Should

ID	8
Requirement:	The product could be connected to others with the same sort of device
Source:	- Theoretical framework: §2.4 (Geurts et al. [34]) and §2.5 - Interviews with clients of Van Raam
Rationale:	Having the option to compare personal statistics with that of other users and connecting with friends and family could be motivating for the user.
Priority:	Could

ID	9
Requirement:	The product could be connected to a smartwatch
Source:	- Theoretical framework: §2.5 - Interviews with clients of Van Raam
Rationale:	Connecting the product to a smartwatch could show more personal data next to the physical data and give the user more insight into their own health.

Priority:	Could

ID	10
Requirement:	The product could have live tracking for the user's therapists
Source:	- Interview with occupational therapist
Rationale:	Giving the user's therapist insight into the user's data could accommodate a way of therapy in which the user can be helped from a distance and can rehabilitate in their own environment. However, this is rather hard to implement and will not be part of this thesis.
Priority:	Will not

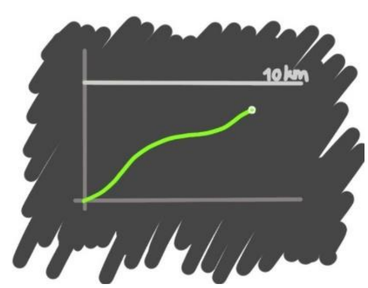
5.2.2 Brainstorm

During the divergent phase, a word cloud was made that can be found in Appendix 3. During the convergent phase, this word cloud was extended and three different types of data visualizations were chosen. Moreover, icons and time were highlighted as useful parts for the prototype, without being part of the visualizations. Based on requirement 2 and 3, each visualization shows the distance that has been traveled, along with the goal that has been set by the user. The visualizations that have been chosen are ones that are most fitting for these purposes. Furthermore, all the chosen designs are simple with only the most important data showing, to make it understandable at a glance and thus meeting requirement 6. As mentioned before, apart from these three designs, a design for the control group was made up as well. The four visualizations are described below.

1) **A Circular progress bar with more specific numbers inside for clarity.**
   This option is chosen because in the examples of the most popular health apps, almost all apps have a circular progress bar, so this aspect seems to be user friendly. The progress bar fills clockwise and the filled part resembles the traveled distance whereas the empty part shows what distance is still left, compared to the goal. However, in the theoretical framework can be found that just a circular visualization on its own, without anything to compare it to is rather hard to interpret so inside the circle more explicit information will be shown in the form of numbers. These numbers are displayed as a fraction, with the progress on top and the goal on the bottom.

Figure 12: Sketch of circular progress bar design

2) **A line graph with a goal. This is located in a coordinate system and shows distance over time.**
   A line graph was also a popular choice in the most popular apps and from E. Swires-Hennessy's paper on presenting data [28] can be concluded that it is a visualization that is rather intuitive. Besides, it is two-dimentional, which means that this visualization gives more insight than just the distance as the relative speed can be conducted as well. The moving green line shows the traveled distance over time and reaches towards a static grey line indicating the goal. This line is horizontal, so it shows the desired distance to be reached.



3) **A bar chart with a finish line.**
A bar chart is another example of a generally intuitive visualization [28] and was often used in the examples of popular fitness apps. The bar shows the progress and is placed horizontally, to resemle a race from point to point rather than a growth of some sort if it were vertical. The finish line was added to give the user a more realistic and fun goal to work towards in this "race" and along the horizontal axis an index is placed to use as a point of reference.

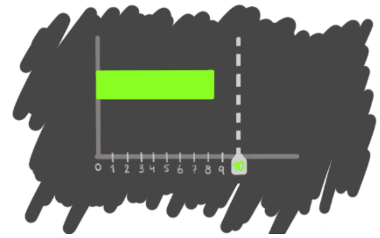


Figure 14: Sketch of bar chart design

4) **Control visualization: numbers**
The final design is that of the control option and is therefore a rather simple one. It consist of plain numbers to test wether visualizations have an added value over just numbers. These numbers are presented as a fraction, where the goal is shown on the bottom and the progress on top. Moreover, it is consistent with the other designs in the sense that the progress is compared to the goal.

Figure 15: Sketch of control group design

After that, with the knowledge that high saturation grabs more attention [32], each option was made in four variations:

1) A rather basic version without specific values and with only the progress in a noticeable color
2) The same basic version but with only the goal in a noticeable color
3) A more detailed version with the specific progress value in numbers and with only the progress in a noticeable color
4) The same detailed version with only the goal in a noticeable color

In figure 16 an example is shown of all four variations of the bar graph, where the top left is version 1, the top right is version 2, the bottom left is version 3 and the bottom right is version 4. All variations for each type of visualization can be found in Appendix 4.

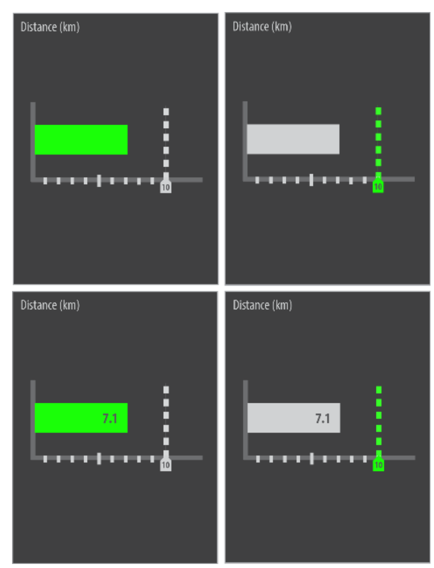


Figure 16: Examples of four different versions of the bar graph

5.3 Conclusion & discussion

To summarize, the most important requirements are:

- All visualizations must at least represent the cycled distance
- The user must be able to set their own goals
- The product must be non-distracting (i.e. no distracting images and only limited interactions)
- The user must be able to track their personal cycling behavior on the go
- The data feedback must be understandable at a glance

The three visualizations that meet these requirements for as far as possible and that are chosen from the brainstorm are:

- A circular progress bar with more specific numbers inside for clarity.
- A line graph with a goal. This is located in a coordinate system and shows distance over time.
- A bar chart with a finish line.

Furthermore, a control visualization was made with simple numbers instead of a visualization.

Finally, four different versions were made of each option with different aspects highlighted with colors and with or without extra numerical data. These options will be used for the lo-fi test, which is described and analyzed in the next chapter.

6 Realisation

In this chapter, the final prototype will be presented. This final prototype will be developed in two steps: a lo-fi test of the visualizations that resulted from the brainstorm and designing a final prototype based on the results of this test. The lo-fi test is used to get an initial response from the participant on the product. This testing moment shows if the participant understands the product and interprets the data correctly. Furthermore, it is used to test what the focus of the visualizations should be and the overall preference in terms of visualization of the data.

First, the lo-fi test is explained, along with its participants and how they are chosen. Then, the method for the analysis of the results is explained, along with how these results can be used for the final prototype. Afterwards, the results of each of these steps are worked out and with that knowledge, a final prototype will be developed, which contributes to answering sub-question 3 of this research: How can complex user data be presented to the user in an understandable way?

6.1 Method

6.1.1 Lo-fi test

Because this test is purely meant as a feedback moment, the testing was qualitative and was done with a small group of five people. These people were approached directly and selected on their easy approachability, and their experience with data visualization. The group was chosen in such a way that there was some variety in the latter.

Before the test could start, the whole testing method, including the prototypes and the interaction with them, were approved of by the ethical committee of University of Twente. Furthermore, all participants signed an informed consent form, from which it was clear to the participant what they were participating in and what the information gathered from the test would be used for. They also had the possibility to decline and to stop at any given moment without it having any consequences for them.

The test was a combination of an interview via video chat and a separate questionnaire, made in Google Forms. With the participant's permission, the audio of the video chat was recorded so all feedback could be listened back to and could be transcribed later. The interview started off with an introduction on the research and documentation of the participants' demographic data. Then, the participant was asked some general questions about their previous experience with similar products, to filter out if previous knowledge played a role in the outcome of the experiment. These questions were as follows:

1) *How old are you?*
2) *What is your sex?*
3) *What is the highest education that you have followed or are currently following?*
4) *Do you have any previous experience with wearables or fitness apps?*
5) *Do you have any previous experience in analyzing or developing data visualizations?*

Next, the participant was sent a link to the digital questionnaire and was asked to fill this in whilst sharing their screen. The questionnaire started with a scenario which the participant should keep in mind when answering the questions. In the questionnaire, all images of the lo-fi prototype were presented, arranged in the groups of four that were mentioned in ideation phase.

After the participant had answered all questions about one type of visualization, they were asked to explain their choices via video chat. They were free to give their own feedback but were also guided by the following questions:

1) *You chose option X, what was your reasoning behind that?*
2) *What aspect caught your eye?*
3) *Do you think anything is missing in this visualization?*
4) *Do you think there are any unneccessary aspects in this visualization?*

Furthermore, other questions were thought of on the spot in reaction to their feedback, creating a semi-structured interview. This was repeated for each type of visualization. At the end of the questionnaire there were some questions about general preference between all types and finally, they were asked for any additional feedback or tips that they might have had that could be used in the continuation of the research. After they were done with the questionnaire, the participants were kindly thanked for their participation.

An example question from this questionnaire can be found in Appendix 5.

Figure 17: Examples of the visualizations shown in the lo-fi test

6.1.2 Data analysis

Because the questionnaire was done in Google Forms, the results could quickly be analyzed. The program automatically gave an overview of all the answers in the form of pie charts and also allowed for an insight into individual answers. Considering this test was meant for feedback, the analysis of the outcome is qualitative and it reflects the most common preferences of visualizations and the auditory feedback from the interviews. The outcome of the analysis was described in text.

6.1.3 Final prototype

For the final prototype, the two most popular options from the lo-fi test were worked out into a more sophisticated prototype using Adobe Illustrator again, where the visualizations now not just stand alone but also have the look of a proper phone app. This includes additional cycling information and a user interface that could eventually be used in an actual app. This interface included a start screen and an option to choose a goal. Furthermore, any important feedback that was gathered from the lo-fi test was included as well. Finally, these vector files were exported again to PNG files, which were used to make a "click-through" app with Figma.

6.2 Results

6.2.1 Results lo-fi test

Overall, the lo-fi test was successful and was executed in the time frame of two days. The demographics of the five participants that can be found below are ordered randomly and all appeared once unless indicated otherwise.

Ages:
21 years
22 years (2x)
23 years
25 years

Educational backgrounds:
BSc Communication Science
BSc Creative Technology (3x)
BSc Electrical Engineering

Experiences with fitness apps/wearables:
Fitbit
Google Fit
Nike Run
Nike Training Club
Runkeeper

Experiences with data visualization/analyzation:
Courses in data visualization (3x)
Thesis on data visualization in news
SPSS / Excel
None

The outcome of the questionnaire was as follows:

Table 4: Overview of the most common choices made in the lo-fi test

Type of visualization	Most common choice
Control option	Fraction with the progress in green
Circular progress bar	With extra numbers and the progress in green
Bar graph	With extra numbers and the goal in green
Line graph	With extra numbers and either with the goal in green or “no preference” on the coloring
All without extra numbers	Line graph (although it is clearer with the extra numbers)
All with extra numbers	Circular bar graph

Interestingly, for the control option and the circular progress bar, almost all participant stated that it is more important to color the progress green, because that is what the user wants to focus on since they already know their goal. However, if there is a finish line involved, as with the bar and line graph, then the finish line should be green because green is more associated with finishing.

Most feedback was similar between different participants and the points that were repeated most are listed below:

- Visualizations have an added value over just numbers: the visualizations are clear for a quick idea and feeling of how far the user is and if they want to know the specific distance, they can look at the extra numbers.
- The green color does grab attention, but it is also associated with having reached the goal already. A better coloring option would be to use a gradient that becomes closer to green as the user progresses.
- In general, the extra numbers make the data clearer. Especially when the user does not have a lot of time to look at where the graph leads exactly.
- The line graph is interesting because it shows more than just distance; also speed and time. These aspects could be interesting to add to the other visualizations as well.
- Using percentages is clear in this case because the goal is exactly 10km. However, if the goal is a less rounded number, percentages do not give enough information as it is then harder to know what distance 1% resembles. It is therefore clearer to use concrete numbers.
- Overall, the visualizations are simple and do not have any unnecessary information that could be distracting. However, the index in the bar graph makes the visualization quite busy without having much added value because the user already looks at the specific number.

6.2.2 Final prototype

Figure 18: All screens of the prototype of the line graph (top) and the circular progress bar (bottom)

Because the line graph and the circular progress bar were chosen as the best visualizations overall, these were used for the final prototype. Information on time, speed and paddle frequency were added, based on feedback from the lo-fi test and the interviews with clients of Van Raam. Besides, for the line graph the finish line was colored green and for both visualizations the progress was colored in a gradient starting with red and ending in green, depending on the progress. Examples of the two parts of the prototype are displayed in figure 18 and as shown, each type of screen has the same data in both versions.

6.3 Conclusion & Discussion

All in all, the feedback from the lo-fi test was similar between participants and the most important points were:

- Visualizations have an added value over just numbers
- A gradient should be used for the progress that becomes closer to green as the user progresses
- Adding concrete numbers make the data clearer
- Speed and time might be interesting to show as well

These points were added to the designs of the most popular visualization types: the line graph and the bar graph, which were each made into a "click-through" app for the final prototype. This prototype will be used for hi-fi testing, which will be explained in the next chapter.

7 Evaluation

This chapter is about the second and final test of this research: the high-fidelity test. First, it describes how the hi-fi test is conducted and how the results are analyzed. Afterwards, the results are shown and the analysis is done to finally come to a conclusion and answer sub-question 4 about what form of data feedback is the most effective at a glance to improve cycling behavior of patients with CVA.

7.1 Method

7.1.1 Videos

In the hi-fi test, the final prototype was presented in the form of several video's, each showing a different screen from the prototype. The videos showed how the app would be used on the Easy Rider and were filmed from a first-person point of view using a head-mounted GoPro camera, so that it looked as if the viewer of the video was sitting on the trike themselves. The footage was shot outside of RRD and the phone was mounted to the handlebar of the trike. Afterwards the videos were edited using Adobe Premiere Pro and Adobe After Effects.

Each video showed a different progress to mimic what the visualizations would look like in different stages of the ride, starting with the start screen before the ride. The visualizations were shown for different amounts of time per video, but the amount of time in each video before the visualization came in the shot, was kept constant. The time, speed and paddle frequency were all animated so they would change during the video as they would in real life. This data was all in Dutch because this research was conducted in The Netherlands. Furthermore, all these videos, including the introduction video, were made twice: once with the circular progress bar and once with the line graph.

Finally, all videos were exported as an MP4 file.

7.1.2 Questionnaire

For the test, a questionnaire was made with Qualtrics, so that testing could be done independently and thus could reach a sufficiently large test group of at least 50 people. The link to the questionnaire was spread through the social media platforms Facebook, LinkedIn and WhatsApp. Together with the link a short explanatory message was shared with the request for anyone between the age of 18 and 70 years old to fill in the questionnaire and for all readers to share the link with others. The link was spread both publicly as well as via private messages. The whole questionnaire was in Dutch and it was available until a sufficient amount of more than 50 responses was recorded.

The questionnaire started with an informed consent form, which the participant had to agree to, to continue with the experiment. Next, they were asked to answer the following questions about their demographics, where question 1 and the explanation part of question 4 were open and the others were closed:

1) *How old are you?*
2) *What is your sex?*
3) *What is the highest educational level that you have done or are currently doing?*
4) *Do you have any experience in making and/or analyzing data visualizations? If so, what?*

Once these general questions were answered, each participant was randomly put into either a group that only tested the circular progress bar or a group that only tested the line graph. This division was automatically made by Qualtrics and the participants were equally divided. Both groups had the exact same questions, but with different visualization types.

For each group, a short explanation of the research and the experiment was given, and an introduction video was shown. After this introduction, the video related questions began. The first video was shown and as soon as it was finished, the questionnaire automatically went to the next page, so the video could only be watched once. Then, there were two questions about each video: either "What distance have you traveled so far?" and "What was your current speed?" or "What distance have you traveled so far?" and "How much time has passed so far?". These sets of questions alternated, and which questions would be asked specifically, was mentioned with each video, so the participant knew what parts to look at. The questions could be answered by sliding slide bars to the right value. Using slide bars in all questions made sure that the type of answer input was similar for all questions and all people, without limiting the possibilities for answering to a form of multiple choice. An example question can be found in Appendix 6

The whole process repeated itself six times in total, with each time a different video. The questionnaire was tested in a pilot test with 1 participant before making it public, so design flaws could be fixed.

7.1.3 Data analysis

The results from the questionnaire were downloaded from Qualtrics in the form of an Excel sheet, where the data could easily be analyzed and turned into clarifying graphs. The information that was of interest in this analysis was how many people answered each question correctly and which visualization group these people belonged to. To count the amount of right answers, the COUNTIF(range; value) was used, which counts all answers that are a specific value. Because some participants may have rounded their answers, a double count was done: one where only answers were counted that were exactly right and one where also rounded values were counted.

Because the amount of people in each group were not completely equal, the amount of right answers per question were turned into a percentage in order to compare them to each other properly. This was done with a simple equation of $\% = \frac{number\ of\ right\ answers}{total\ number\ of\ answers} * 100$. These percentages were then made into a bar graph, which showed the comparison of the amount of right numbers per question in each group. To make the deviation between the amounts with or without rounded numbers, two separate bar graphs are made.

Any participations that were not completed, were not counted, because these appeared to be from participants that also had a finished version. Using the unfinished versions in the analysis would therefore mean that those participants would be counted more than once.

Finally, an average was taken over the differences between the right answers of the two visualizations with the formula $avg\ difference = \frac{sum\ of\ differences}{number\ of\ data\ points}$, to conclude which type was generally understood better. The standard deviation was then calculated using the following formula:

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where $\{x_1, x_2, \dots, x_N\}$ are the data points, $\bar{x}$ is the average of those data points and N is the number of data points.

The same analysis was then repeated on the amount of right answers per sex for each visualization separately. For the influence of age, educational background and previous experience with data visualization/analysis, the same graphs were made, but no statistical analysis was applied.

7.2 Results

7.2.1 Videos

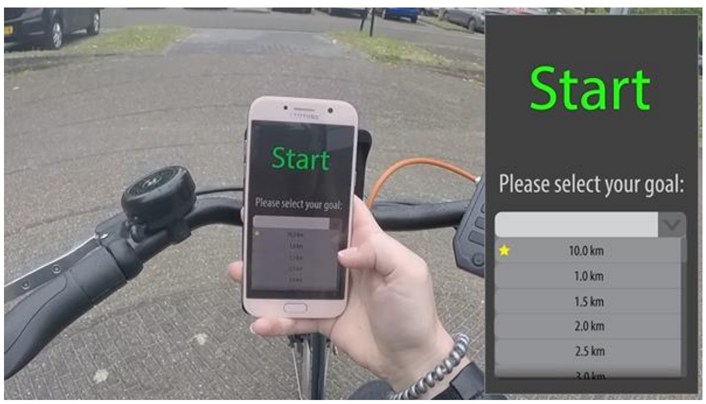


Figure 19: Screenshot from introduction video; choosing a goal

The first video shows the cyclist setting a goal of a distance of 10 km in the start screen of the app (see figure 19), after which the cyclist steps on the bike and puts the phone in the phone holder. When the first visualization shows up on the phone, a bigger example of the phone screen is displayed on the side of the video as well. The visualization shows all data starting at 0, as seen is figures 20 and 21 below.

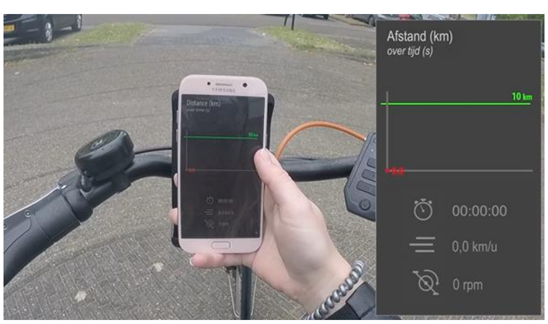


Figure 20: Screenshot from introduction video; line graph starting at 0

Figure 21: Screenshot from introduction video; circular progress bar starting at 0

This initial video sets the context for the rest of the test and shows what to expect in the following videos. In those videos, the cyclist is riding the Easy Rider and the phone shows different progress stages in the visualization. The distances shown are 1.6 km, 3.9 km, 5.4 km, 7.1 km, 9.6 km and 10.0 km.

The first two progress stages of 1.6 km and 3.9 km are shown the longest, for 5 seconds. The third and fourth are shown for 3 seconds and the last two are only shown for 1 second. Any footage before the visualization comes into shot, is 3 seconds long in all videos. With showing the visualizations at different time lengths, the clarity of the visualization at a glance can be tested. Whichever type of visualization is understood best during a shorter time is the best option for at-a-glance feedback.

Figure 22: Screenshot of video; line graph at 3.9 km

Figure 23: Screenshot of video; circular progress bar at 3.9 km

Figure 24: Screenshot of video; line graph goal reached

Figure 25: Screenshot of video; circular progress bar goal reached

7.2.2 Questionnaire

The two different groups of participants in the questionnaire, reviewing either the line graph or the circular progress bar, consist of respectively 33 and 32 participants, with the following demographics:

Table 5: Overview of the hi-fi test participants' demographic data

Demographic	Total	Line graph	Circular progress bar
Age	18-29: 22 30-49: 8 50-70: 35	18-29: 9 30-49: 4 50-70: 20	18-29: 13 30-49: 4 50-70: 15
Gender	Male: 25 Female: 40	Male: 12 Female: 21	Male: 13 Female: 19
Educational background	University education (WO): 29 Higher vocational education (HBO): 22 Intermediate vocational education (MBO): 10 Pre-university education (VWO): 2 Higher general secondary education (HAVO): 2	WO: 13 HBO: 12 MBO: 6 VWO: 0 HAVO: 2	WO: 16 HBO: 10 MBO: 4 VWO: 2 HAVO: 0
Previous experience with analyzing data visualizations	Yes: 18 No: 47	Yes: 9 No: 24	Yes: 9 No: 23

The outcome of the test can be found in figure 26. This bar graph represents the percentage of right answers that are given for each question per group. The positive average difference of 12% (with a standard deviation of s = 15%) suggests that, although not consistently, the circular progress bar gives a better result overall. From the chart can be seen that this is especially true for the videos later on in the questionnaire, where the visualizations were displayed for a shorter time. Other than that, for each video, the question about the distance is answered better than the one about speed or time. This is the case for both visualizations.

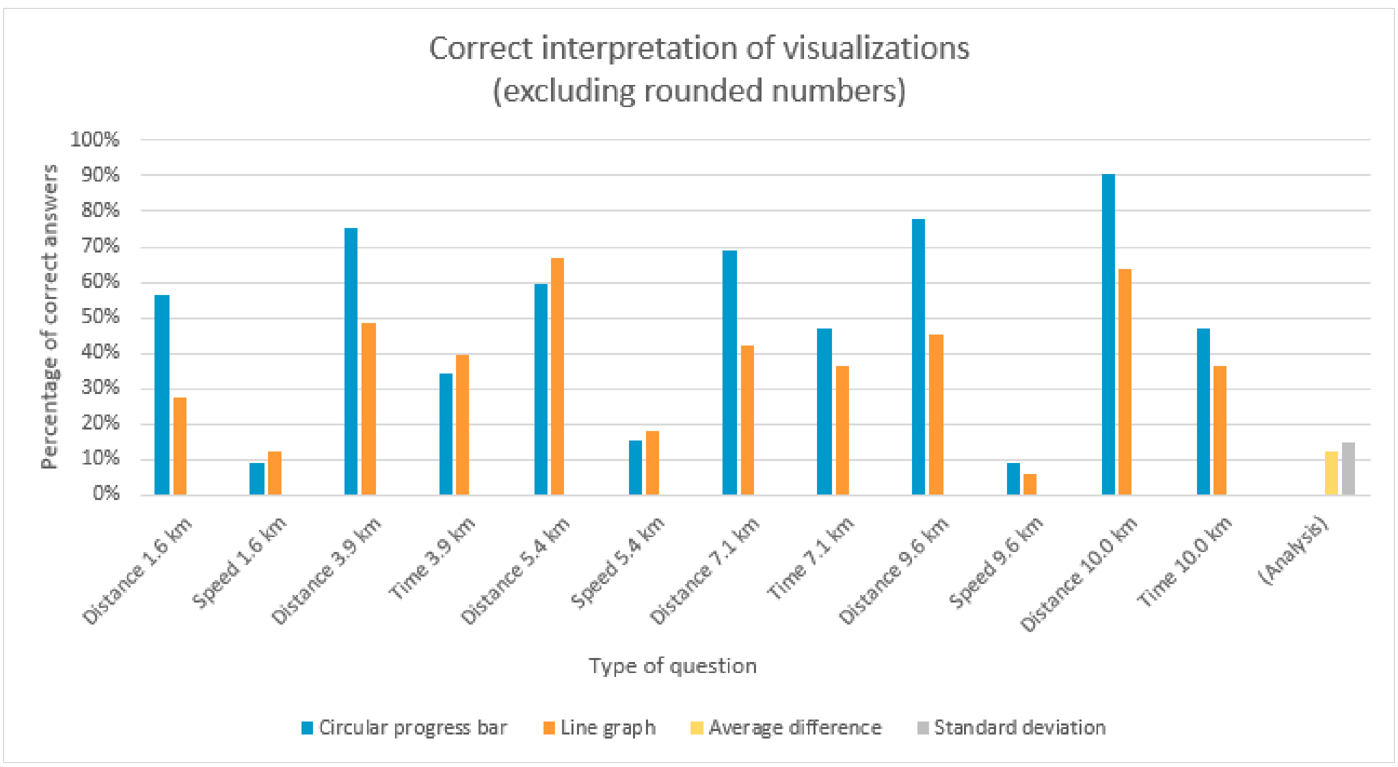


Figure 26: Graphing of the correct interpretation of visualizations (excluding rounded numbers)

With rounded numbers included in the counting, the results are similar to the ones above, however, the numbers have increased for some of the questions. Moreover, the average difference is just slightly lower at 11% and the standard deviation has increased to 17%, which indicated that the differences are less consistent in this case. These results can be found in figure 27.

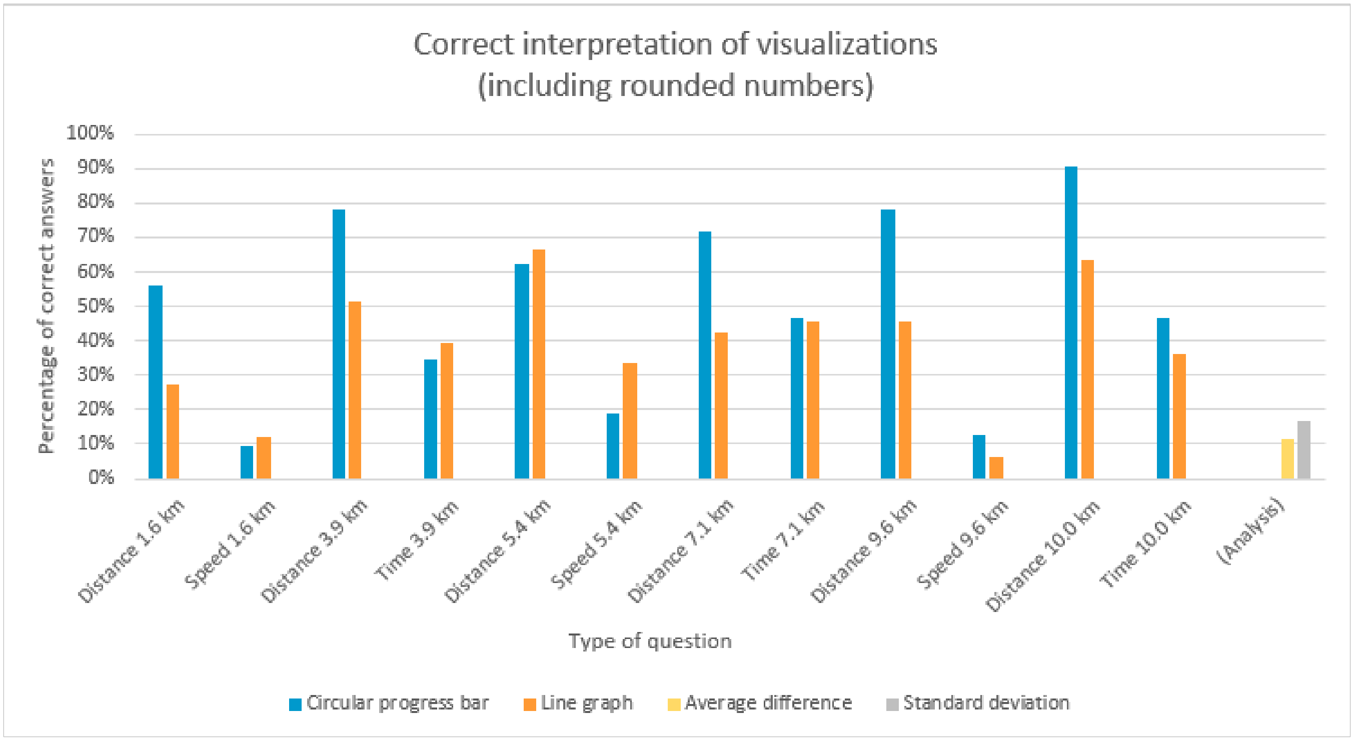


Figure 27: Graphing of the correct interpretation of visualizations (including rounded numbers)

In the analysis on the influence of the participants' demographic data was found that the difference in correct answers between men and women was small. The average difference was -6% (s=18%) for the line graph and 5% (s=16%) for the circular progress bar. In addition, no effect was found of age or educational background. The questions did seem to be answered better by people with previous experience in analyzing data visualizations, but the sample size of this group was too small to be properly analyzed. Therefore, it can be said that the groups of the two visualizations were equally divided.

7.3 Conclusion & Discussion

The questionnaire had responses from 65 participants between the ages of 19 and 70, of which 38% were men and 62% were women. The two groups reviewing either the line graph or the circular progress bar were equally divided.

Overall, the circular progress bar was better understood than the line graph, with an average difference of 12% (s = 15%), which was especially true for the videos where the visualizations were shown for shorter time. This shows that the circular progress bar is the best option for giving feedback at-a-glance, which also answers sub-question 4.

8 Conclusion & Discussion

This chapter will give an overview of the findings of this research, after which the research question of this thesis will be answered. Finally, the results will be discussed.

8.1 Summary

The research question of this thesis is defined as:

What is the best way to communicate at-a-glance feedback about cycling performance to patients with CVA during cycling?

To answer this question, four sub-questions were answered first, which was done throughout this report. Firstly, the current recovery procedure for patients with CVA was described in chapter 2, based on findings in existing literature. What has been concluded is that recovery for patients with CVA generally consists of a rehabilitation process for 6 months after the accident, including help from occupational therapists, physio therapists and psychologists to train motor and cognitive skills. The goal of the rehabilitation process is to make the patient independent again.

Secondly, in chapter 2 the methodologies for measuring cycling behavior of patients with CVA was also explained. Applicable sensors are accelerometers, GPS trackers, force sensors, Hall sensors and smartphones and smartwatches are often used as well.

Thirdly, ways to present complex user data to the user in an understandable way were both provided in chapter 2 as well as gathered from the lo-fi test in chapter 5, in which feedback of 5 participants was provided to several visualization designs. These designs were partly based on the findings of chapter 3 and the two with the best feedback in the test were the line graph and the circular bar graph, both with extra numeric data and both with the progress colored in a gradient that develops towards green.

Lastly, the most effective form of at-a-glance data feedback to improve cycling behavior of patients with CVA was found through the execution of a hi-fi test. Using several videos in combination with a questionnaire, the understandability of each visualization at a glance was tested. The test had 65 participants between the age of 19 and 70 years, of whom 38% were men and 62% were women. This test showed that the circular progress bar was understood better at a glance than the line graph.

8.2 Conclusion

From the findings of this research can be concluded that the best way to communicate at-a-glance feedback about cycling performance to patients with CVA during cycling is by using a simple non-distracting visualization. Testing has shown that the best one to use for this purpose is a circular progress bar with a numerical fraction in the middle, showing the concrete goal and progress. Moreover, the progress should be brightly colored to grab attention and it should be a gradient that reaches green when the goal has been achieved. An example of this visualization can be found in figure 32.

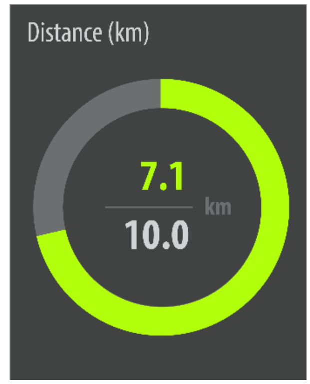


Figure 28: Example of the best visualization of this research

8.3 Discussion

Although this research gives clear results, there is room for discussion. The research was limited by unexpected restrictions that had to be taken into account. Furthermore, improvements could have been made to increase the validity of the outcome.

8.3.1 Restrictions

This research was restricted by national measures against the spreading of the COVID-19 virus. Firstly, because no face to face contact was possible, all user testing had to be done online, which limited the testing possibilities. If this measure were not in place, the hi-fi test could have been done with participants riding on the bike and using the visualizations themselves, rather than them watching videos about it. Although the outcome would be expected to be similar to the digital test, the experience could be a platform for a better monitoring of the user's reaction and opinion to the visualizations. The hi-fi test would then be a qualitative research rather than a quantitative one as it was now.

Other than that, due to the lockdown in The Netherlands during most of the period in which this research took place, all research had to be done from home, rather than at location at either the University of Twente or Roessingh Research and Development. This limited the communication between all parties involved and thus slowed down the research process.

8.3.2 Points of improvement

This research could have been improved, especially regarding the hi-fi test. Some flaws were overlooked and were later mentioned in feedback and some were noticed, but deliberately not acted upon. The latter applies to the fact that people were able to fill in the questionnaire multiple times. This could have been avoided by having the participants sign in or fill in some sort of ID. In this research that option was left out because it brings along the risk of privacy violation but adding it to the questionnaire would increase the validity of the outcome of the test.

A flaw that was overlooked until after the testing was that each video contained a pause button. The questionnaire was programmed such that after each video was done playing, it would automatically move on to the next page, so the video could only be seen once. However, participants did still have the chance to pause and play back the video if they were quick enough. This could have negatively influenced the outcome of the research because pausing the video cancels out the at-a-glance aspect of the test. This issue did not come up in the pilot test, but only after the test had been sent out. In future testing this feature should be switched off.

Finally, the test could have been improved by adding an extra example question so the participants could see what they were supposed to do beforehand. This was suggested in feedback that was voluntarily given by several participants, outside of the questionnaire itself. They mentioned that with the first video they had no idea of what to look at and what they would have to do with the information in the video. This is reflected in the results as the first video had lower scores than the second one, eventhough they were displayed for the same amount of time. An introduction video had already been made for this purpose, but that proved not to be enough.

9 Future Work

This research is highly conceptual and needs further assessment to prove whether the outcome is valid. Therefore, it would be recommended for future work to improve the test method of this research by improving the points mentioned in the previous chapter and by troubleshooting. Furthermore, testing should be done with patients with CVA instead of with healthy people. Considering patients with CVA often have cognitive and visual impairment, they might need a longer time to interpret the information in the visualizations. Therefore, the outcome can potentially be different from the outcome of this research. Furthermore, if the design of the circular progress bar is indeed proven to be useful through further research, then it could be implemented into the current Van Raam app and possibly other cycling apps, as the principle of at-a-glance feedback might be useful for a wider public than just patients with CVA.

Appendix 1 – Top 10 'health tracker' apps in the Google Play store

Table 6: Characteristics of the top 10 results for search 'health tracker' in the Google Play Store

Name	Creator	Data input	Data output	Motivational strategy
Stappenteller - gratis stappen- en calorieënteller [54]	Leap Fitness Group	- Pedometer - GPS tracker - Manual input - Phone's calendar	*Types of data:* - Number of steps - Walking time - Number of calories burned - Walking distance - Walking route - Amount of water consumed - Date *Visualization:* - Numbers and icons - Bar graph with calendar - Map - Circular progress bar	- Free to use - Easy to use; automated tracking - Intuitive graphs - No need to log in - All functions are accesible - Daily step report - Realtime step info in phone's notification bar - Personal goal setting
Health Mate - Total Health Tracking [55]	Withings	- Blood pressure sensor - Pulse sensor - Smart scale - Sleep tracking device - GPS tracker - Pedometer - Manual input - Phone's calendar - Database *This app works in combination with the Nokia Steel HR smartwatch*	*Types of data:* - Heart rate - Blood pressure - Sleep cycle - Weight - BMI - Walking route - Walking distance - Number of steps - Walking time - Average speed - Number of calories burned - Date *Visualization:* - Numbers and text - Bar graph	- Free to use - Personal goal setting - Overview of full health history and progress - Coaching program - Scoreboard; competition with family and friends - Challenges and badges - Personalized tips (verified by midwives) and weight tracking during pregnancy

			- Line graph - Area graph - Circular progress bar - Icons for progress - Map	
Stappenteller Calorieën en Gewichtsverlies Tracker [56]	Pacer Health	- Pedometer - GPS tracker - Manual input - Phone's calendar	*Types of data:* - Number of steps - Number of calories burned - Walking distance - Walking time - Walking route - Average speed - Weight - BMI - Example exercises - Date *Visualization:* - Numbers and text - Circular progress bar - Bar graph with calendar - Explanatory image - Countdown bar - Horizontal progress bar	- Free to use - Easy to use; automated tracking - No extra device needed - No need to log in - Challenges and badges - Support between friends - Groups with live interaction - Easy to combine with other health apps
Stappenteller - Pedometer & Calorieteller [57]	Leap Fitness Group	- Pedometer - Manual input - Phone's calendar	*Types of data:* - Number of steps - Walking distance - Number of calories burned - Walking time - Date *Visualization:* - Numbers and icons - Filled sphere chart - Bar graph with	- Free to use - Easy to use - Challenges and badges - Innovative design

			calendar - Calendar with numbers and icons	
Calorie Counter - MyNetDiary, Food Diary Tracker [58]	MyNetDiary.com	- Manual input - Phone's calendar - Camera - Database	*Types of data:* - Number of calories taken - Number of calories burned - Number of steps - Water intake - Weight - Weight loss - Nutritional data - Date *Visualization:* - Shaped progress bar - Numbers and icons - Line graph with goal - Bar graph with calendar	- Easy to use - Personal goal setting - Calculated calorie plan - Diet suggestions - Weight forecast - Food database - Notifications - Science from registered dietritians - Share experiences
Adidas Running - Hardlopen en Fitness [44]	Runtastic	- Pedometer - GPS tracker - Manual input - Phone's calendar	*Types of data:* - Walking distance - Walking time - Number of calories burned - Average speed - Walking distance - Walking route - Type of exercise - Date *Visualization:* - Numbers and text - Icons - Map - Circular progress bar - Bar graph with calendar	- Audio support during exercise - Live tracking and support from friends - Personal goal setting - Challenges - Group with friends - Ranking against friends - Compatible with different fitness apps - Variety of activities

GymRun Training Dagboek en Fitness Tracker [59]	Gym App Team	- Manual input - Phone's calendar - Database	*Types of data:* - Lifting weight - Number of reps - Type of exercise - Exercise time - Number of sets - Body measurements - Date *Visualization:* - Numbers and icons - Area graph with calendar - Explanatory image	- Easy to use - Personal goal setting - Exercise suggestions - Saving favorites
Moodflow: Year in Pixels & Better Mental Health [60]	Urban Hero Labs	- Manual input - Phone's calendar - Database	*Types of data:* - Rating - Emotions - Activities - Date *Visualization:* - Numbers and text - Color coding with calendar - Bar graph with calendar - Icons	- Personal tracking - Overview of full history - Notifications - Suggested activities - Challenges - Psychology based - Personalization options
Running App - Run Tracker with GPS, Map My Running [61]	Leap Fitness Group	- Accelerometer - GPS tracker - Manual input - Phone's calendar - Database	*Types of data:* - Walking distance - Walking time - Walking route - Average speed - Average elevation - Date *Visualization:* - Nubers and icons - Map - Bar graph (with and without	- Beginner friendly - Training plans - Personal goal setting - Overview of full history - Audio support - Professional fitness coach

			calendar) - Area graph - Line graph	
Sportractive GPS Running Cycling Distance Tracker [62]	sportractive.com	- Accelerometer - GPS tracker - Manual input - Phone's calendar	*Types of data:* - Walking time - Walking distance - Walking route - Average speed - Average elevation - Type of activity - Body measurements - BMI - Date *Visualization:* - Numbers and text - Map - Color coding - Icons - Line graph - Area graph	- No ads - Personal goal setting - Variety of activities - Overview of full history

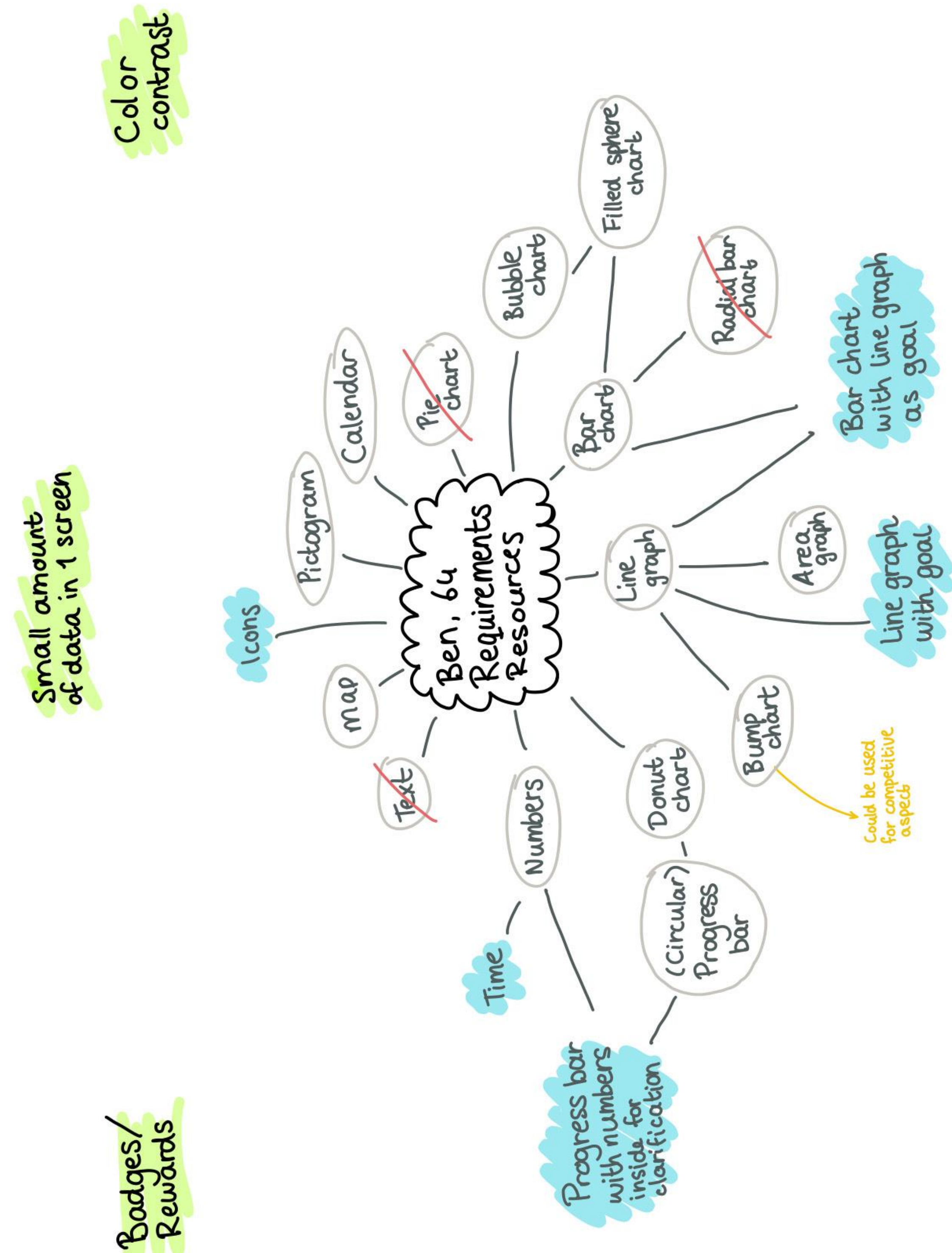
Appendix 2 – Top 5 fitness apps most recommended online

Table 7: Characteristics of the top 5 highest rated fitness tracking apps

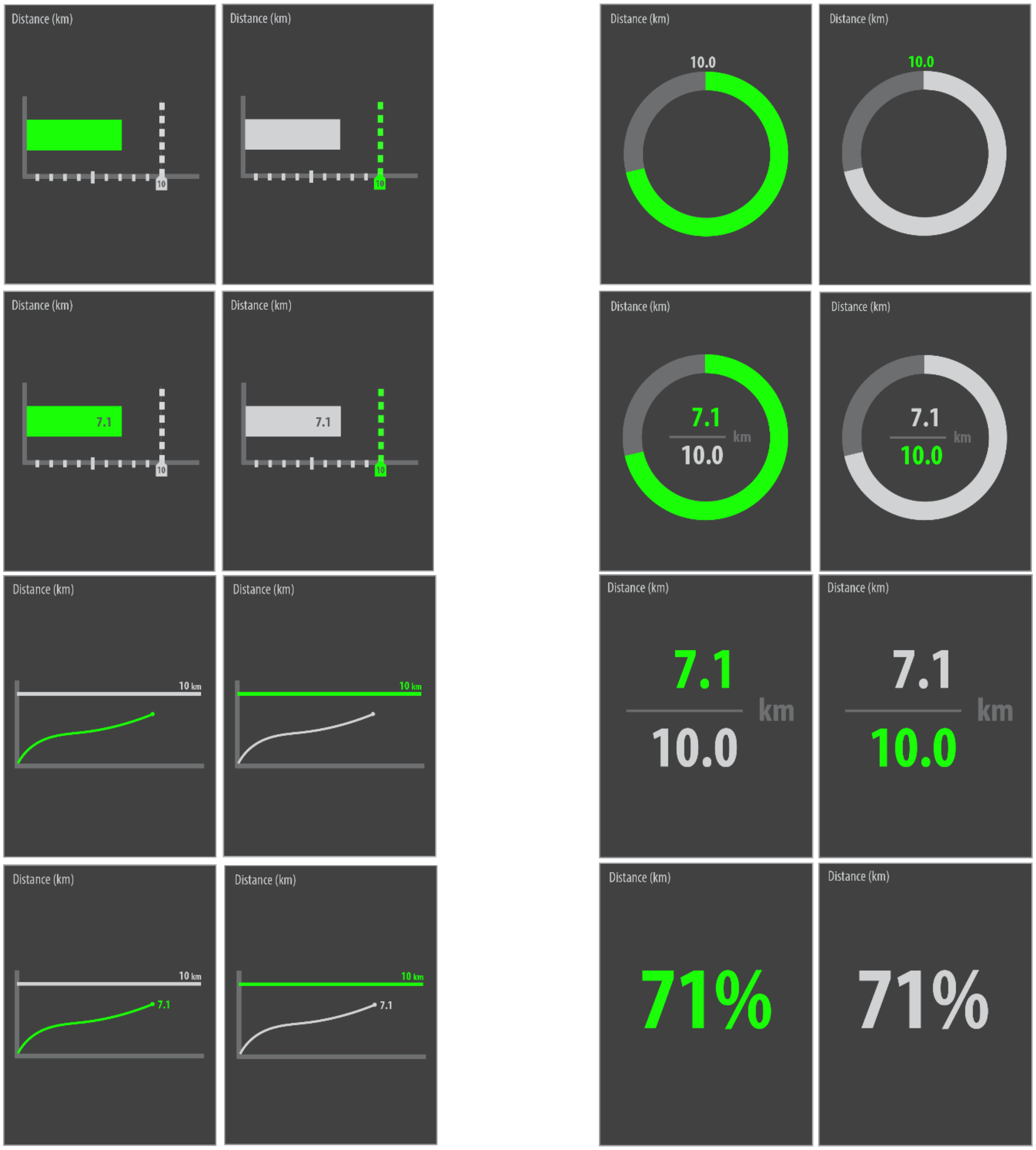
Name	Creator	Data input	Data output	Motivational strategy
Google Fit [42]	Google LLC	- Pedometer - GPS tracker - Pulse sensor - Manual input - Phone's calendar	*Types of data:* - Number of steps - Walking speed - Walking route - Walking distance - Walking time - Heart rate - Number of calories burned - Date *Visualization:* - Numbers and incons - Map - Circular progress bar - Line graph	- Easy to use - Personal goal setting - Challenges and badges - Overview of full history - Variety of activities - Notifications - Professional guidelines from American Heart Association and World Health Organization
Runkeeper [43]	ASICS Digital, Inc.	- Pedometer - GPS tracker - Pulse sensor - Manual input - Phone's calendar - Database	*Types of data:* - Walking speed - Walking distance - Walking route - Walking time - Number of calories burned - Heart rate - Date *Visualization:* - Numbers and text - Map - Icons - Bar graph	- Personal coaching - Audio support - Sharing with friends - Personal playlists - Personal goal setting - Training programs - Overview of full history - Notifications
Adidas Running - Hardlopen en Fitness	Runtastic	- Pedometer - GPS tracker - Manual input - Phone's	*Types of data:* - Walking distance - Walking time - Number of calories	- Audio support during exercise - Live tracking and support from friends - Personal goal setting

[44]		calendar	burned - Average speed - Walking distance - Walking route - Type of exercise - Date *Visualization:* - Numbers and text - Icons - Map - Circular progress bar - Bar graph with calendar	- Challenges - Group with friends - Ranking against friends - Compatible with different fitness apps - Variety of activities
Jefit [45]	Jefit Inc.	- Manual input - Phone’s calendar - Database	*Types of data:* - Lifting weight - Number of reps - Type of exercise - Muscles targeted - Exercise time - Number of sets - Body measurements - Date *Visualization:* - Numbers and icons - Circular progress bar - Explanatory image - Calendar	- Easy to use - Suggested activities - Training programs - Personal logging - Challenges and prices - Personal goal setting - Connect with friends
Calorieën teller [46]	MyFitness Pal Inc.	- Manual input - Phone’s calendar - Camera - Database	*Types of data:* - Number of calories taken - Number of calories burned - Water intake - Weight - Weight loss - Nutritional data - Date *Visualization:* - Numbers and text - Line graph	- Easy to use - Personal goal setting - Synchronizes devices - Calculated calorie plan - Weight forecast - Food database - Notifications - Share experiences with friends

Appendix 3 – Brainstorm lo-fi prototype



Appendix 4 – All variations of the initial designs



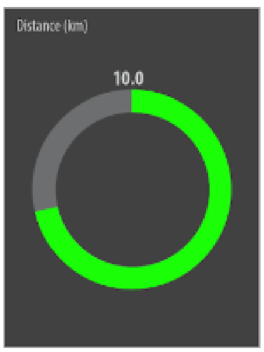
Appendix 5 – Example question from the lo-fi test

Data visualization in cycling

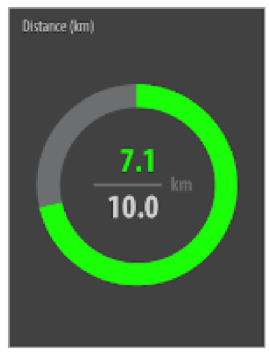
* Required

Circular progress bar

Please choose which visualization speaks to you the most, considering you are trying to reach your goal of 10km: *



○ Option 1



○ Option 2

○ No preference

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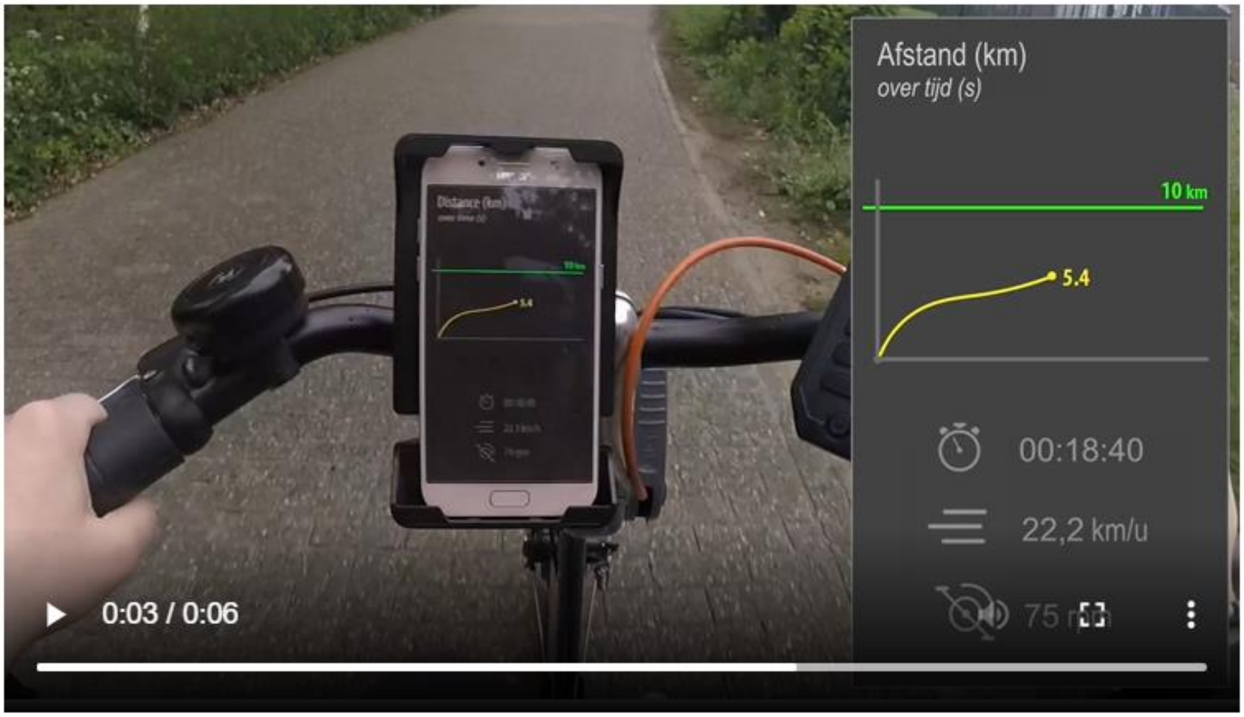
Appendix 6 – Example question from the hi-fi test

Afstand en Snelheid



Hoeveel kilometer heeft u tot nu toe afgelegd?

	0	1	2	3	4	5	6	7	8	9	10
Afgelegde afstand (in km)											

Welke snelheid had u hier?
(meedere antwoorden worden goedgekeurd)

	0	5	10	15	20	25	30	35	40	45	50
Snelheid (in km/u)											

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