AN ERGONOMIC APPROACH TO THE DESIGN OF BICYCLE HANDLEBAR GRIPS

Master Thesis

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Preface

When somebody asks me what I have studied, I will never answer with ‘Industrial Design’ or ‘Integrated Product Design’. Instead, I tell them that I study problem solving. Yes, it is true that the focus of the faculty of Industrial Design Engineering is on creating consumer products for (mass)production, but I believe our skillset is much broader and versatile than that. The project that I will be telling you about in this report is a great example of how an industrial designer can be deployed anywhere. It started with a subject of which I did not have much prior knowledge and I was not particularly attracted to and ended with me being an expert in the fields of bicycle handlebar grips and the ergonomics of the human hand and wrist during cycling, and almost feeling bad that the project is already over.

Before I allow you to read the story of what I went through the last couple of months I want to thank a few people that helped and guided me and made me feel like it was less of an individual project.

Peter, thank you for your endless and contagious enthusiasm. I don’t often meet someone who has such vast knowledge and passion for a subject and knows how to convey that towards others (me in this case). With such passion comes criticism, something my work could often use, and which I am sure has taken it to the next level.

Renate, many thanks for both your substantive and personal support. You always managed to ask questions that forced me to re-evaluate my work properly and update where necessary. Next to that I am grateful for and impressed with your availability and the time you were able to dedicate to me.

Mike, Hanneke and all other Widek employees, thank you for giving me a glimpse of how things work at your company, both in design and production as well as in marketing.

Thanks to my parents and roommates for enduring my endless rambling and complaining. I hope you believe me when I say I enjoyed this project very much.

Thank you to all my fellow graduates at the faculty of Industrial Design Engineering for much needed support, creative input and help with experiments. Good luck with your own graduation projects!

Lastly, I want to thank everyone who participated in my experiments, tests and research. It is your input that widened my view and taught me so much.

Enjoy the read!

Rob

Summary

This project is carried out in collaboration with bicycle accessories manufacturer Widek BV. Widek came with the plan to create a new design for bicycle handlebar grips with an increased ergonomic value compared to the currently available alternatives. The origination of this plan lies with the release of a paper containing new ergonomic knowledge on the pressure discomfort of the hand (di Brigida et al., 2021) and the realisation that the current situation around bicycle handlebar grips offers opportunities for improvement.

This report describes the process of shaping the assignment, gathering information, creating a concept and concluding the completed project.

Introduction

Because this is not the usual way Widek approaches the development of a new product, they have left the initial assignment quite broad: 'develop a new bicycle handlebar design with a focus on the ergonomics of the user'. To further define this assignment, explorative research is done to the client, their portfolio, production methods, clients, users and vision, and the context of bicycle handlebar grips in the current market. This allowed defining a scope for the project.

Research

The research within this project consists of four different studies: (1) A literature study to the ergonomics of the human hand and wrist, (2) market research on the current and predicted context, (3) field work to gain insights into this context and (4) a survey among (potential) users to collect reasoning behind the found insights.

Design

In the design phase, a problem list is created containing all collected problems regarding the ergonomics of bicycle handlebar grips in the current context. This problem list is arranged based on importance and feasibility within this project and translated into a list of requirements and wishes that the concept must meet. Based on this, a focus area is defined within the original scope of the project: (1) pressure peaks on the hand and (2) incorrect wrist positions. Developing different solution directions resulted in three concepts of which physical prototypes are made. Using these prototypes, the concepts are assessed during user testing. This assessment, together with the research outcomes from this project, has led to the proposal of one of these concepts (see image 1).

Concluding

This project is concluded with a preview of possible further development of the proposed concept by listing recommendations regarding the collected problems outside the scope focus area and additional research directions, found during concept creation.

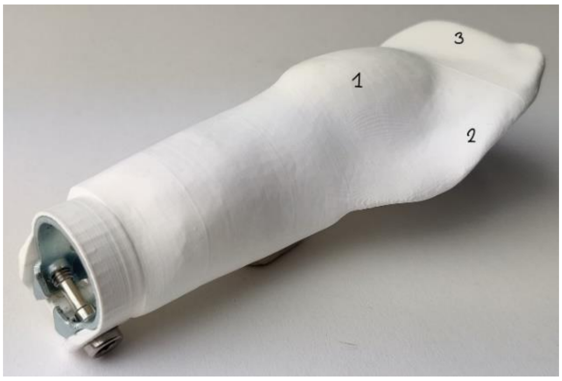

Image 1: The proposed concept and result of this project containing the region (1) bump and the region (2) + (3) wing.

Glossary

BHG(s)	Bicycle Handlebar Grip(s)
OEM	Original Equipment Manufacturer
AM	Aftermarket
PDT	Pressure Discomfort Threshold
PPT	Pain Pressure Threshold
LoR	List of Requirements
R&W	Requirements and Wishes

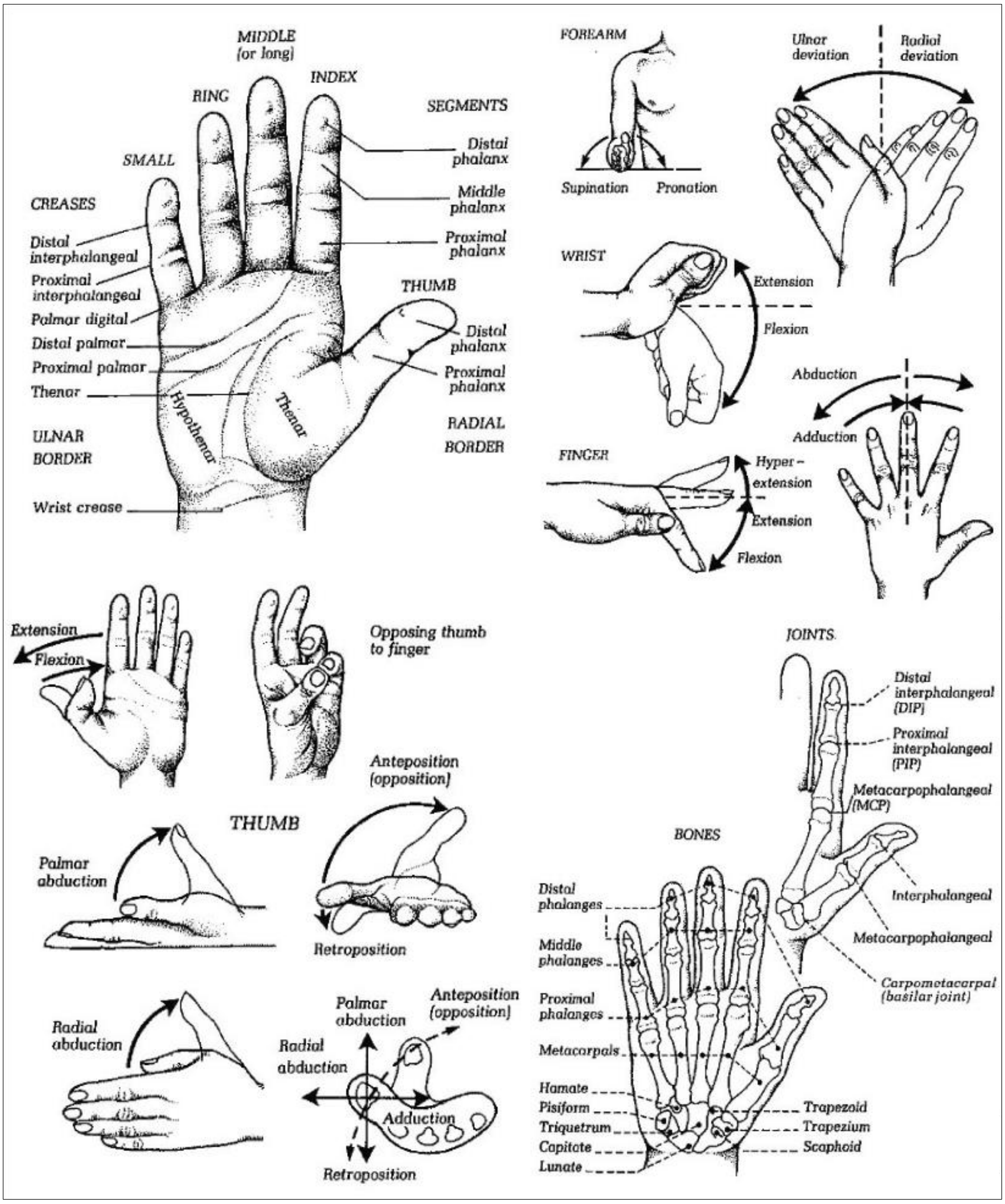

Image 2: Names of parts and movements of the hand (American Society for Surgery of the Hand, 2006)

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1. Introduction

Bicycle handlebar grips (BHGs) are one of the three contact points between a person and their bicycle. Comparing this contact point to the other two contact points, the saddle and the pedals, the BHGs are lagging in terms of comfort. Saddles are already being optimised using different kinds of shapes and materials to increase comfort and pedals are only loaded when pushing down. On top of that, is this load being damped by the shoes, ankle joints and knee joints of the user. By improving the comfort of the BHGs, the general comfort experience of the bicycle is taken to a higher level.

This report describes the process of a design project concerning the comfort of BHGs. The assignment of this project is given by a client who is a manufacturer in the bicycle sector. In this report, the steps of the design process are discussed, and all found insights and choices made are described.

In the following chapter, the first step of this project is described. This step consists of introducing the client and the project brief, which contains the initial problem, given information and the assignment.

1.1 Client introduction

In this section, the client within this project, Widek B.V., is introduced and a look is taken into their portfolio, production methods, clients, users and vision.

Widek is a Dutch company that manufactures and sells bicycle accessories. Their main products are bells, spoiler straps and BHGs which are designed by their in-house team of designers (see image 3). Since this project is focused on the design of BHGs, it is relevant that Widek already has experience with manufacturing several types of BHGs, all with a different focus (comfort, grip etc.). More than 95% of these products is manufactured in their factory in Krimpen a/d IJssel (NL) where the company was founded almost 100 years ago.

Widek has divided their factory into four major departments: (1) a metal workshop where parts are made by sheet metal stamping and chrome plating, (2) a weaving mill where the spoiler straps are made, (3) an injection moulding shop where plastic parts are made and finally (4) an assembly hall where the parts are assembled into final products.

When looking at Widek's sales, it is noteworthy that they do not sell directly to consumers. 75% of their products are sold to bicycle manufacturers that assemble them directly on the bicycles, these are called original equipment manufacturer parts (OEM) (Widek BV, 2021). The other 25% are sold to wholesalers who in turn sell the products to consumers. These are called aftermarket parts (AM). An interesting fact is that although the split in number of products between OEM and AM is 75 - 25, the split in revenue lies at 60 - 40. This difference can be explained by a higher sales price when selling individual products, which is caused by bulk discounts.

Widek's vision regarding this project is that they want to combine their existing knowledge on BHGs, originated from years of manufacturing, with insight gained from research on ergonomics and the BHG market to create a new type of BHGs that can be manufactured requiring as few adjustments as possible to their existing manufacturing process.

(a) (b) (c)

Image 3: Three main product categories: (a) bells (Widek BV, 2020a), (b) spoiler straps (Widek BV, 2020b) and (c) BHGs (Widek BV, 2020c).

1.2 Project brief

In the project brief, the assignment is explained after an interpretation and iteration of the original assignment given by the client. This project brief is created before the start of the project and has been approved by the supervisory team. The original project brief can be found in appendix K.

Since the initial assignment by Widek needed more focus, the project was kicked off with explorative research on the difference in bicycle types to narrow the primary scope of this project. The results of this research are used to compose the project brief.

Introduction

In this section, the target bicycle and their corresponding user are introduced along with the substantiation of the choice for this target group.

Widek has divided bicycles into five categories. These categories are based on body posture during use (see image 4). The scope of this project includes category 4. The choice for this category is based on the wishes of the client, insights from this project brief and further substantiated by market research (see section 2.2).

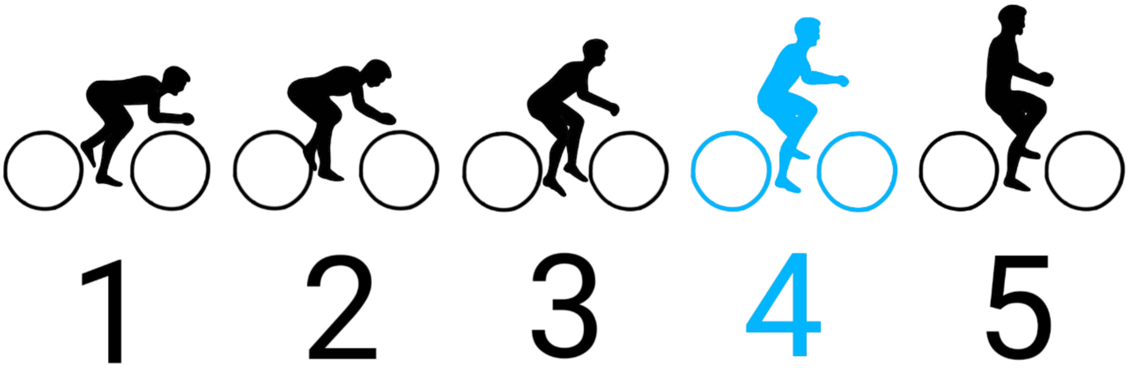

Image 4: The five bicycle categories based on posture of the cyclist. (1) The aerodynamic posture using a racing handlebar that produces the most complaints, (2) the aggressive posture with a straight handlebar, (3) the performance-focused tour bicycle with a straight handlebar, (4) urban bicycles and e-bikes with a raised and slightly curved handlebar and an active, upright posture, and (5) the leisure bicycle with a fully curved handlebar resulting in an axial load on the BHGs and a leaning back posture (SQlab, 2021).

Explorative research

The bicycle industry is growing bigger than ever. Between 2015 and 2020, average bicycle retail prices in the Netherlands have increased from €914 to €1499 (+64%). The total turnover from bicycle sales has increased with 30% in 2020 compared to the year before, and even doubled between 2010 and 2020 to a record height of €1.65 billion (Stichting Landelijk Fietsplatform, 2021). Next to this increase in spending on bicycles, the number of people preferring the bicycle in favour of the train or car is also increasing. Between 2019 and 2020 (the first year of the COVID-19 pandemic), travel time and travel distance by car and train in the Netherlands decreased with 25% and 60% respectively, while the decrease in bicycle use was only around 10% (see appendix B) (CBS, 2021).

Looking at these developments, Widek wants to seize this opportunity to increase the quality of BHGs and secure their position in the upper market segment.

Problem definition and scope

In this section, the problem definition and the scope of the project as given by the client are briefly stated.

Problem definition

Existing BHGs fit the current use of bicycles. Looking at developments that indicate increasing use frequency and duration of bicycles and an increase in quality and expectations, an increased level of ergonomic quality is desired.

Scope of the project

The goal is to collect and distil current knowledge on handgrips (anthropometrics, biomechanics and experience) and to relate this knowledge to the design of BHGs. After this, the next step is to bundle this knowledge into a LoR and develop a new BHG design with a focus on the shape of the BHGs and the posture of the cyclist.

Assignment

The main objective is to design the shape of a new BHG concept design that fits the needs of the changing bicycle market by focusing on the ergonomics of the hand and the posture of the cyclist.

The second chapter of this report describes a literature study on handle ergonomics and how this relates to BHGs in the established context (see chapter 2).

The third chapter will discuss be the development and proposal of a new BHG shape design by applying the collected insights to the defined context and scope. This shape design will contribute to Widek's goal of developing BHGs with a higher ergonomic quality (see chapter 3).

1.3 Personal vision

I personally believe that the BHG is a part of the bicycle that has been lagging compared to the development of the bicycle and its parts and can use improvement to make it more fit to the human form. I enjoy tackling problems that people encounter (even if they are unaware of those problems) and to come up with solutions to these problems to make their lives just a little bit easier. In this project, the focus will be on the shape of the BHG and a solution that solves its associated problems for the widest possible group of users. As confirmed in the project brief, ergonomics is mainly associated with the human posture and physical (dis)comfort, while in reality there is more to it. In the following study, other aspects of product design are therefore also considered, such as ease of use, appearance and (the feeling of) safety.

Improving multiple aspects of BHG ergonomics might contribute to making cycling an even more pleasant activity and so the growth of the bicycle's role in European traffic.

2. Research

In this chapter exploration of the context of this assignment is described. This is done by performing a literature study, market research, field work and a survey among (potential) users. The findings are grouped per subject and the most important insights are summarised.

2.1 Literature review

This study first investigates the definitions of comfort and discomfort. These terms are relevant for the improvement of BHGs since it is of great importance that the solution feels comfortable and does not cause discomfort. Secondly, the sensitivity of the hand is explored to find out what parts of the hand need attention to prevent overload and where pressure must be reduced. After this, the position of the wrist relative to the hand holding the BHG is studied. From the explorative study it appears that this position might affect the experience of discomfort during use. Lastly, a review of previous studies describing recommended BHG dimensions has been done.

Discomfort definition

When studying and discussing ergonomics, the terms comfort and discomfort are often used. For further understanding, these terms are first investigated.

The International Ergonomics Association (IEA) (2021) describes ergonomics as “being focused on optimising human well-being and overall system performance”. Well-being is related to comfort and discomfort, and therefore studied in this project.

It is a common idea that comfort and discomfort are opposites on the same scale, but most researchers follow the vision of Zhang et al. (1996). They explain discomfort as being associated with feelings of slight pain, soreness, numbness, stiffness, and that it can be reduced by eliminating physical constraints. However, this does not necessarily produce comfort. The elimination of physical constraints is something that could be included in the R&W of this project. Ashkenazy and DeKeyser Ganz (2019) state that discomfort can be physical or psychological and that it is characterized by an unpleasant feeling resulting in a natural response of avoidance or reduction of the source of the discomfort. They say that pain is one of the causes for discomfort, but not every discomfort can be attributed to pain. Hamberg-van Reenen et al. (2008) state that it is the other way around, and that discomfort could lead to pain in the long run. Lastly, di Brigida et al. (2021) say that, in a continuum discomfort scale, pain can be considered as an extreme on it, where the value of discomfort is highest.

After comparing definitions for discomfort created by several researchers in the field of ergonomics, this section is concluded by specifying the definitions that will be used in this project. Firstly, the definition by Zhang et al. (1996), elaborating symptoms of discomfort and mentioning the elimination of physical constrains as a solution. Secondly the statement by Ashkenazy and DeKeyser Ganz (2019) that substantiates this solution by stating that discomfort can lead to avoidance of the source of the discomfort. The question of what comes first (pain or discomfort),, is not relevant in this project since the assignment is to minimise both. For this reason, no decision is made regarding these statements, as well as for the definition by di Brigida et al. (2021).

Hand sensitivity

During use, the product to be improved (BHGs) is in constant contact with the hand. Therefore, the first focal point of this research is investigating the sensitivity of the human hand.

In their research on hand and elbow sensitivity, di Brigida et al. (2021) created a map of the human hand that visualises the differentiation of the different regions from the most sensitive (lowest discomfort threshold) to the least sensitive ones (highest discomfort threshold) (see image 5). The regions with the lowest pressure discomfort threshold (PDT) are coloured dark red, and those with the highest are coloured yellow and green.

The regions of the hand that have the highest PDT (regions 7, 15, 16, 17 & 18) are located on the hypothenar and, potentially more interestingly, the middle of the palm between the hypothenar and thenar regions. When designing a solution for this project, these regions need attention since the pressure on the hand should be distributed according to the corresponding PDT levels.

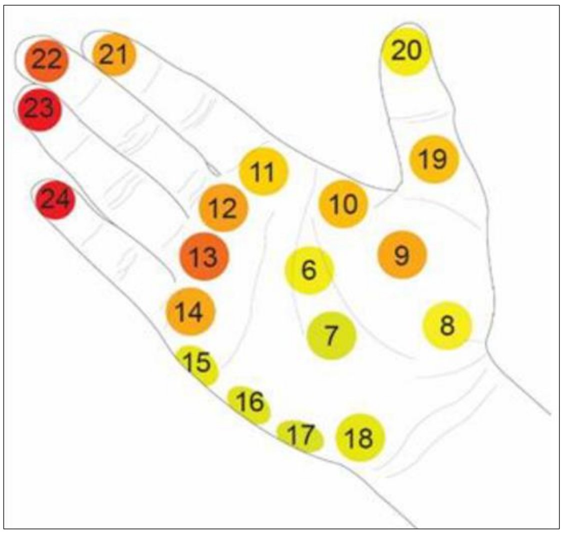

Image 5: Sensitivity map visualising the PDT distribution of the hand (di Brigida et al., 2021).

This research also investigated the difference between male and female subjects (see appendix A) and concluded that there is a significant difference ($p = 0.011$) in hand sensitivity between males and females, where males appear to have a higher PDT. This difference in hand sensitivity between genders is in accordance with previous work of back and buttocks sensitivity (Vink & Lips, 2017) and in contrast with the absence of difference in gender for foot sensitivity (Buso & Shitoot, 2019).

A similar study by Fransson-Hall and Kilbom (1993) also investigates the sensitivity of the human hand. The difference between these studies is that the latter investigates the pain pressure threshold (PPT) instead of PDT. Serving as a warning signal, pain should be taken seriously as it may be considered as an indicator of potential cell damage and cell death (Hardy et al., 1967).

The insights gained from this study can still be used since pain is seen as an extremity of discomfort (see subsection ‘Discomfort definition’ in section 2.1). The results from this study have been mapped as well (see image 6) and show the PPT per region compared to the average PPT of the hand. The regions of the hand that have the highest PPT are the hypothenar, the area between the hypothenar and thenar and parts of the fingers. This corresponds with the previously discussed study by di Brigida et al. (2021).

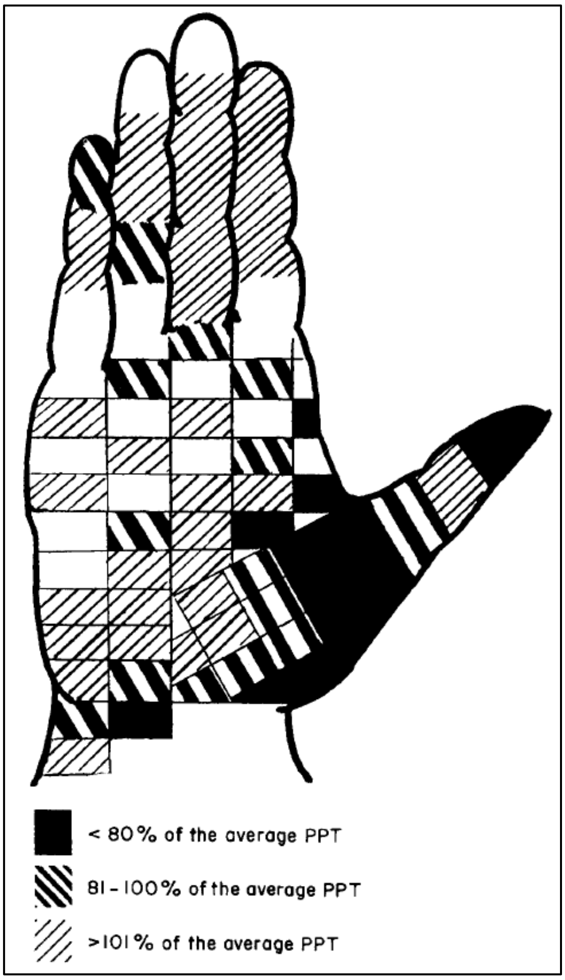

Image 6: Sensitivity map visualising the relative PPT of the hand (Fransson-Hall & Kilbom, 1993).

Results also show that sustained pressure does not hurt at once but becomes painful after a short time. Also, on average, the female PPT corresponded to two-thirds of the male PPT (see appendix A). In addition, no systematic difference was found in PPT between the right and left hands. This corresponds with the main body of literature (di Brigida et al., 2021).

Tichauer & Gage (1977) state that when looking at hand-tool design, tools should not be specifically shaped to one hand. For example, handles with finger grooves are only suitable for one particular size of hand and when over- or undersized hands hold the handle, the interphalangeal joints may be exposed to high pressure. Instead, according to Fraser & International Labour Office (1980), the tool shapes should be generalized and basic, put together to fit the contours of the space of the grasping hand. Bennet (1971) reports that compressive stresses increase inversely with the area over which the load force is spread, which implies that the stress level at a desired location can be lowered through smoothing. All edges and corners of a tool that are not part of the functional operation should be rounded, and surface protrusions should be eliminated.

Another insight provided by Husain (1953) that might be useful when working on BHGs is that low pressure maintained for a long time induces more tissue damage than high pressure over a short period. They therefore recommend that actions involving exposure to external surface pressure should be organized for the user to obtain intervals of relief between periods of external surface pressure to the hand. Moreover, the permissible level of external surface pressure decreases with increasing time of exposure to external surface pressure. This imposes a major challenge in this assignment, since recommending against constant contact between the hand and the BHG means that the user needs to take their hand off the handlebar and relinquish control over the bicycle, potentially creating a dangerous situation.

This section has yielded a great amount of information on the sensitivity of hands and how they should be loaded to minimalize discomfort. However, all the collected insights relate to tests that were done with hands that are in a flat position and lying on the dorsal side (back of the hand), where during cycling the hands are put under load while the fingers are flexed around the BHG. To be more certain of the insights on hand sensitivity, a study should be done on PDT and PPT of the hand in this flexed position.

Wrist position

Next to the sensitivity of the hand, the posture of the wrist is a major cause of discomfort when riding a bicycle. That is why this subsection takes a closer look at wrist position when riding a bicycle.

Some of the most common causes of discomfort when riding a bicycle are numbness and tingling in the fingers. According to Stanbury (2020), these are typically caused by compression of a nerve pathway, restriction of circulation to the hand or restriction of circulation to a nerve. These compressions and restrictions can occur when the hands deviate from the neutral position for an extended period of time (see images 7 and 8). According to research by Ergotec (2012), this concerns the ulnar (red) and radial (yellow) nerves, which are two major nerves in the arm and the hand. To avoid pain, these nerves must run straight and the carpal tunnel (the nerve tunnel on the palm side of the hand) must be uncompressed. Carpal tunnel syndrome (see image 9) can occur when the median nerve (the third nerve into the hand) is compressed through the "tunnel" between the bones of your wrist. Numbness in your second and third finger occurs if your wrist is in one position too long. Handlebar palsy is caused by prolonged pressure on the ulnar sensory nerve, which causes your hand to ache and the ring and little fingers to feel numb (Leisz, 2020).

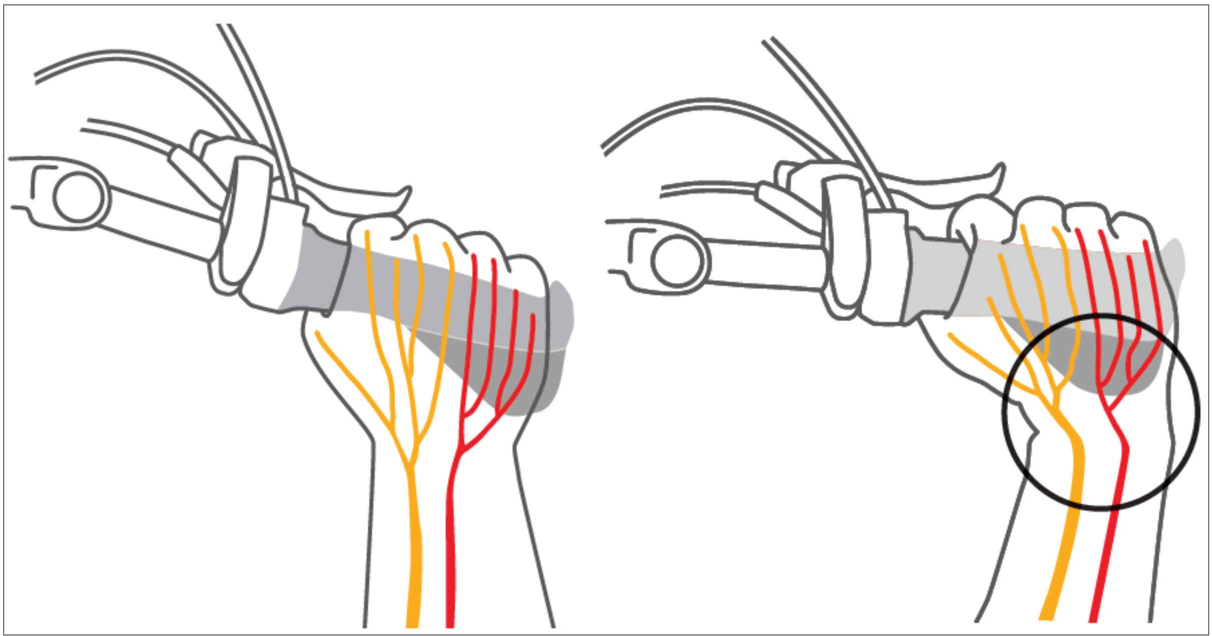

Image 7: Radial deviation of the wrist (Ergotec, 2012).

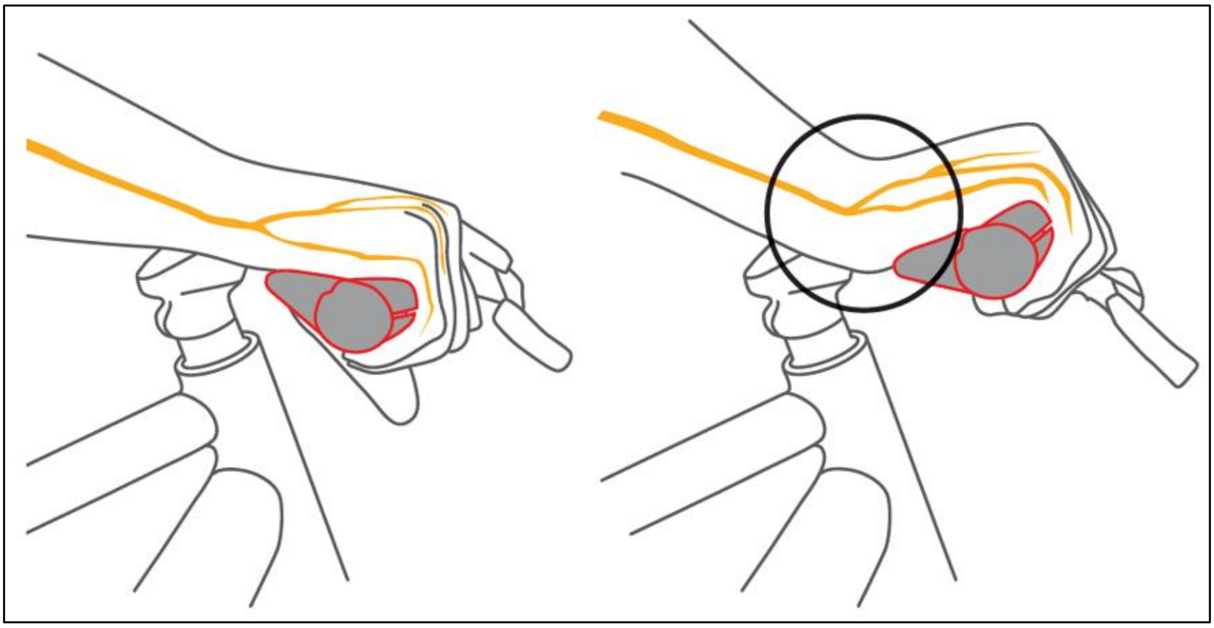

Image 8: Extension of the wrist (Ergotec, 2012).

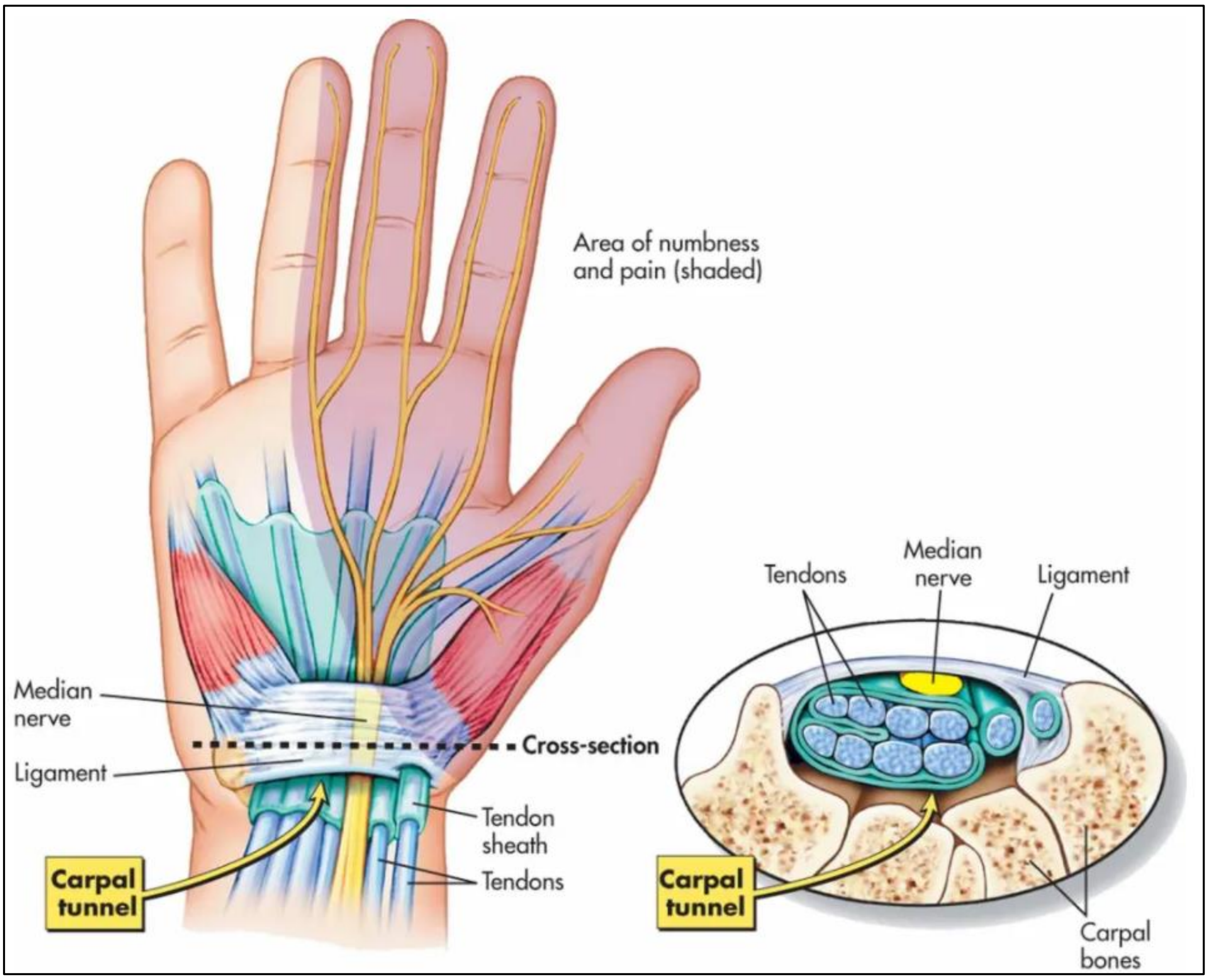

Image 9: Visualisation of the carpal tunnel syndrome (Lushington Chiropractic, 2016).

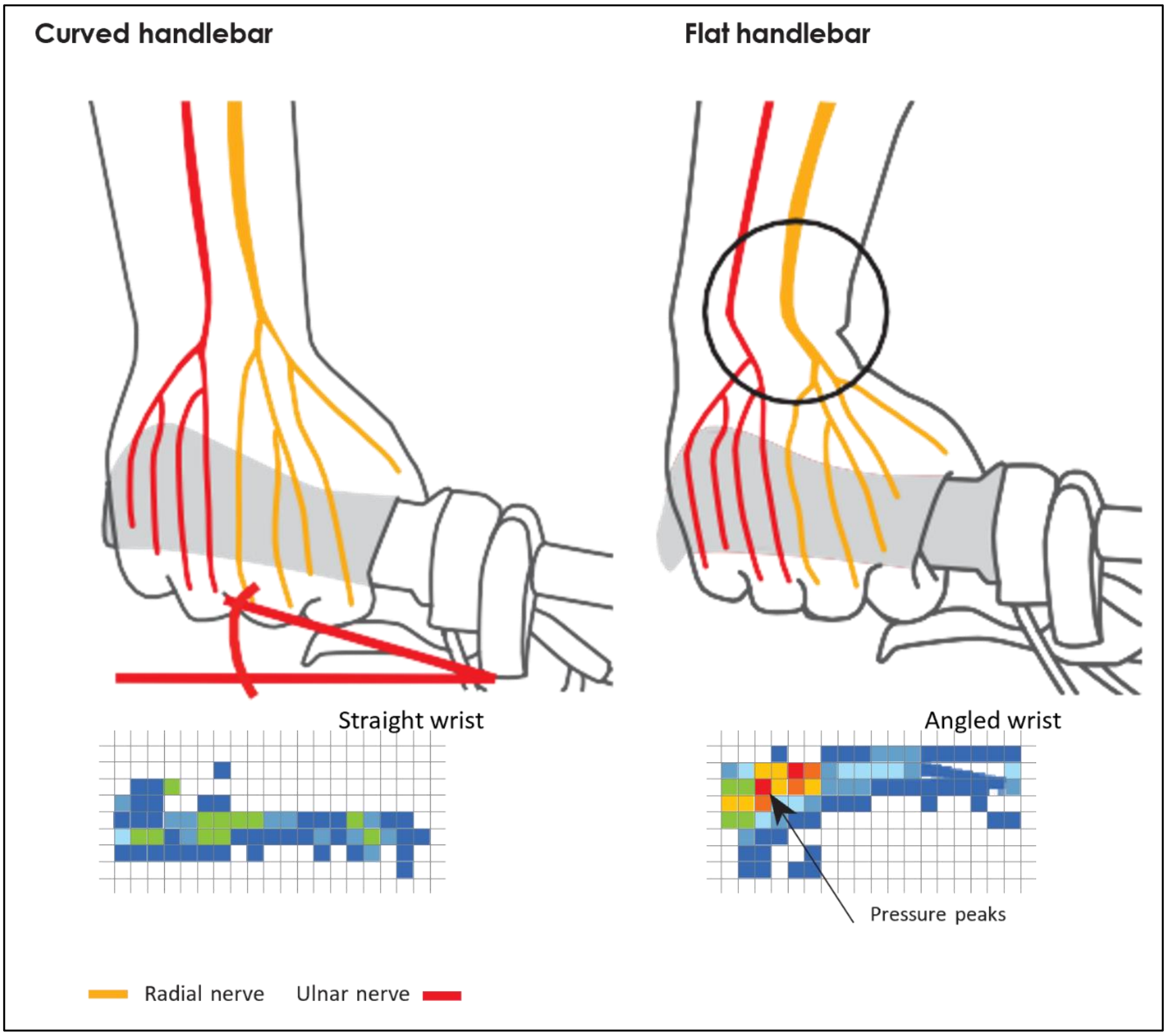

Image 10: Radial deviation of the wrist caused by a difference in handlebar angle and the accompanying pressure maps showing pressure peaks (Ergotec, 2012).

Straight handlebars are more common on sport bicycles, as they provide more direct steering control. But they also cause more problems. As seen in image 10, straight handlebars force the wrist in a radial deviation causing problems with the nerves. Also, this position of the wrist causes pressure peaks in the hand.

The in the research by Ergotec (2012) proposed solutions for these problems go by the name of “dynamic riding”, suggesting the cyclist keeps changing hand positions as they ride. This prevents long periods of static posture and built-up tension in the muscles, which causes even more pressure on the hands and nerves.

To enable dynamic riding, the bicycle must be fitted with a handlebar or BHGs that allow multiple safe hand positions. Two existing examples of this are multi-position handlebars or added bar-ends (see image 11).

To cycle with minimum discomfort, the user must make sure to move the entire body and never stick to one basic posture. Particularly hands, arms, shoulders and the neck benefit from deliberate changes in posture. The best handlebars are those that encourage the user to adopt neutral body postures and frequently vary the position of the hands on the BHGs.

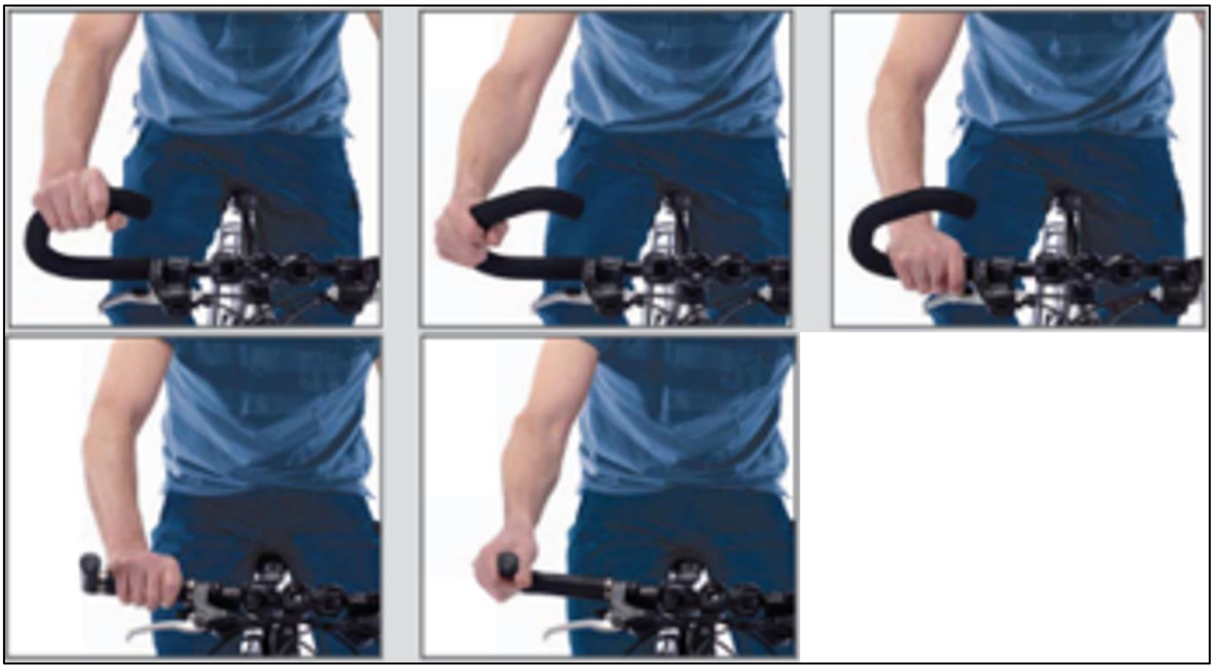

Image 11: Multi-position handlebars and bar-ends displaying dynamic riding (Ergotec, 2012).

BHG dimensions

When designing BHGs, the shape is not the only variable. Another important part is the dimensions of the BHGs. A lot is already known about handle dimensions from previous studies, and these insights are collected in this subsection.

In a study by Kong and Lowe (2005), they investigated 1988 US Army anthropometric data (Gordon et al., 1988) and created the equation below that relates the length of the hand to their suggested handle diameter (see image 12).

$$Handle\ diameter = 0.233 \times Hand\ length$$

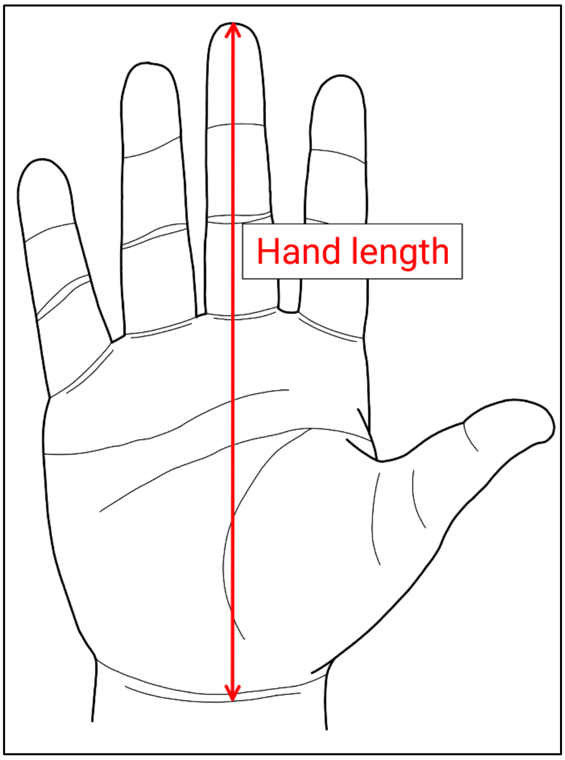

Image 12: The selected hand length (Chang et al., 2010).

This equation was then used in a study by Chang et al. (2010) and applied to bicycles to create three categories based on size and their suggested handle diameter (see table 1). They also studied the effect of using a handle that is the incorrect size category for users on the satisfaction rating (see image 13).

Table 1 containing the three size categories, their corresponding hand lengths, and suggested handle diameters (Chang et al., 2010).

Size category	Hand length [mm]	Handle diameter [mm]
Small	175.5	40.9
Medium	186.7	43.5
Large	196.2	45.7

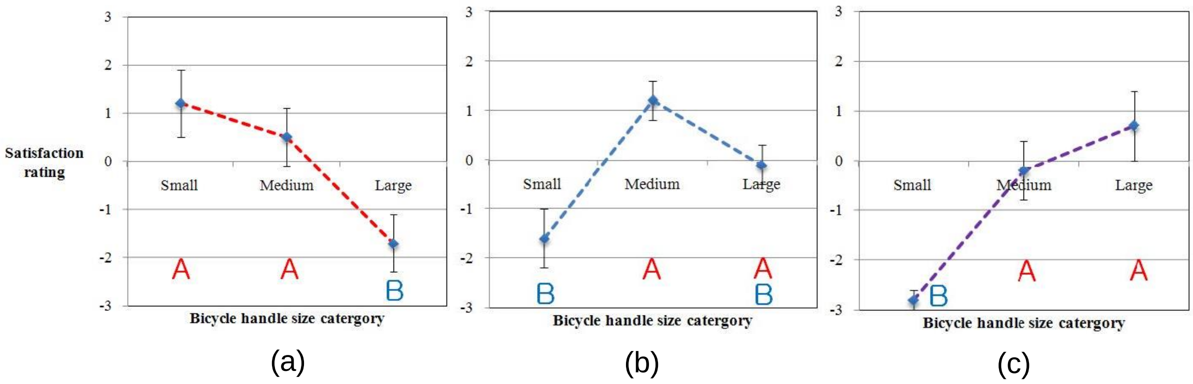

Image 13: Satisfaction rating for (a) small, (b) medium and (c) large hand groups (Chang et al., 2010).

To verify this method of calculating bicycle handle diameters for the Dutch market, it was redone using the Dined 2004 Dutch adults 20-60 mixed dataset (Dined, 2004). From this dataset, several hand lengths are tried (see table 2) to find the groups that are used in the study by Chang et al. (2010), since they remain undefined. From the Dined 2004 Dutch adults 20-60 mixed dataset (Dined, 2004), it is found that the percentiles P25, P50 and P75 are an acceptable match with the size categories from the 1988 US Army anthropometric data (Gordon et al., 1988). This means that the population is divided into three groups where the medium group is the biggest and the small and large groups are equal in size.

Table 2 containing three size categories (S/M/L) based on Dutch population, their corresponding hand lengths and handle diameters suggested by the equation from Kong and Lowe (2005) (DINED, 2004) (TU Delft, faculty of IDE, 2020).

Size category	Hand length [mm]	Handle diameter [mm]
Small (P1)	157	36.6
Small (P5)	166	38.7
Small (P25)	178	41.5
Medium (P50)	187	43.6
Large (P75)	196	45.7
Large (P95)	208	48.5
Large (P99)	217	50.6

In their study on handle diameters using grip force distributions, Seo et al. (2007) state that grip force when applying torque is greatest for handle diameters which allow the fingertip and thumb forces work together against the palm, and smallest when fingertip and thumb forces are acting in direct opposition (see image 14). This research is not specifically on bicycle handles, but hand tools in general, meaning that the found insights cannot be directly adopted into the design solution of this project but must be verified in the correct context.

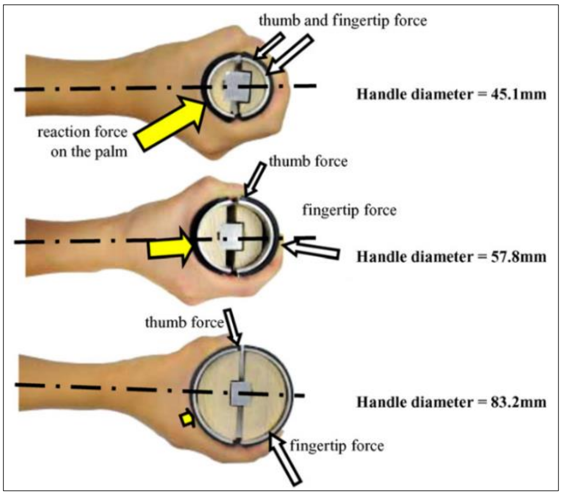

Image 14: Typical finger positions, their corresponding force directions and resulting reaction force size and direction on the palm when grasping handles of different diameters (Seo et al., 2007).

In a follow-up study, Seo and Armstrong (2008) investigate the relationship between contact area between the handle and the hand, and the handle diameter (see image 15). This study concludes that the bigger the handle diameter, the smaller the contact area between hand and handle (and thus reducing grip) (see image 16). By maximising the grip, the feeling of safety is also maximised, which in turn adds to an increase in comfort. But since the use of BHGs mainly comes down to supporting the hands instead of the hands squeezing, pulling, pushing or rotating the BHGs, a lower level of grip will be sufficient to provide a satisfactory feeling of safety.

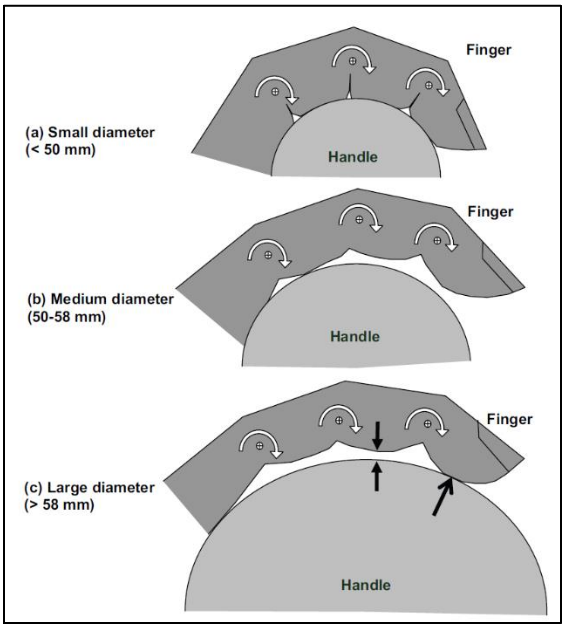

Image 15: Handle fit for (a) small, (b) medium and (c) large handle diameters. When a handle diameter is too small, folding of the skin results in reduced contact area (a). When a handle diameter is too *large, it's surface may not fit the curvature of the* flexed finger (c) (Seo & Armstrong, 2008).

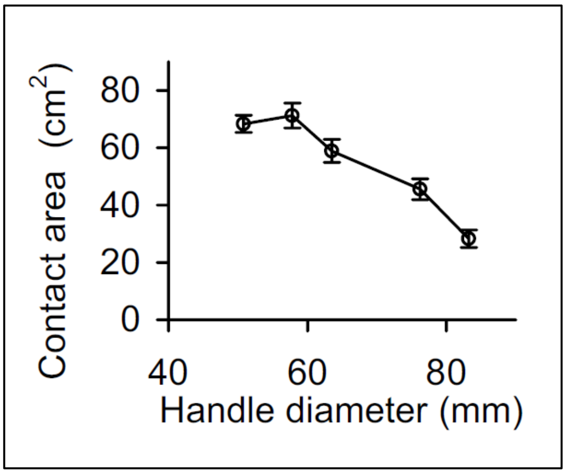

Image 16: Contact area as a function of handle diameter (Seo & Armstrong, 2008).

In a study by Ingole et al. (2020) specifically on bicycle ergonomics, the following dimensions are suggested: the average BHG diameter of proposed handle is found to be 29.5 [mm]. Minimum & maximum handlebar width is found to be 340 [mm] and 540 [mm]. The focus of this study was to minimise discomfort. The recommendations in this study are based on measured anthropometric data combined with subjective evaluation of the participants.

When looking at BHG width, Putz-Anderson (1988) concludes that since the average hand breadth at metacarpal is 85 [mm] for females and 93 [mm] for males (DIN 33 402, measure 3.19), the recommended minimum handle length is 100 [mm], while 115-120 [mm] is preferable. This research is also not specifically on bicycle handles, but hand tools in general.

While there is a lot of information available around handle design, not all this information is suitable for specifically designing BHGs because of the differences in focus. Most handles are designed for pushing, pulling or rotating, while BHGs are designed with a priority on supporting. Because of this difference, the diameter must be verified for use in the correct context. The recommended handle width however can be used since the hand width does not vary with different handle uses. This found information will be used as the basis of the concepts, but the exact dimensions will be determined later during follow-up research and testing.

2.2 Market research

As discussed in the project brief (section 1.2), the bicycle market has been divided into five categories based on body posture. The reason for this division is that these different postures cause different weight distributions on the contact points (BHGs, saddle and pedals) between the bicycle and the user. Because of these differences, the bicycle categories also require different solutions.

In this section, the current market and the developments in this market are being investigated. This includes the explorative research from the project brief and an elaboration thereon. The gained insights will be used to substantiate the decision on what bicycle category will be targeted in this project.

Popularity cycling

Looking at the Dutch market in the last few years (2018-2020), all means of transportation are in decline (see table 3). This decline can be credited to the outbreak of the COVID-19 pandemic which requires the majority of the population to minimise travel. We see that of the three major means of transportation (car, train, and bicycle) the decrease in bicycle use is much smaller than the other two. This indicates a growth of popularity of the bicycle in the Netherlands.

Table 3: displaying the decrease in number of trips, distance per trip and duration per trip in the period 2018-2020. Based on data from: (CBS, 2021).

	Trips [#]	**Distance [km]**	**Duration [h]**
Car	-15%	-26%	-24%
Train	-59%	-60%	-60%
Bicycle	-17%	-13%	-9%

Sales figures of electric bicycles further confirm their increase in popularity in Western Europe. In Germany alone consumers bought more e-bikes in 2020 than electrified cars were sold in all of Europe (Germany e-bike sales: 1.95 mil. Europe e-car sales: 1.34 mil.) And in the Netherlands, e-bikes outsold all new cars in 2020 by 53% (547,000 e-bikes vs 357,414 cars) (van Schaik, 2021).

Popularity bicycle types

In addition to researching the popularity of cycling in general, an investigation to the popularity of bicycle categories is done. The reason for this investigation is to look into the popularity of the five different bicycle categories (see section 1.2) and substantiate the certain category that is chosen to focus on. Because these categories are based on body posture of the user, and the differences in posture require different solutions, one target bicycle category is chosen.

In their study on the attitudes towards e-bike usage in twelve European countries, Shimano (2021) states that when looking at users who are likely to purchase an e-bike within the next 12 months, city e-bikes (category 4) are the most popular choice (31%). They also found that 27% of those questioned indicate they are more likely to use or buy an e-bike now than they were before the pandemic, with 39% saying they would use one to avoid public transport. When looking at other reasons mentioned by users to purchase an e-bike, the report states that 37% under the age of 24 said they would use an e-bike to lessen their impact on the environment, whereas 41% of those over the age of 55 said they were looking for an alternative to a motor vehicle (see image 17).

When investigating target users, it was found that Europe-wide, the most likely age groups to consider e-bikes were 25-34 and 35-44. This is 26.9% of the total European population (PopulationPyramid.net, 2021).

A market research report by GfK (2020-2021) stated that when looking at the Netherlands, the turnover of e-bikes is dominating the market. Both in sales numbers and sales value with averages of 50% and 75% respectively. This difference can be explained by the fact that the prices of e-bikes are higher than those of non-e-bikes.

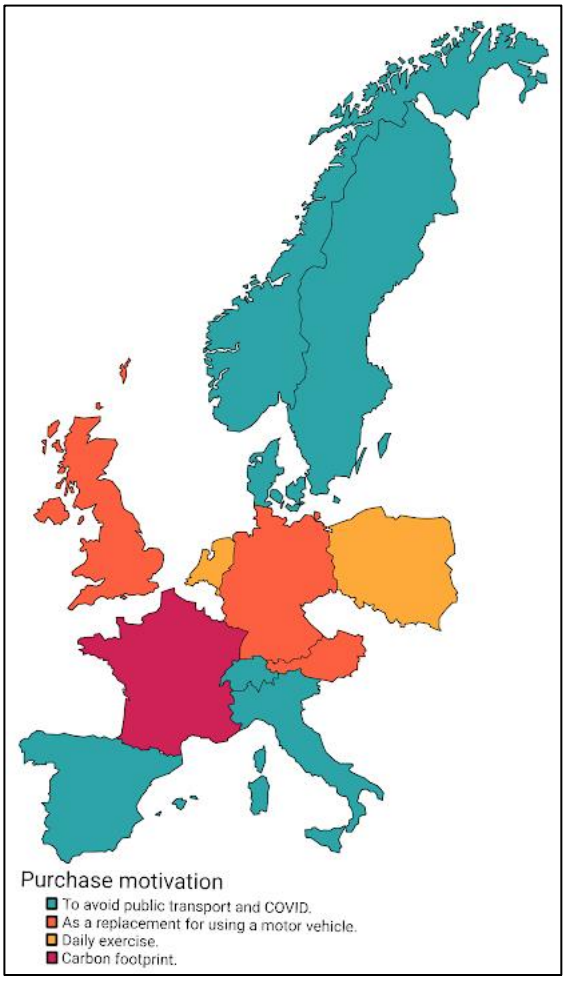

Image 17: Map of countries in Europe where purchase motivation for e-bikes was researched and their most mentioned arguments (Shimano, 2021).

The report also shows that the split between male-female for city bikes lies around 30-70, while these numbers for city e-bikes are around 15-85. This indicates that when purchasing e-bikes, male users are buying female or unisex bicycle models (unisex models get counted as female models).

The third interesting insight in the report is that in the current market around 80% of sold bicycles is a category 4 bicycle (see appendix C).

2.3 Field work

To increase the insight in the current use of BHGs, field work was done. This field work consisted of visiting a bicycle parking, where lots of bicycles can be found in one place and counting all these bicycles and their interesting characteristics like bicycle type, BHG type and damage to the BHG. In addition to counting, all interesting cases are photographed. These photographs are then clustered corresponding to the found characteristics and inspected to find patterns. Collages of these clustered photographs can be found in appendix D.

The count is performed at Rotterdam Central Station, in the north side bicycle parking. Here, a total of 1039 bicycles were counted in the course of half a day (see table 4).

The first thing that was looked at is the category of the bicycle. If a bicycle is not category 4 (see image 18), it was not looked at further. This was the case for 771 bicycles, leaving 268 bicycles (25.8%) that are within category 4. The BHGs of bicycles that are within category 4 are examined to determine their type. The options here are: round BHGs (cylindrical symmetrical) consisting of 83 bicycles (31%); or BHGs with an ergonomic shape which amounted to 173 bicycles (64.6%) and includes all shapes where something has been done to try to improve the comfort of the user. The third option here is a combination of different BHGs where the user had either lost or replaced one of their BHGs. This was found on 12 bicycles (4.5%).

Image 18: An example of a category 4 bicycle: the Gazelle Grenoble C8 HMB (Koninklijke Gazelle, 2021).

In addition to the type, it has also been counted whether the BHGs have been assembled correctly or not. This applies only to BHGs with an ergonomic shape since the round ones are symmetrical and rotating them does not cause any difference. 79 bicycles (45.7%) have been counted where the BHGs are mounted incorrectly (see images 19). In this study, it cannot be said with certainty whether the handles were mounted incorrectly during assembly or whether this happened later during use. Incorrectly assembling and using products that are shaped to reduce discomfort counteracts the ergonomic effect of those products. This is also the case for BHGs, since incorrect use of the specific shape causes pressure point at regions of the hand that are not supposed to endure these amounts of load. It was noticed that most of the incorrectly mounted BHGs are not secured using a fastener but rather clamped to the handlebar using the materials elasticity. Even though plastic slip-on BHGs have a diameter up to two millimetres smaller than the handlebar, water can still get between them and lubricate the connection, reducing friction and enabling the user to rotate or even pull the BHGs off the handlebar (P. van de Lagemaat, Personal communications, January 18, 2022).

(a) (b) (c)

Image 19: Photographs showing various incorrectly mounted BHGs. (a) Ergonomic shape rotated upwards directing the protrusions onto the palm and creating peak pressure points. (b) The ergonomic shape is rotated exactly 180° indicating the person who mounted it misinterpreted the shape. (c) The protruding palm rest is rotated downward causing an extension of the wrist when leaning.

Another point of interest that was counted is whether BHGs show signs of damage or wear. 90 bicycles (33.6%) have been found with notable damage or wear on their BHGs. Analysing the photographs has led to two subgroups: the first one where BHGs are worn by use over time and show marks of friction (see images 20 and 21), secondly the BHGs that suffered damage from an external cause. Most probably, this damage is caused by impact (falling) but there are also bicycles found with clear damage from the bike racks (see image 22).

Image 20: Photographs showing various BHGs with friction damage. All three display most wear on the hypothenar and thenar regions, indicating load is maximum on these regions.

Image 21: Photographs showing various BHGs with friction damage on hypothenar regions highlighted.

(a) (b) (c)

Image 22: Photographs showing various BHGs with damage by external reasons. Parts have broken off at (a) and (c), and (b) shows damage caused by rough handling in the bike rack.

It was also counted whether there were electric bicycles in the bicycle parking. It was expected that this number would be very low, since this was a public bicycle parking next to the train station. It came as no surprise that there were only 3 e-bikes in this parking.

Lastly, two other features were looked at: bicycles that have an alternatively shaped handlebar, and bicycles with bar-ends. Only four bicycles with an alternatively shaped handlebar were counted (which were all damaged, see images 23) and there were only two bicycles with bar-ends. The bicycles that have bar-ends do not fall within category 4 but are counted to indicate that the bar-ends are also being watched.

(a) (b)

Image 23: photographs showing alternatively shaped handlebars damaged by impact (a) and wear (b).

Table 4: Results of a study on numbers of bicycles and their properties in two bicycle parking facilities.

Properties	**Rotterdam Central Station**	**Widek Bicycle parking**
Total number of bicycles	1039	15
Bicycles outside cat4	771	4
Bicycles within cat4	268 (25.8%)	11
Cat4 bicycles with round BHGs	83 (31%)	2
Cat4 bicycles with ergonomic BHGs	173 (64.6%)	9
Cat4 bicycles with a combination of BHGs	12 (4.5%)	-
Cat4 bicycles with incorrectly assembled BHGs	79 (45.7%)	4
Cat4 bicycles with damaged or worn BHGs	90 (33.6%)	4
Number of e-bikes	3	7
Bicycles with alternative handlebar shape	4	-
Bicycles with bar-ends	2 (not cat4)	-

This bicycle counting field work was repeated in the bicycle parking of the factory of the client since that would give a more accurate representation of the target bicycle and its user (adults with mostly category 4 bicycles versus old train station bikes which are mostly category 5). This parking only consisted of 15 bicycles in total (see table 4) so it is not in proportion to the Rotterdam Central Station count. of which more than 70% of the bicycle belonged to category 4 of which more than 80% had ergonomic BHGs. Remarkable is that 4 bicycles were counted with incorrectly assembled BHGs and 4 bicycles with BHGs that showed signs of damage or wear and that on the bicycle parking of a bicycle accessories factory. A total of 7 bicycles are electrically powered, and none had alternative handlebars or bar-ends.

2.4 Survey

The fieldwork that was carried out has yielded a lot of insights on the current context around BHGs (amounts of misuse and damage to BHGs), but the explanation around these found insights is still unknown. Therefore, an additional study to the thoughts on, the experiences with, and the expectations from BHGs is done among Dutch cyclists in the form of a survey which has been completed by a total of 24 participants.

This survey consists of three sections. First, participants are asked about their experiences with BHGs. After that, they are asked to elaborate on their cycling behaviour to find out what kind of cyclist they are and get insight in the reasoning behind their answers. Lastly the participants are asked to assess a selection of existing BHGs, add-ons and handlebars. Because the goal of this survey is to collect the reasoning behind answers and actions, the majority of the questions are asked as open-ended questions.

The collected insights that are of the greatest value for the establishment of design criteria are clustered and listed in this section. The survey with all its questions and transcribed answers can be found in appendix E.

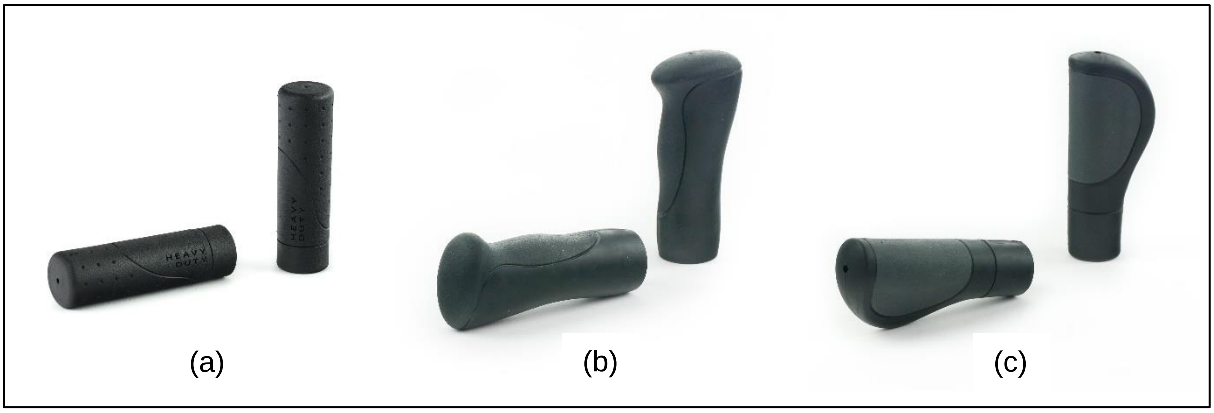

Image 24: examples of BHGs produced by Widek: (a) Heavy Duty (Widek BV, 2020d), (b) Ergoline Tour (Widek BV, 2020c) and (c) City Comfort (Widek BV, 2020b).

Behaviour

- Looking at the examples shown in image 24, one third of the participants compare their BHGs with example (a), where some of those participants indicate additional features to increase grip and comfort. Only 8% of the participants say they have BHGs comparable to example (b). 25% of the participants say their BHGs look like example (c).

- 80% of participants take daily rides that are shorter than 20 minutes and mention this as the reason to never experiencing physical discomfort. For this reason, they state not to have high standards regarding BHGs.

- One third of the participants does not experience differences between short and long bicycle rides. Another one third notes that they do experience signs of BHG related discomfort on longer rides. The last group of one third of the participants realised that they often change their hand positions during rides, or even ride without their hands on the straights.

Biggest annoyances

- Loosening and easy movement of BHGs is mentioned by a quarter of the participants to be the greatest annoyance regarding to BHGs and the main reason to replace them.

- Another reason mentioned by 20% of the participants to discard their BHGs is when weathered BHGs become sticky and release material that stains the hands.

- Participants care about control of the bike with regard to safety and want their BHGs to retain their grip for a long time, even when wet from the rain. Four of them state that surface finish wears off rapidly and the BHGs become completely smooth and thus slippery.

- One participant mentioned they had metal parts on their BHGs and that these get very cold during cold weather. These metal parts also provide no grip compared to the plastic parts.

Experienced problems

- 25% of the participants experience pressure peaks on their palms and numbness in hands and fingers. They mention incorrect positions of their wrists and a lack of support and comfort.

Purchase and installation

- More than 80% of the participants never investigated or purchased BHGs. The four participants that did either choose the cheapest options or let themselves be advised by a bicycle mechanic. None of the participants ever installed BHGs themselves but 40% had this done by their local bicycle mechanic shop.

- three participants mention they have monthly subscriptions at a bicycle lease company. These companies take care of the maintenance of the bicycles, but these participants complain they cannot choose what parts their bicycles receive and describe the BHGs to be the cheapest option.

- 50% of the participants that ever bought BHGs state there is a huge range of BHGs available online in all price categories, but the downside is that they cannot be tested before purchase. The other half mentions that in the local bike mechanic shops they can try BHGs and receive expert advice, but the range is very limited.

Purchase and lifespan

- Over half the participants think the lifespan of BHGs should be similar to that of the bicycle. 25% finds it acceptable to replace BHGs only once during the life of a bicycle. A quarter of the participants are satisfied with a lifespan similar to other parts and accessories so everything can be replaced or maintained during periodic service. Even though some wear is expected, it is the last part of the bicycle they would replace.
- The most important criterium according to one third of the participants is the price of the BHGs. They will mostly choose the cheapest option but do understand more complicated shapes and features cause increased prices.
- Decisions on comfort and material are based on initial contact and not extensively tested.

Appearance

- 75% of the participants indicate they prefer BHGs with a neutral look (both shape and colour) that do not stand out compared to the rest of the bicycle. Given reasons are that shapes which deviate greatly from the neutral, cylindrical shape confuse or even look uncomfortable to the user. These shapes are also viewed as ugly and associated with either athletic applications, the elderly, or people with special needs.
- When assessing BHGs with plug fasteners (see image 25), half of the participants did not understand their function and was deterred by this. The other half that did understood the function praised the fact that the BHGs would not come loose and rewarded them with a higher estimated price.
- The use of multiple colours and materials (see images 25 and 26) also increased the feeling of quality of the example BHGs with three of the participants.
- Two participants mention they do not react well to the combination of ergonomic shapes and geometric shapes in a BHG. It makes them feel like the BHG is only half developed (see image 26).

Image 25: Example BHG Widek (Widek BV, 2020f)

Image 26: Example BHG Widek (Widek BV, 2020b).

Additions

- When assessing additions to the handlebar or BHGs (bar-ends or inner bar-ends), 60% of the participants believe that this these are over the top for the use of their city bicycles (see images 28). Four participants do not see the added value of these additions and dislike the distance to the brake levers. Because they stick out, the lifespan of the plastic bar-ends is estimated to be lower than the BHGs by one participant. The inner bar-ends on the other hand look indestructible due to their material appearing to be harder plastic and are estimated to have a very long lifespan.

- Two participants indicate they associate organic shaped BHGs with increased ergonomics, while geometric shapes are associated with being futuristic and less ergonomic.

- BHGs with multiple parts are viewed as too complicated and hard to install on the handlebar by a quarter of the participants. These would have to be installed by a bicycle mechanic (image 27).

- 65% of the participants associate all handlebar additions with serious cyclists that take very long rides at high velocity. But this is something that if done, participants would prefer to take their road bike (racing bike).

Image 27: Example BHG Ergotec (Ergotec, 2020)

Image 28: Example Handlebar additions (left) bar-ends and (right) inner bar-ends (Ergon Bike Ergonomics, 2021) (Hoogstrate, 2018).

Butterfly handlebars

- Half of the participants state that butterfly handlebars (image 29) are also associated with elderly users or certain specific applications like cycling tours of very long distances. These are associations participants do not want to make with their regular city bikes.

- These butterfly handlebars require a lot of modification to current systems on the handlebar and two participants have some trust issues regarding the stiffness of this handlebar. One also states these handlebars are too bulky and due to the great amount of possible hand positions the brake levers are not always accessible.

- Five participants think the foam sleeve of butterfly handlebars gets wet and soggy in the rain and is very prone to wear and ripping. This increases the need for periodic maintenance and is not very sustainable for both the environment and the user's wallet. On top of that, these handlebars are estimated by four participants to have a very high purchase price.

Image 29: Example BHG butterfly handlebar (Denham, 2011)

2.5 Conclusions

The findings described in this section are a broad summary of the acquired knowledge regarding the design of BHGs. This includes insights that explain the unexplained results from the field work (section 2.3) in the form of the thoughts on, the experiences with and the expectations from BHGs among participants.

For the purpose of this project, the research goes deep enough, and the findings form an excellent foundation for the first iterations of an ergonomic BHG. If, after the completion of this project and the release of the concepts, it appears that there is a demand for an iterated concept, additional research can be done to find new points and methods for improvement.

3. Design

In this chapter, the design of the project is described. First, a problem list is composed. Based on this list, a list of design requirements (LoR) has been created. Then, solutions to these problems and requirements are collected and grouped, giving inspiration to product concepts. Three product concepts are developed and assessed, after which one concept is chosen. This chosen concept is then further elaborated.

3.1 Problem list

This section contains current problems regarding BHGs and their context found in the research chapter of this report (see chapter 2). The list of found problems is arranged according to my personal view on different criteria which include the importance, urgency, and feasibility of finding and implementing solutions to these problems (see appendix F). This means that the higher on this list, the higher the priority of solving this problem.

Pressure peaks

Research has shown that the human hand can be divided into regions with different PDT and PPT values (see image 30). In the current context, cyclists experience pressure peaks exceeding these thresholds. These pressure peaks are caused by incorrect design, mounting or use of the BHGs in combination with the pressure of the hands on the BHGs.

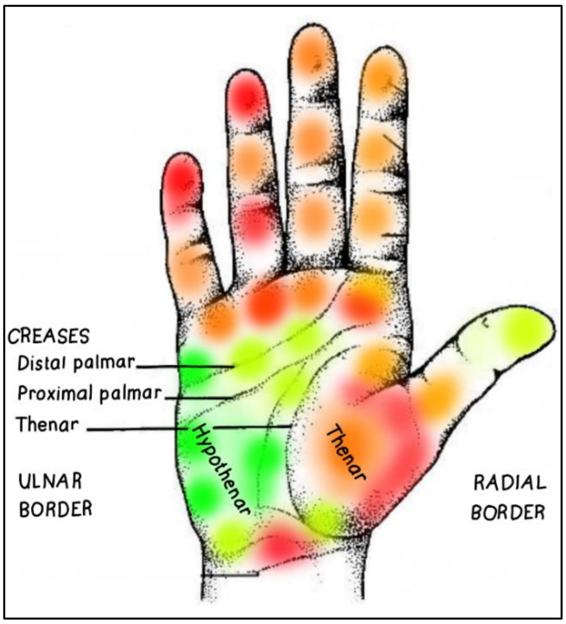

Image 30: The discomfort threshold map of the hand.

Incorrect wrist position

The second cause for physical discomfort is users adopting an incorrect wrist posture that increases the load on the human body. Any position that differs much from the neutral posture increases the chance of throttling circulation to, in and from the hand, which can cause pain or numbness. These more demanding postures are also caused by incorrect design, mounting or use of the BHGs.

Loosening of BHGs

One of the biggest annoyances that was mentioned by 25% of bicycle users is loosening of BHGs. This can occur when (rain)water creeps between the handlebar and BHGs, during hot weather which softens the material or incorrect installation of the BHGs and enables the BHGs to rotate around the handlebar or even come off completely. Loosening of the BHGs could be the cause of the previously mentioned problems (pressure peaks and incorrect wrist position) when the BHGs rotate out of their correct position. Next to that it causes a safety hazard when the user tries to steer the bicycle and BHGs moving separately of the handlebar cause the bicycle to move differently than expected.

Type of buyer

When selling to OEMs, the seller has time to prepare a sales pitch and often has a personal meeting with the buyer. During this meeting the seller has time to explain their product and let the buyer try them out. When selling AM, the buyer often has no idea what they are searching for and no seller that can give advice (when shopping online or in a large sports store).

Misinterpreted features

The misinterpretation of features in the BHG design by both user and mechanics results in incorrect use and incorrect installation of the BHGs. These, in turn, can lead to earlier mentioned problems (pressure peaks, incorrect wrist position and loose BHGs).

Price

Due to their disinterest and ignorance, most users are not willing to pay much for their BHGs. The majority of users base their purchase decision on price and appearance and will often choose the cheapest option. This applies to both OEM as AM sales.

Surface finish and material (temperature)

Some BHGs contain materials with high thermal conductivity like certain metals. This causes these parts to reach high temperatures in summer or low temperatures in winter.

Testing / range

This problem applies to AM sales only. Consumers face the problem that when purchasing BHGs online, the range of products is huge, but they cannot be tested. This means that consumers rely on product descriptions by the seller or manufacturer and customer reviews (if there are any). When purchasing BHGs at a local bicycle mechanic the range of products is often very small but comes with the expertise and service of a salesman or mechanic.

Unappealing appearance

The appearance of the BHGs is of major influence on their marketability. Research showed that 75% of participants have a strong opinion about BHG appearance (see section 2.4). BHGs with striking or outstanding shapes, colours or materials are distrusted or associated with types of cyclists the majority of users does not want to be associated with.

Surface finish and material (weathering)

Weathering of the handles makes them feel sticky and leave stains on the user's hands. This is according to 20% of participants, the biggest annoyance after loosening of the BHGs (see section 2.4).

Surface finish and material (impact)

Since BHGs stick out from the rest of the bicycle, most impact is focused on these parts. The ends of the BHGs are expected to be the first to damage because of impact.

Surface finish and material (wear)

When the surface texture wears off and the BHGs become smooth, or when rain or sweat gets the BHGs wet, grip and thus (the feeling of) safety decreases.

Problem selection

Solving all the problems listed in this chapter will take much more time and resources than are available within this project, it is unwise to tackle them all. For this reason, a decision has been made to define a focus area within the scope of this project by selecting problems that will be detailed and those which will be explored. The problems that are outside this focus area are included in the LoR (section 3.2) and morphology (appendix G) to lay a foundation for finalising the final product.

The problems that are within this focus area are the first two problems on the list: pressure peaks and incorrect wrist position. All other problems mentioned in this chapter are included in the creation of concepts, but no definitive decisions are made.

3.2 List of Requirements

This section contains the requirements and wishes (R&W) that, according to the research, the design for a BHG within the stated use context of this project must meet. To create an overview, the R&W are clustered based on the focus on different aspects of the design.

This list is created from all known and found R&W for the design of regular BHGs combined with newly found R&W related to the problems found in chapter 2. To remain within the scope of this design project (set in chapter 1) the focus is on R&W that correspond with the problems that are tackled within this project. Therefore, these will be mentioned first. This however does not mean that in a normal situation these R&W are prioritised.

An attempt has been made to describe the R&W in such detail that they can be used for the design of BHGs without prior research.

This LoR also includes R&W that are not important within the scope of this project but will become relevant in the later stages of product development.

Performance

During use, the product should refrain from causing peak loads on the palm of the hand, meaning that the loads on the hand may not exceed the PDT of each corresponding region (see section 2.1). To achieve this, the contact area between the product and the hand should be maximised, and the high PDT regions should be loaded more than those with a low PDT.

During use, the product may not cause wrist positions that are far away from the neutral form of the forearm. Therefore, the flexion, extension and deviation of the wrist, and the pronation of the forearm (see Glossary) should be minimised during use and may not be greater than 15° (Middlesworth, 2020).

When in use, the product must not be undesirably movable, meaning it must be secured using a fastener. Preferably, this fastener must be secured and loosened using a tool, and it should loosen as little as possible over time during regular use of the product.

The product must be compatible with existing and conventional handlebar add-ons. It must not interfere with the installation and location of brake levers, a bell and e-bike controls and must be compatible with the installation and location of shifters (trigger shifters or twist-grip shifters).

The product must remain its grip as long as possible when exposed to weather (moisture) and use (wear).

Look and Feel

The product should be as small and light as possible within the solution space to minimise material use and be in line with the size and weight of similar existing products on the market.

The shape and the colour(s) of the handle should not deviate so much from similar existing products on the market that it scares off potential customers.

The product must be recognisable as a BHG and not cause any unappealing associations that may scare off potential customers. Instead, the appearance should enable intuitive use.

The finish of the product should be associated with positive characteristics like grip and comfort and not be associated with negatives like sticking to hands when used.

Since Widek mostly manufactures commissioned products, it does not have a clear corporate identity that needs to be met.

Testing

The influence of peak load reduction, wrist position and using a fastener on the product must be tested both short-term and long-term using a diverse group of test subjects, as well as the attractiveness of the appearance and the target consumer price. Also, the manufacturing process must be tested (e.g., the draft for injection moulding).

Environment

The product must function and keep functioning when exposed to the climate of Western Europe since this is the region it is designed for. The product must be able to endure temperatures ranging from -10 °C to 40 °C and a humidity ranging from 50% to 100%. Since most bicycles are used and parked outside, the product must be able to endure constant direct sunlight and constant direct contact with water (and snow and ice) without any decrease in the quality of the features.

Life in Service

The product must be able to endure use in line with the expected use (and abuse) of a bicycle. The product must be able to endure constant outdoors conditions and being used for up to 4 hours per day (friction and compression). The lifespan of the product must be at least 5 years with average use, and it should be able to endure occasional impact without losing its main functions.

Maintenance

Replacement of the product must be as easy as possible. When being removed, the product must not leave behind marks (e.g., adhesives) on the handlebar that complicate replacement or even make it impossible (scratch marks are likely but acceptable since the do not negatively influence the installation of replacement products). In accordance with the performance R&W on fasteners, the product must be replaceable using a common tool to undo the fastener and the replacement of the product must be as intuitive as possible (both disassembling as assembling).

Target Product Cost

The consumer price of the product must be in line with the target bicycle and user, being above average. Widek has indicated that this results in a price that may range from €15 to €35.

Transport and Packaging

Transport and packaging of the product should be as efficient as possible. The product must be stackable on itself without being damaged when stored in crates for shipment to OEM clients. For AM sales, the product must be packable in pairs (left and right) and while remaining packaged, be touchable and testable. All types of transport and packaging should be as environmentally sustainable as possible.

Quantity and Production Facilities

The BHG must be producible in batches (for smaller orders) as well as in continuous production (for bigger orders) and batch size must have no influence on the production methods (meaning it is a matter of when the manufacturing process is terminated). Minor adjustments in the design of the product must have as little influence on the used production methods as possible (e.g., replacing an injection mould).

The product must be producible using the existing production facilities of Widek which are 2K plastic injection moulding and various metalworks. The product must also be producible using as few actions as possible.

Materials and end of life

Regarding the (dis)use of certain materials in the design of the product: parts that are made of metal, or other materials that have a high thermal conductivity must be covered and not be on the surface of the product.

The use of plastics that are injection mouldable is required since that is the major in-house production method at Widek. There are no R&W regarding environmental sustainability, but the product should be as durable as possible with the smallest possible footprint.

All different materials used in the product must be separable for waste separation and as many parts as possible must be recyclable.

Standards, Rules, and Regulations

The product must comply with all legal R&W regarding consumer products, bicycles, handlebars and BHGs. For example: NEN-EN-ISO 4210-5 regarding the minimum axial force a BHG must be able to withstand (International Organization for Standardization, 2015b). Or NEN-EN-ISO 4210-2 regarding torque specifics of bolted joints and the width of the handlebar (International Organization for Standardization, 2015a)

Installation and Initiation of Use

When assembled outside of the production facility, the assembly process must be as clear and intuitive as possible for workers in a bicycle factory (OEM) as well as private users and bicycle mechanics (AM).

3.3 Concepts

This section explains how the concept designs originated from the LoR and provides a detailed description of each concept. A summary is given of additional findings that emerged during concept creation at the end of the section. While iterating on the problem, the decision was made to narrow the project's scope (as explained before) and focus on the two paramount problems. For that reason, the remaining problem solutions are not covered in depth.

Process

First, the problems from the problem list are explored and tackled individually, and ideas are generated to these problems. The full morphological overview of these solutions can be found in appendix G.

After this, the tinkering and prototyping started. The first step is to incorporate participants of various hand sizes (female: P15, P69, P97; male: P24, P50, P57, P88 (DINED, 2004)) and ask them to squeeze their hand shapes in a piece of foam clay (see images 31 and 32).

Image 31: Squeezing a hand shape at a handlebar angle of 45°.

Images 32: The unedited shape of a hand in foam clay.

After this, half of the foam clay hand shapes (7/14) are edited to remove all protrusions around the fingers and obtain a cleaned and more general shape (see image 33).

Image 33: Foam clay hand shape with protrusions removed.

These shapes are then painted using an imprint of the PDT map of the hand (see image 34) to reflect this map onto BHG shapes and learn what regions need attention (see image 35).

Image 34: PDT map painted on a hand to make a print on the prototype. Based on research in chapter 2.

Image 35: Foam clay hand shape with a print of the PDT map.

The next step that has been taken is to add material in the places where the PDT is highest i.e., the green regions (see image 36). The idea is that when material is added in these regions, it increases the pressure on these regions and thus reducing pressure on regions with a lower PDT (where feelings of discomfort first occur).

Image 36: Foam clay prototype with a print of the PDT map and added material on the high PDT regions.

The general BHG shape has been divided into 4 different regions (see image 37) to increase clarity when discussing the following prototypes and concepts and their features.

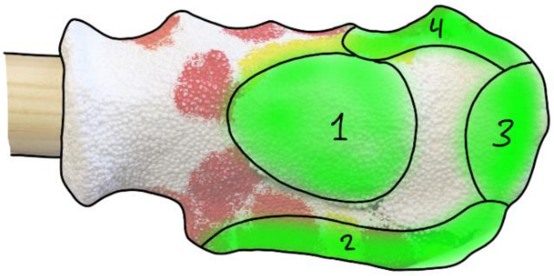

Image 37: Four designated regions used when discussing concepts. The region (1) bump, region (2) + (3) wing and region (4).

Following these tinkering steps has yielded three different concept directions which will be elaborated in the following parts of this section. These concept directions have all been scanned using a 3D scanner creating digital CAD files. This allows for digital retouching to smoothen the surface and to add a fastener for safe and reliable performance testing (see image 38) before creating physical prototypes using a 3D printer. The function of this added fastener is only to secure prototypes to the handlebar during testing and is in no way a design choice or part of the concepts.

Image 38: A digitally added feature enabling the use of a fastener on a prototype.

Concept 1

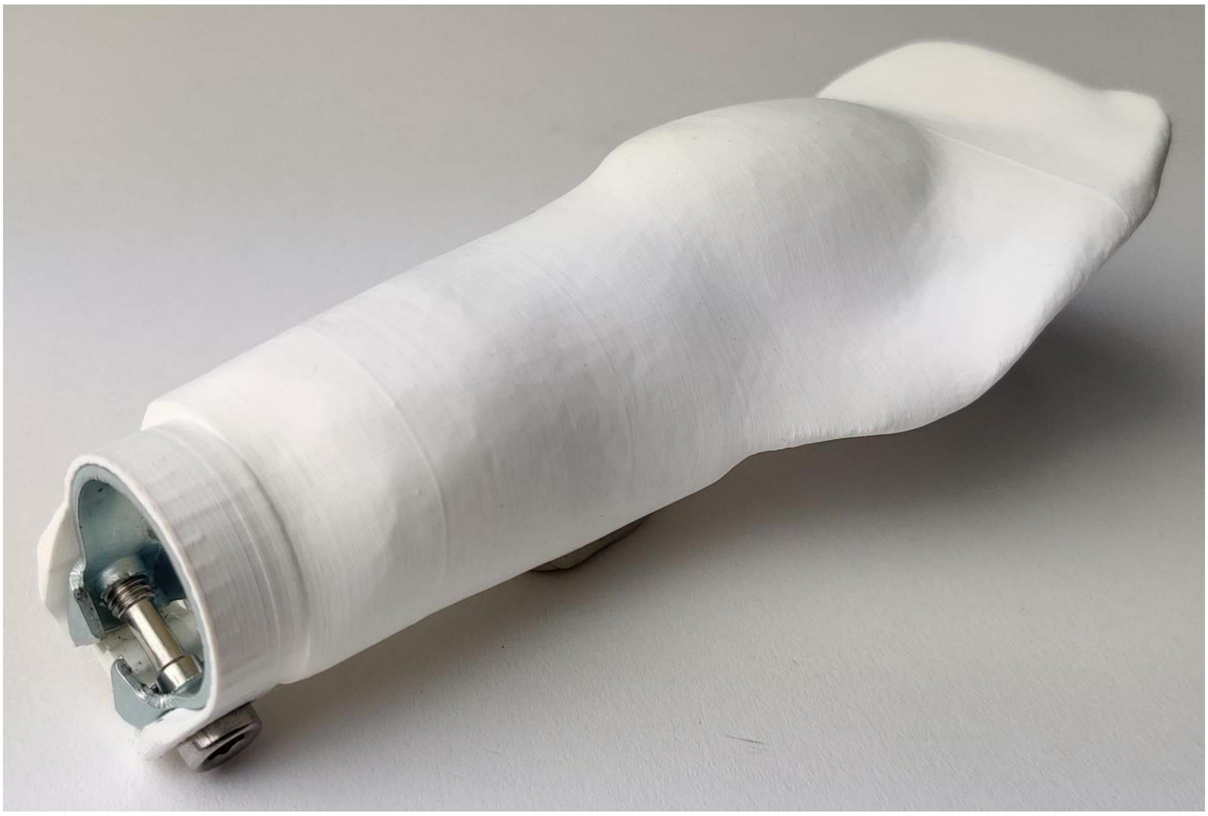

Image 39: Concept 1.

The first concept originated during the process described earlier in this section. First the foam clay model is stripped from all protrusions that are related to the shape of the hand model (length, width, and fingers). For this concept, a decision was made to not remove the region 2 + 3 wing with the reason that this wing maximises the contact area between the concept and the hand so that the pressure is distributed most evenly. Then the print of the PDT map on the foam clay hand shape models is investigated and protrusions are added or increased in size in regions with the highest PDT. The main added protrusion in this concept is the region 1 bump. This bump is supposed to fit in the region of the hand palm between the thenar and hypothenar that appears to be curved when the hand is folded around the BHG. The region 1 bump will fill the resulting cavity, so the pressure is distributed more evenly.

Concept 2

Image 40: Concept 2.

The second concept originated in the same fashion as the first one. The main difference between these concepts is that in this concept, the region 2 + 3 wing is also removed, leaving the region 1 bump behind as the only feature. Reasoning behind this is that when the concept has no region 2 + 3 wing, the impact of hand size and the angle of the handlebar are smaller, and the design is simpler. As long as the user places their hand in such a way that the region 1 bump is placed on the corresponding region of the hand palm, the region 1 bump will have effect in distributing the pressure more evenly on the hand palm.

In addition to that, it appeared that the region between the region 1 bump and where the region 3 wing was placed became relatively flat, in contrary to the rest of the concept that is supposed to be cylindrical. This flat area also contributes to the increased pressure distribution since it increases the contact area between the concept and the hand compared to a totally cylindrical concept. The effect of this particular feature has already been proven and implemented by a competitor which has introduced BHGs for mountain bikes that solely rely on this principle. A comparison of pressure measurements between this competitor's BHG and a standard cylindrical BHG indicates that the pressure peak on the palm of the hand is halved using this flattened region (see images 41 and 42).

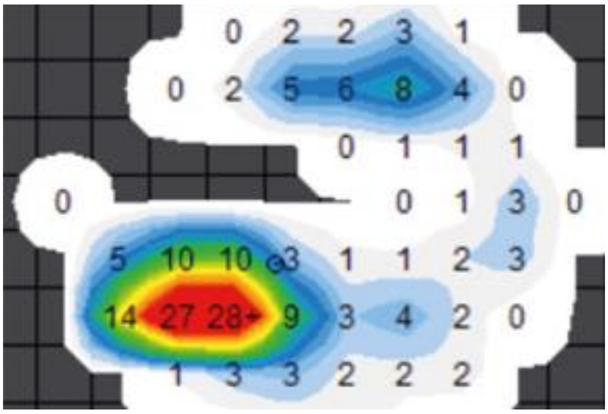

Image 41: Pressure measurement round handle (left hand) (SQLab, 2020a).

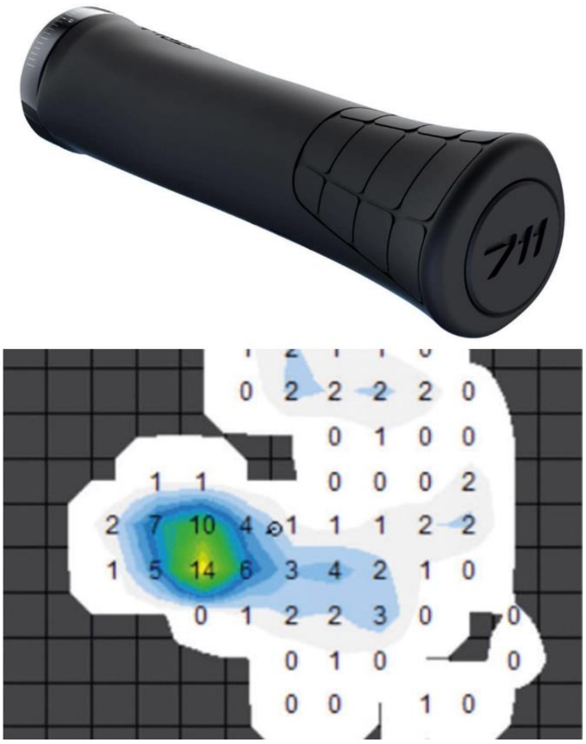

Image 42: Pressure measurement and the corresponding BHG SQLab 711 (left hand) (SQLab, 2020b).

Concept 3

Image 43: Concept 3.

For the third concept was chosen to not implement the region 1 bump so that an accurate assessment can be made to the effect of this feature. This feature does have the region 2 + 3 wing and is also fitted with a protrusion in region 4. This region 4 feature is a remainder of the hand shapes that were squeezed into the foam clay models and is expected to increase support for the ring finger and small finger.

Additional findings

In this subsection, additional findings are listed that have been discovered during concept development.

Relationship BHG size and bicycle frame size

During prototyping, the idea came up to create different concept sizes. The reason for this is when there are multiple sizes available, a buyer can purchase a size that fits best to their hands. And when there is only one size available, outliers are even further away from their ideal fit.

To substantiate this proposal, research is done to the relationship between body measurements relevant to BHG sizes (hand length and hand width) and those relevant to bicycle frame sizes (stature and crotch height). The findings are listed below while the full research can be found in appendix H.

There is no linear relationship between stature and crotch height, meaning both these measurements must be used for selecting the correct bicycle frame size.

There is no linear relationship between hand length and hand width, meaning both these measurements must be used for selecting the correct BHG size.

There is no linear relationship between hand width and stature or crotch height, and no relationship between hand length and stature or crotch height.

These results show that the hypothesis about relating BHG size to bicycle frame size is incorrect, and the advantages of assembling a specifically sized BHG onto a certain frame size in the factory do not apply.

Female and male sizes

In a second attempt to find an argument in favour of creating or recommending the use of multiple BHG sizes, the difference in hand size between females and males is researched (see appendix H).

Comparing these measurements shows that there is a difference between female and male hand sizes, but that the differences between the outliers and the average are so little that the disadvantages (higher production cost, machine adjustments per size, different packaging and marketing and potential errors by users and mechanics) outweigh the advantages (a BHG that fits just a little bit better for the outliers).

Handlebar angle

During a research trip to a bicycle store, it was noticed that there are two different handlebar models available for bicycles within category 4. The difference between these two handlebars is the angle of their bends. Where one handlebar has two bends of 45° (or 135°) each, the other has two bends of 30° (or 150°) each (see image 44). The initial plan was to design concepts that work for both handlebars.

During prototyping it appeared that there is a problem that occurs when testing a concept made using a specific handlebar angle on the other handlebar. What happens is that the region 2 wing is a good fit for one handlebar angle, but when tried on the other, a gap appears (see image 45). This gap indicates that the contact surface area between the concept and the hand decreases, which suggests that the pressure in the rest of the hand (that still touches the concept) has increased. This problem mainly occurs when concepts that are based on the 45° handlebar are tested on the 30° handlebar.

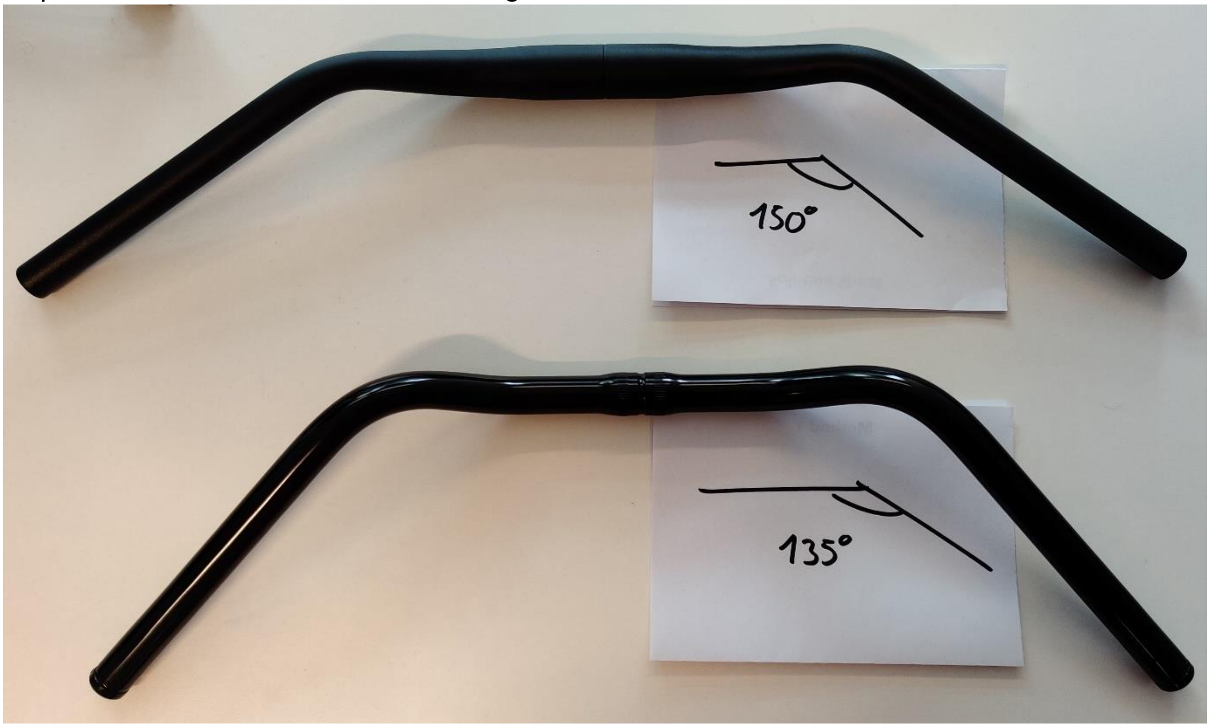

Image 44: Two different category 4 handlebars.

Image 45: The resulting gap when testing a concept based on a 45° handlebar at 30°.

For this reason, and other potential problems, a decision was made to narrow the scope of this project and choose one handlebar angle to design for.

When investigating the market research report by GfK (2020-2021) it appeared that the 45° handlebar is much more common than the 30° variant (see appendix C). The difference is so great that in the top 20 sold bicycles (both e-bikes as non-e-bikes) no bicycles appear that have the 30° handlebar. Therefore, the decision is made to base the concepts in this project on the 45° handlebar. Even though the predictions are that the 30° handlebar will gain ground in the future, this is still too uncertain to decide to design for this angle.

3.4 Concept assessment

After generating concepts and creating their physical prototypes, assessing these concepts is the next step. The goal of this assessment is to verify the concepts, how their features meet the found problems and to assist in the decision process of selecting a final concept design that will be recommended. The main points of interest in this assessment are thought and experiences of the participants on the appearance and comfort of the concepts based on their shape. First, the performed assessment and interviews are explained. After that, the findings are summarised and discussed.

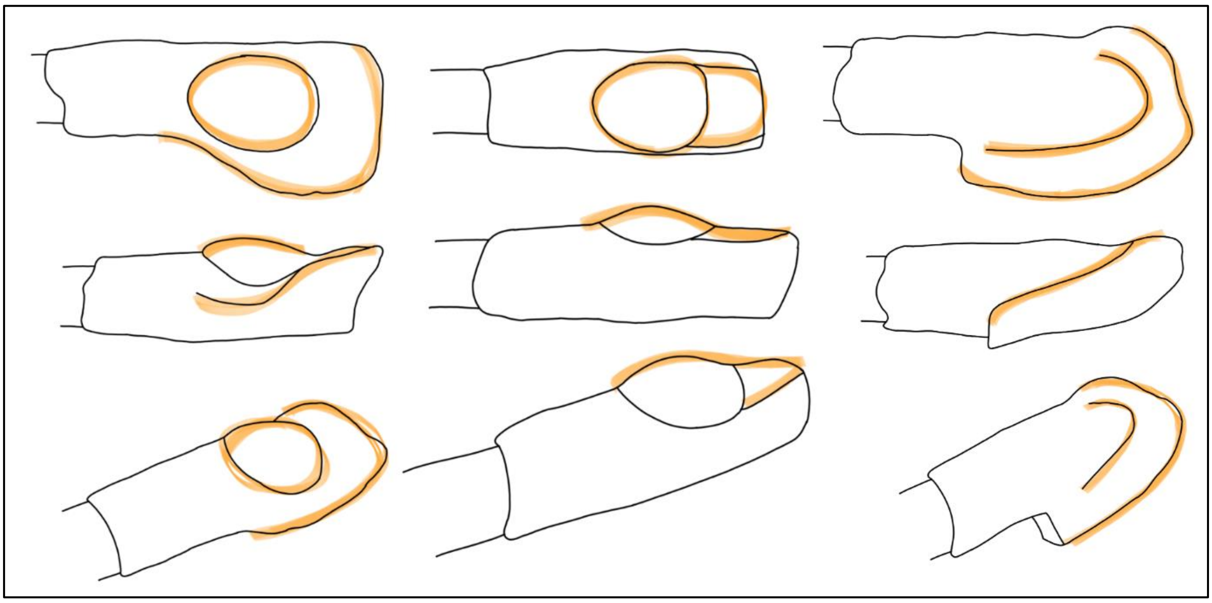

Image 46: Different views of the three concepts with accentuated features.

Assessment setup & questions

To perform the assessment, prototypes of each concept have been made (a left-handed and a right-handed version). These prototypes are made using a 3D printer and are printed in white PLA. This colour has been chosen because PLA has the tendency to become rather shiny when being 3D printed, and when prototypes are 3D printed in black (a more realistic colour for BHGs) the surface relief and shapes are much less visible. It is therefore important that before the assessment the participants are made clear that only the shape and physical comfort should be considered, and not the finish of the concepts (material, colour, etc.) or other features found on regular BHGs.

An additional handlebar standard has also been made (see image 47). This handlebar standard allows the concept prototypes to be assessed on an actual bicycle handlebar but without the need for a bicycle (and all the complications that come with it). This way, the assessment can be performed as consistent as possible.

Image 47: Handlebar standard made for physical assessment.

The handlebar standard is placed on a desk in a way a participant can take place right in front of it on a saddle stool enabling them to assume the correct sitting height and distance from the handlebar (see images 48 and 49). These distances are taken from average measurements from the most sold category 4 bicycles in 2021 (see appendix I).

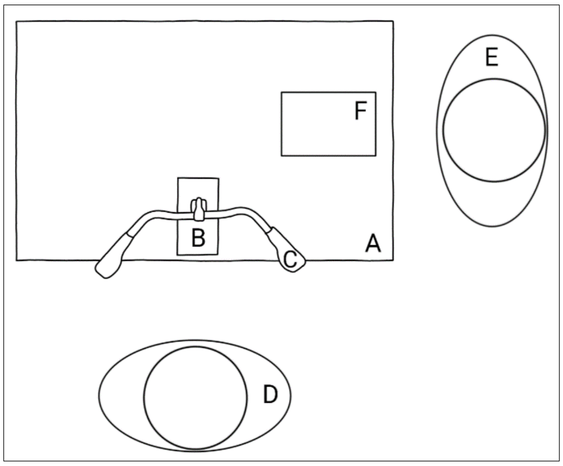

Image 48: Overview of the assessment setup with (A) a desk, (B) the handlebar standard with (C) mounted concepts, (D) the participant, (E) the observer and (F) the interview questions.

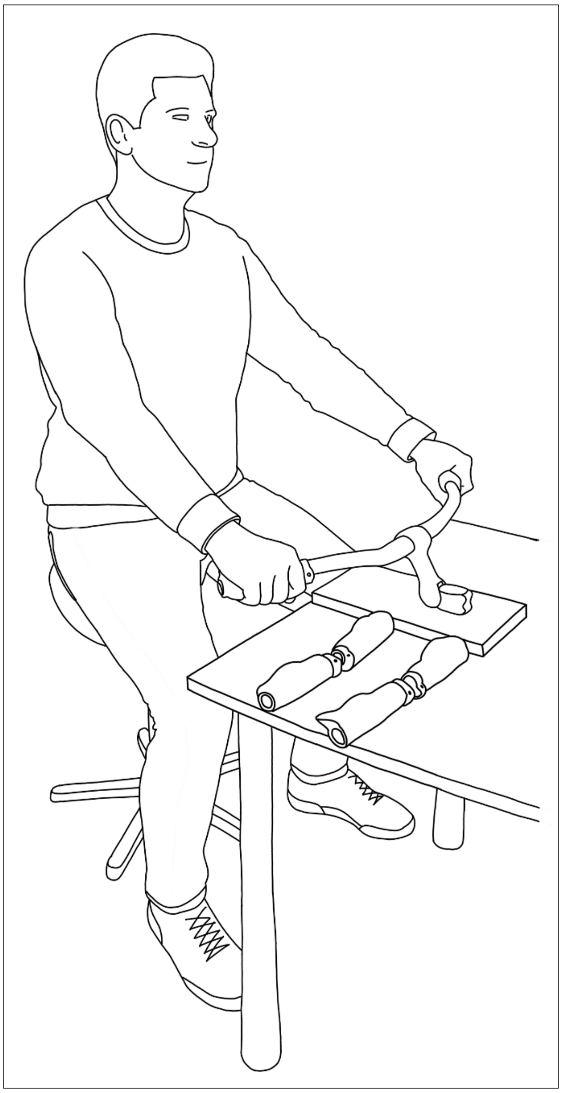

Image 49: Image visualising a participant during concept assessment.

A total of ten participants took part in this concept assessment, of which five are female and five are male. Their ages range from 26 years old to 64 years old (see appendix J), the spread of their hand sizes compared to Dined 2004 Dutch adults 20-60 mixed dataset (Dined, 2004) can be seen in image 50.

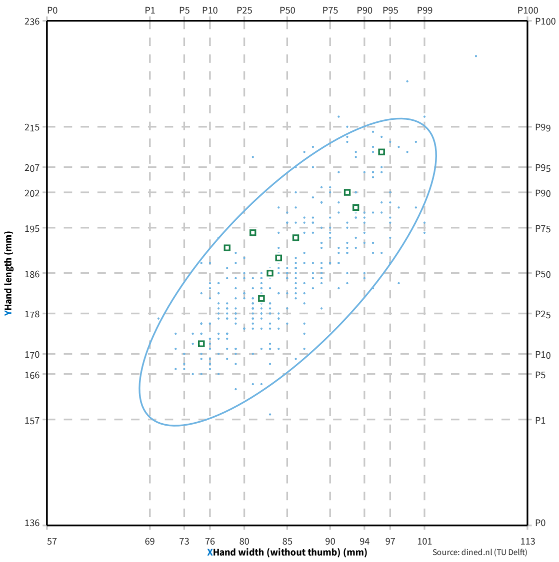

Image 50: Visualisation of the hand length and hand width of the participants (squares) compared to the hand length and hand width of the Dined 2004 Dutch adults 20-60 mixed dataset (dots) (Dined, 2004).

The concept assessment interview consists of four sections. First, the participant is asked to their gender, current age, hand length and hand width. This info is collected to verify the breadth of the assessment.

In the second section, the participant is asked to give their opinion on the visual attractiveness of the three concept prototypes. The prototypes are placed on the desk in front of the participant who is not yet allowed to touch the prototypes. This is done to ensure opinions on visual attractiveness and expected comfort are solely based on the shape of the concept prototypes, like it would be when a customer browses through BHGs when shopping.

The third step in this assessment is to mount the concept prototypes on the handlebar standard, ask the participant to assume the correct position and let them try the prototypes. During this free testing, the participant is asked to give the concepts a grade on a scale from one to ten, based on appearance and based on comfort, and to substantiate this grade as well as they can. After this, the participant is handed printed photocopies of the concepts and asked to mark their favourite area on the concept with a green marker and their least favourite area with a red marker.

Lastly, the concepts are again placed on the desk in front of the participant together without being mounted on the handlebar standard, to ask several closing questions. The participant is asked what their favourite concepts are based on appearance and based on comfort, if they are willing to purchase their favourite concept, how much they are willing to pay for this concept and if they would recommend this concept to anyone.

During the assessment tests and interviews, all audio has been recorded to ensure the observer could remain fully engaged with the assessment and the participant without the need to make notes. After the assessment, these audio recordings are transcribed and summarised.

Findings

In this subsection, the summarised findings are listed. The complete summary of the assessment interviews can be found in appendix J.

Visual attractiveness

Concept 1 scores highest on appearance ratings, because participants view this shape as most traditional and associative with existing ergonomic BHGs (see image 51). This is mainly because of the inclusion of the region 2 + 3 wing and the exclusion of further major protrusions.

Participants also indicate that the region 1 bump on concept 1 looks smaller than the one on concept 2, since that concept lacks the region 2 + 3 wing.

Another advantage of combining the region 1 bump and region 2 + 3 wing is that the wing explains the orientation the concept is supposed to be mounted in.

Votes for concept 3 are based on the distrust generated by the region 1 bump. Participants also declare that when a BHG has a pronounced and recognisable shape it is associated with higher levels of comfort because it looks like a lot of thought and work went into the design.

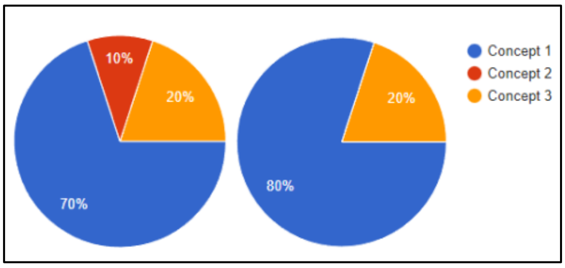

Image 51*: Participant's favourite concepts based on* visual attractiveness before (left) and after (right) physical testing.

(Expected) comfort

Concept 1 also scored high on the comfort ratings (see image 52). This is also caused by the region 2 + 3 wing and its association with high support. After testing, participants indicate that the region 1 bump feels a lot better than they expected (both for concepts 1 and 2), and that they notice a relief of pressure in the other regions of the hand. Another advantage of the region 1 bump is that participants indicate they feel the increased support regardless of the position of the hand on the concept (during regular use). This is beneficial for using handlebars with alternative bend angles.

The votes for concept 2 are substantiated by the experience that this concept works better for users that are outliers in size, since it does not have the region 2 wing. When outliers with small hand use BHGs that are too large and have the region 2 wing, the size will be counterproductive (see image 13). When outliers with large hands use BHGs that are too small and have the region 2 wing, their hands will fall over the edges which creates peak pressure points.

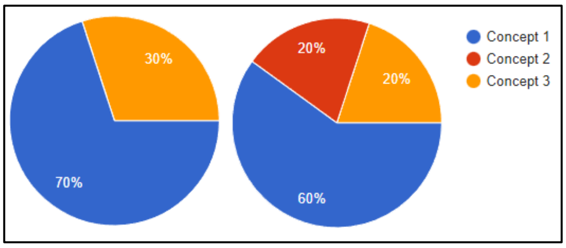

Image 52*: Participant's favourite concepts based on* expected comfort before (left) and experienced comfort after (right) physical testing.

Grading

Looking at the grades given by the participants (see table 5), concept 1 has the highest overall score. Concept 3 has a slightly higher comfort grade but loses points on the appearance grade, and concept 2 loses on both criteria.

Table 5: Average grades and their standard deviation per concept, based on appearance and comfort.

	Average grade appearance	Average grade comfort
Concept 1	7.5 (SD = 1.08)	7.4 (SD = 1.82)
Concept 2	6.4 (SD = 0.97)	7.0 (SD = 1.26)
Concept 3	7.1 (SD = 0.73)	7.6 (SD = 0.85)

Favourite areas

When asking the participants to point out and explain their favourite and least favourite areas of each concept, all of them were positive about the region 2 + 3 wings on concepts 1 and 3 (see image 53). Almost all of them were positive about the region 1 bump on concepts 1 and 2 and indicate that they missed this protrusion on concept 2.

The participants that dislike the region 1 bump (both in concept 1 and concept 2) are the participants with the smallest hands. They indicate that for them, the region 1 bump is too high, which results in an uncomfortable pressure peak in that region.

Some participants indicate they disliked the lack of the region 2 + 3 wing on concept 2, and some indicate that the diameter of the prototypes could be smaller and more consistent.

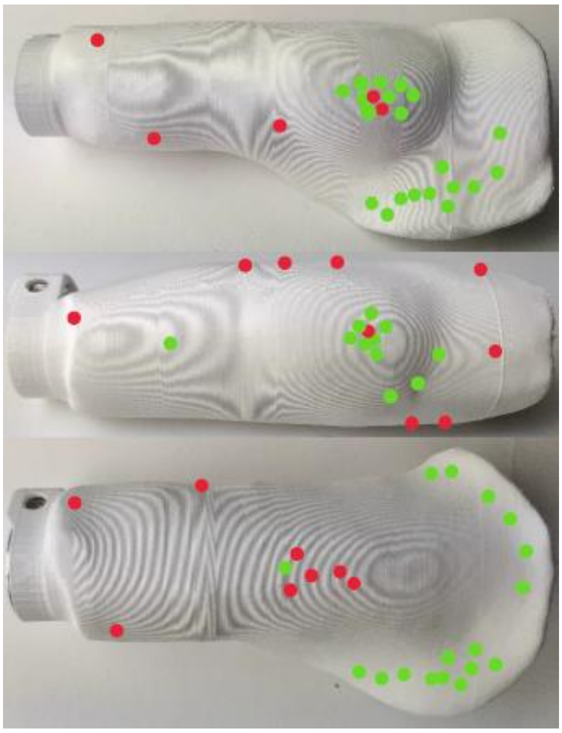

Image 53: A summary of the favourite (green) and least favourite (red) areas indicated by the participants.

Willingness to pay

When asking participants about the willingness to pay for their favourite concepts, most of them indicate that they hardly cycle. When they do, the rides are by no means long enough for them to experience discomfort. They also indicate that none of them has even bought BHGs and most of them think they never will. Nevertheless, they indicate how much they are willing to pay for their chosen favourite concept if it was the case that they needed to purchase new BHGs (see image 54).

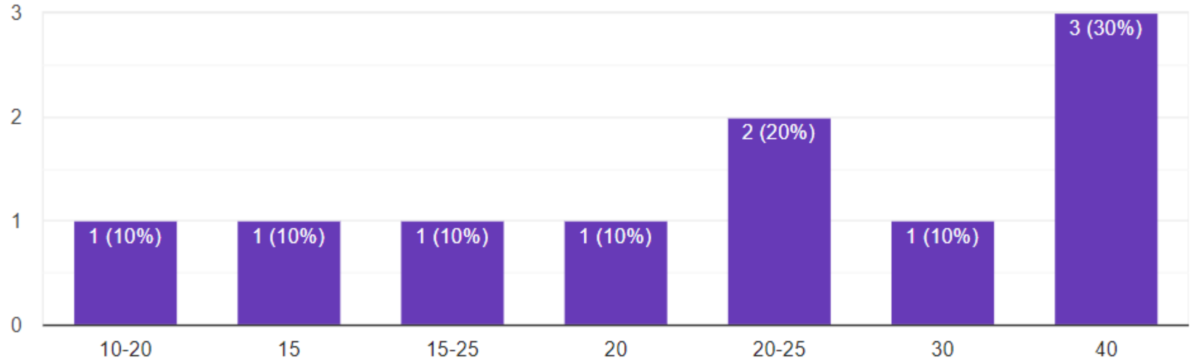

Image 54: The amount *(€)* participants are willing to pay for their favourite concepts.

3.5 Final concept

Image 55: Concept 1 on the handlebar standard.

In this section, the chosen recommended concept will be revealed and described, and the substantiation for this choice will be explained.

The concept that is chosen to recommend for further development into a product to introduce to the market is concept 1 (see image 55). This is the concept with the region 1 bump and region 2 + 3 wing.

This concept has been selected based on a combination of the two criteria discussed in the concept assessment (see section 3.4), being physical comfort and visual attractiveness. When asking participants of this assessment to grade the three concepts, concept 1 scored the highest average (7.5/10). This score can be attributed to the following reasons:

Firstly, participants are positively surprised by the region 1 bump. This bump enables a better pressure distribution on the hand palm by filling the cavity between the thenar and hypothenar regions that appears when the hand is folded around the BHG. Filling this cavity means that the same force (from the hand onto the BHG) is spread over a larger area, reducing pressure on the low PDT areas.

Secondly, research also found that this newly addressed region of the hand has a relatively high PDT (see image 56), which is only more reason to increase the pressure in this particular area (di Brigida et al., 2021; Fransson-Hall & Kilbom, 1993).

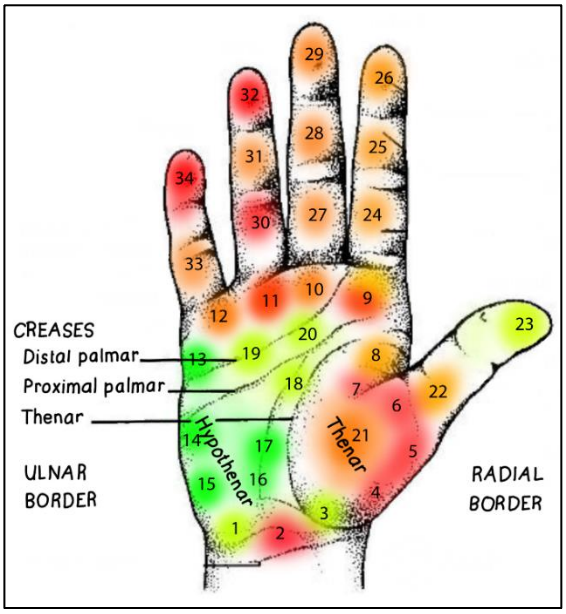

Image 56: Visualisation of the PDT map of the hand including the newly addressed regions by the region 1 bump (16, 17, 18, 19, 20).

In addition to that, participants are positive about the region 2 + 3 wing. This wing also greatly increases the surface area between the BHG and the hypothenar region of the hand, which is also one of the high PDT regions.

The appearance of this concept also appealed to the participants because since its introduction a couple decades ago, the region 2 + 3 wing has become a trusted and recognisable feature that is associated with increased comfort, and it is almost indispensable when it comes to bicycles in the higher segment. This wing has the additional effect that it seems to divert attention from the region 1 bump, which makes it seem less outstanding.

4. Concluding

This final chapter of this report describes the end of this project. First, all design recommendations regarding the further development of the chosen concept are listed and discussed. After that, the next steps needed to finalise the design are summarised. And lastly, a personal reflection on this project is written.

4.1 Recommendations

In this section, all recommendations regarding the further development of the chosen concept and future research suggested to enable this development are listed. This concerns both insights gained from the concept assessment interviews (regarding physical comfort and visual appearance) as recommendations regarding problems from the problem list that are outside the scope of this project.

Development BHG

In this section, recommendations regarding iterating and improving this concept will be discussed. Within the scope of this project, only the problems regarding pressure peaks on the hand and an incorrect position of the wrist are concerned and incorporated in the concepts (see subsection 'Problem selection' in section 3.1). All other problems that are found during research (see appendix F) have led to a list of recommendations which will be discussed afterwards.

Pressure peaks

For test subjects with smaller hands, it appeared that the region 1 bump in the latest concept 1 prototype is too large. Because of this, the pressure in the corresponding hand region becomes too high, resulting in a decrease of comfort. This could be solved in multiple ways:

First, manufacturing the concept using the final materials (with a hardness comparable to current BHGs) could lead to the region 1 bump becoming a lot softer since there is a large material thickness (see image 57). This could result in compression of the bump and it shaping to the hand of the user.

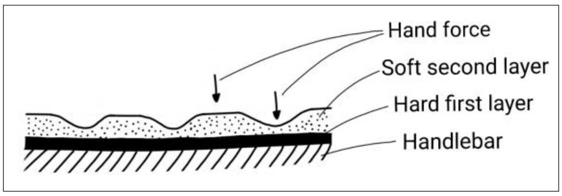

Image 57: Section view of a BHG visualising the different layers and thicknesses.

Another option is to manufacture the region 1 bump from a different material as the rest of the concept, giving the opportunity to use a material that can be softer. This could also enable the bump to shape to the hand more easily.

Lastly, if the two previous options fail, the decision could be made to decrease the size of the region 1 bump so that it can be comfortably used by users with smaller hands. I would only recommend this option if the group that experiences the current region 1 bump size negatively has hand sizes larger than a to be determined size, and the decreased region 1 bump size still has effect for large hands up to a to be determined size.

An alternative for decreasing pressure in certain regions of the hand is to manufacture these regions from a softer material, so that these regions are displaced further than others under pressure. This increases the pressure distribution since more pressure is placed on the regions that do not deform.

Incorrect wrist position

The market research revealed that most of the top 25 popular bicycles uses a 45° angle handlebar. This handlebar angle however forces the wrists in an ulnar deviated position which is detrimental to the comfort of this handlebar. The design of the BHG can only solve this to a certain extent, which means that it would be beneficial to move towards the use of handlebars with a smaller bend. Although this decision is not up to the BHG manufacturer, it is in close contact with the bicycle manufacturers and advice can be given on this.

Loosening

Since loosening of BHGs emerges as the biggest annoyance of users, I recommend using a fastener in the final design to keep the BHGs in their place. To maximise ease of use and recyclability, I recommend a clamp ring with a bolt on the inside of the BHGs (see image 58). This bolt can be fastened and loosened using a hand tool to adjust the angle of the BHG or replace it altogether.

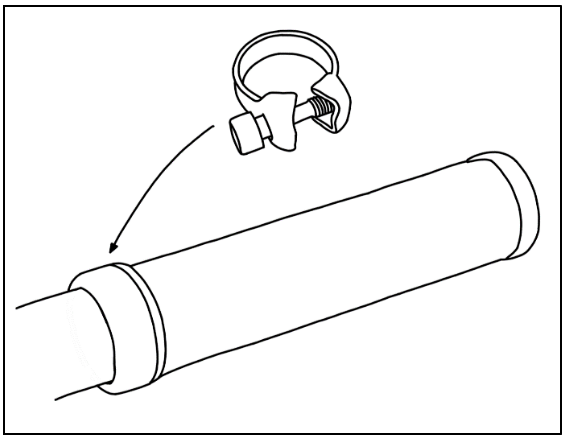

Image 58: Using a clamp ring as fastener.

Another advantage for using a clamp ring over a solution where the BHG gets bolted to the handlebar (see image 59) is that the use of a clamp ring is not dependent on the manufacturer of the handlebar (as long as the diameter is consistent) since it is a clamping connection. The preferred tool for this solution is a hex key since this is in line with many other fasteners on current bicycles.

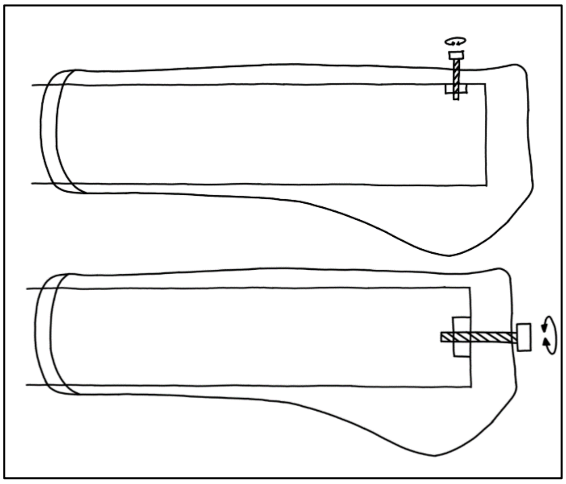

Image 59: Examples of bolt fasteners that require adjustments to the bicycle handlebar.

Type of buyer

Since Widek has indicated that most of their sales are to OEM clients, and that is also the plan for this potential product, I recommend designing this product to be marketed for OEM clients specifically. This can be done by not deviating from current and standard installation methods to prevent a decrease in factory speed and include recognisable and familiar features in the design like the region 2 + 3 wing. When bicycle brands place large orders, Widek could consider including the brand identity of the client into the design.

Misinterpreted features

Because the research has shown that a lot of BHGs are used and/or installed incorrectly, I recommend adding use cues to the design that inform the user or mechanic in what orientation the BHG must be used and/or installed (see image 60). This could be done by including intuitive icons on the design relating the orientation relative to the bicycle or handlebar.

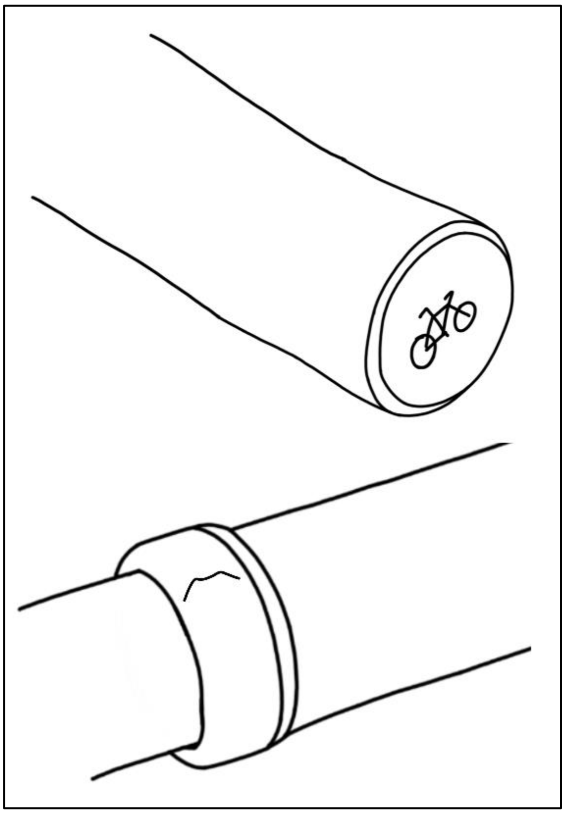

Image 60: Examples of icons as use cues on BHGs to indicate the orientation of the BHG: a bicycle icon in the same orientation as the bicycle the BHGs are mounted on (top) or a handlebar icon in the same orientation as the handlebar the BHGs are mounted on (bottom).

Price

Since consumers indicate they (almost) never purchase BHGs, and if they do, they go for the cheapest option, it is also beneficial to aim for the OEM market. Since the overall price of bicycles in category 4 is increasing, a consumer won't notice what part of that goes towards the BHGs. This means that the bicycle manufacturer can offer the best BGH that is in line with the quality of the bicycle where the consumer would choose the cheapest option.

Unappealing appearance

Consumers are generally hesitant of purchasing something that is too new or stands out too much from the current context and competition. In order to meet the user as much as possible, I recommend keeping this in mind when developing this product. For example, by using organic shapes instead of geometric ones, not using more than two colours and materials, using neutral colours, using colours and materials that are associated with comfort and quality and to flatten protrusions as much as possible.

Production

It is in Widek's interest to remain the production method of this concept as close to their current BHG production method as possible to keep costs as low as possible. Currently, Widek manufactures BHGs using 1K and 2K injection moulding. They prefer to keep it that way and not go up to 3K for example, since that requires major adjustments to their equipment. This means that this must be taken into account when designing the final concept.

The two components can be utilised in two different ways: the first one is to use a first component (with the hardness of current BHGs) to create most of the BHG, and then use the second component (with a lower hardness) for protrusions or low PDT areas. Producing the product this way there are added possibilities to focus on the comfort of the hand surface, but the whole BHG could lack rigidity and deform.

The second option is to use a rigid first component to reduce deformability and create a structural base for the protruding features of the product. And then use the second component to cover the whole first component as a body and surface finish. This approach improves the use of a mechanic fastener since the first component is unlikely to deform around this fastener. A disadvantage is that the advantages of using different surface materials (and hardness, finish etc.) are not applicable.

Weighing the advantages and disadvantages of both options, I recommend the second one and use the first component to create a solid frame for the BHG. This allows more freedom of form in the design and ensures the functioning of a mechanic fastener.

Future research

The limitations of this project, both in time and resources, had led to unexplored research directions. In this section, these recommended research directions will be discussed.

Research

To make informed decisions regarding the recommendations on the problem list, additional research is valuable. This research can dive deeper into the individual problems that have not been explored in the same depth as the pressure peaks or the incorrect wrist position.

Next to this additional research, all new findings that emerge on the pressure peaks or incorrect wrist position are also valuable and could be incorporated into the design.

Validation

During the concept assessment phase of this project, the performed tests are all short-term (several minutes per concept). For more accurate results, I recommend producing more accurate prototypes which also take into account hardness, surface material, colour etc. and performing long-term tests consisting of participants cycling longer rides multiple times.

Another interesting item to test is the sensitivity of the hand surface when the hand is curved around a BHG instead of extended like in the observed studies (subsection ‘Hand sensitivity’ in section 2.1). It could be possible that the pressure discomfort map looks different in this curved position.

For additional verification and increasing additional knowledge, I recommend introducing this project to medical experts who specialise in the hand, wrist, arm and shoulder. I believe this project could greatly benefit from this kind of collaboration since these kinds of experts often know what the complaints and their causes are, and how they can be prevented.

4.2 Next steps

This section looks ahead at the steps to be taken to further develop the proposed concept into a production-ready design.

The first step is to go back to the problem list (section 3.1) and look into the problems to be solved. Most of these problems are in need of additional research, which will gain new insights and generate solutions. These solutions then need to be incorporated into the product concept and be verified during user testing. Next to the problem list, the LoR (section 3.2) must be taken into account. The final product must meet these R&W before production can start.

When the concept meets all R&W and contributes as much as possible to solving the problems of the problem list, it must be translated into a 3D model. Since it is such an organic shape, this will be done by starting off with a 3D scan of the concept. This 3D scan will be sliced to make drawings from these cross-sections which will form the basis of the shape. This is all done parametrically so that adjustments can be made later if necessary. This 3D model then will be 3D printed and tested extensively using a wide range of participants and hand sizes. This process is repeated until the shape is satisfactory.

The final shape then needs to be translated into an injection mould. This is done in two ways: The first option is to send the 3D model of the concept to the mould maker. They then create an injection mould that can produce the final shape. Before approval, a number of casting tests are done which allows for iterating of the mould to remove potential problems or errors. The second option occurs when the product consists of two materials. Widek's current suppliers are not able to make 3D models of these 2K injection moulds, which means that these must be created by their own engineers. The 3D models of these 2K injection moulds are then delivered to the mould maker that produces the Injection moulds.

When the injection moulds are delivered and approved after final in-house tests, production can start.

In addition to testing the concept with end users, technical tests will also be performed. These include ISO and TÜV tests that the product must meet.

4.3 Personal reflection

In this final section of my graduation report, I want to look back and reflect on the project, my original plans and how everything worked out in the end.

Search

I encountered the first challenge regarding my graduation well before the start of the project: I first had to find a project. This meant I had to take a good look at myself and find out what topics or companies would be a good fit and keep me motivated long enough to complete this six month journey I was about to embark on. During this inner search I spoke with several professors from the faculty of Industrial Design Engineering that appealed to me and who I thought had similar working methods and interests. Unfortunately, this did not go as well as I expected and most of these meetings resulted in me having more questions than before these meetings. One of these professors however, after firing a barrage of questions I was unable to answer at that moment (which direction do you find interesting or which part of the design process do you like to do?), commented he believed I find working through the design process so interesting that the actual subject is not even that important to me. After looking back to the design projects I completed in the last couple years, and remembering the great diversity in subjects and approach and that almost all of them brought me great joy, this is a statement I can agree with.

Searching with this newfound vision, I ran into the graduation project proposal by Widek that even came with a professor who had already expressed his interest in this project. Initially, the optimisation of BHGs does not sound like a sexy designer assignment that requires a lot of creativity, but the expected simplicity of the product and huge group of potential users in NL triggered something in me. During my reflection on past projects, I realised that I enjoy coming up with solutions that are simple and non-invasive to make the lives of users as easy as possible. This seemed to me like a project where I could do exactly that.

Working environment

As soon as I started at Widek, I felt welcome. It was not the first time that I did an assignment for a company, but I have never experienced this amount of freedom and support. Where companies usually try to steer the project towards a certain direction, Widek respected my personal process and left me free to do my thing. This does not mean that there was no interest in my project, quite the contrary. Every time I worked at the factory or came in the office I was bombarded with questions about the project and whether there were any updates. This was great for my motivation.

Next to working at Widek for two days per week, I tried working from home for the other three. This was due to the COVID-19 restriction that closed the TU Delft and because one-way travel to Widek by public transport took almost one hour. After the faculty opened again, I could not abandon my home office any faster. Working from home is clearly not for me. I need the social interaction and peer pressure of being in a productive environment filled with people in a similar situation.

I found out that I work best in a strict work schedule, and I am very happy that my mentor facilitated this for me by having a weekly physical meeting to discuss progress and planning. These meetings usually took place on Mondays and were the perfect way to end the previous week on a good note and start the new week motivated.

Research

The research phase I started this project with was supposed to last only a few weeks. I made this decision because in prior projects, I never enjoyed this phase. The reason for my bad relationship with research is that I start generating solutions as soon as I discover a problem, while at the faculty of Industrial Design Engineering you are forced to postpone this until the right amount of research is done. During this project it turned out that I misjudged this, because I extended my research phase with almost two months all the way up to my midterm evaluation. Reasons for this are that I underestimated the number of topics to be researched and the information available, and that I actually started to enjoy soaking up information that could guide me towards solutions.

During this project, the scope and achievable results got shape over time. When I realised that I could only deliver a concept design which tackles a specific focus area within the scope instead of a further developed product design, I regretted extending the research phase. But now during reflecting, I am satisfied with the amount of research I did and how I built a solid foundation for a well-considered and well-founded design for the creation of my concept design and its potential further development in the future.

Tinkering

After my extended research phase I had some trouble starting the design process and kept lingering in the theory and methodology. It took my mentor more than one meeting to motivate me to get over this blockage and start tinkering with bicycle handlebars and clay. During this time, I did a side job for Widek where I assisted them in the creation of a 3D model of one of their existing BHGs by scanning it in my private 3D scanner. After doing these manual jobs, I regained my motivation and inspiration and good ideas started to appear.

I explored by tinkering and prototyping using different types of clay and 3D scanning the shapes this resulted in. I already had a bit of experience with this technology, but I never tried digital adjustment or retouching before. This is something I greatly enjoyed learning, and I believe I have proven my technical skills as a designer by producing physical prototypes that accurately represent the concept design.

Learning ambitions

At the start of this graduation project, I indicated that I wanted to learn more about peripheral matters like planning and reporting since this is my first solo project and, in the past, I mostly focused on the design challenges of projects. I believe that I have learned a lot about these subjects both in how much time it takes to plan ahead and how much work it saves when everything is tracked and recorded. My best experience with this during this project is that I wrote and delivered the content of the first two chapters (Introduction and Research) at my midterm evaluation. And after I received and processed the feedback, I did not have to touch it anymore until the very end of this project.

To me, this project is the decisive evidence that the methods I have learned at the TU Delft faculty of Industrial Design Engineering work for me, and I believe that they are applicable in any kind of project or process to lift it to a higher level of quality.

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Appendix

A. Hand sensitivity

This appendix contains a graph from the research of di Brigida et al. (2021) that visualises the difference in hand sensitivity between females and males.

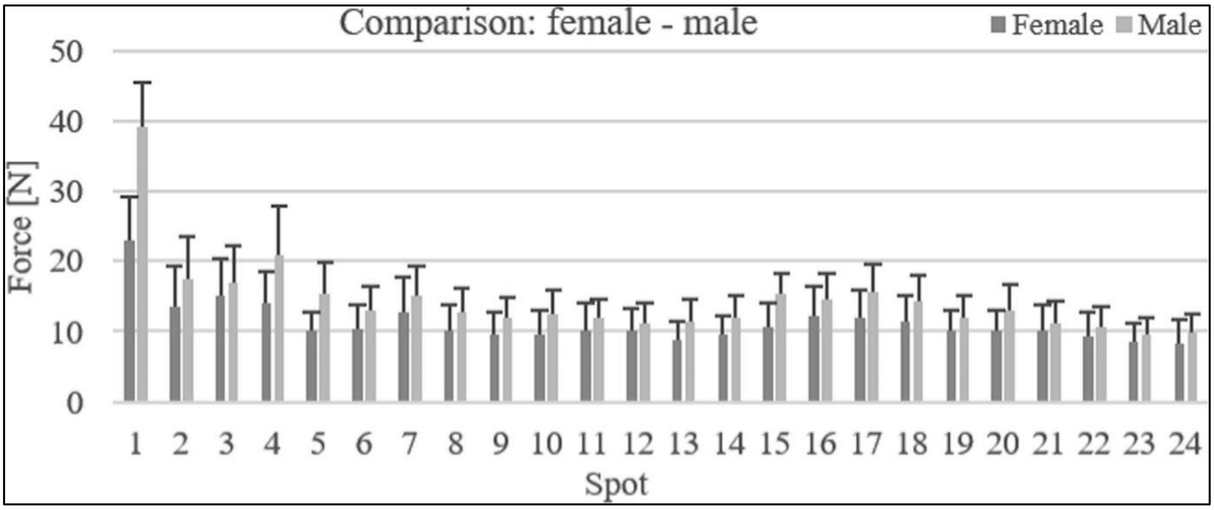

Image 61: Graph visualising the difference in hand sensitivity between females and males (di Brigida et al., 2021).

B. CBS popularity bicycles

This appendix contains graphs visualising the decrease in use of the three most popular means of transportation in the Netherlands (CBS, 2021).

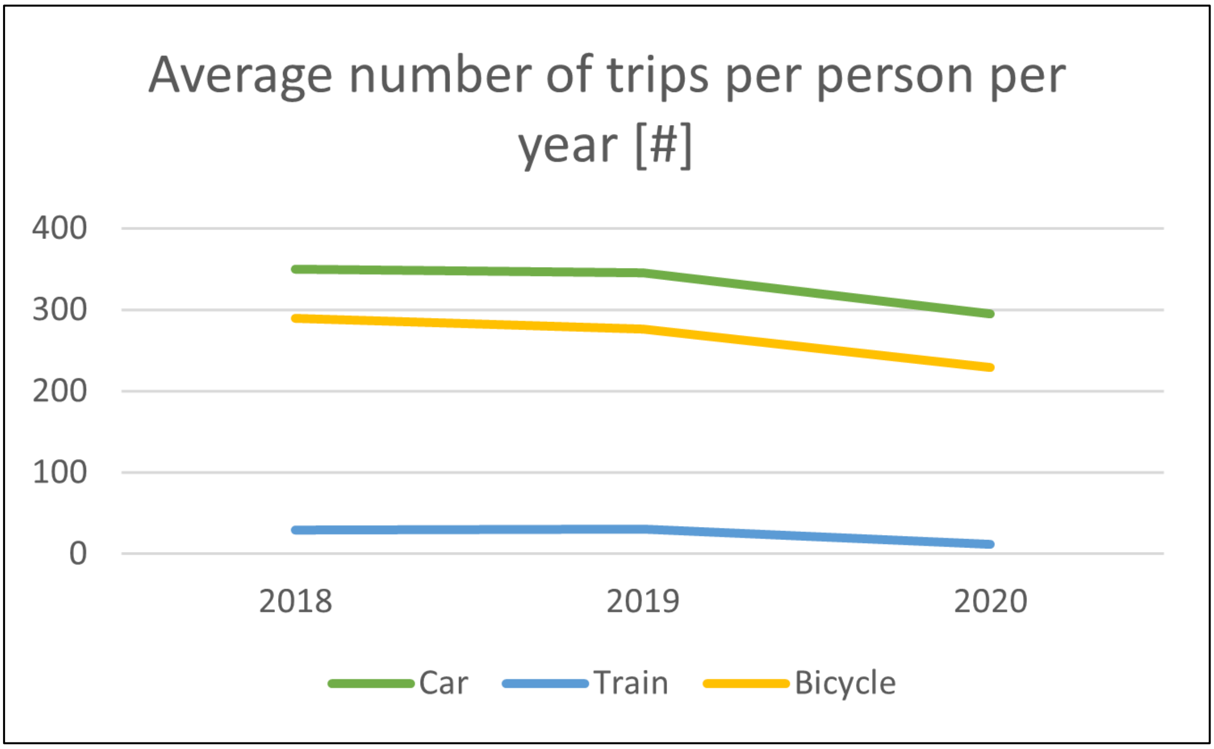

Image 62: Graph visualising the decrease of number of trips per means of transport (CBS, 2021).

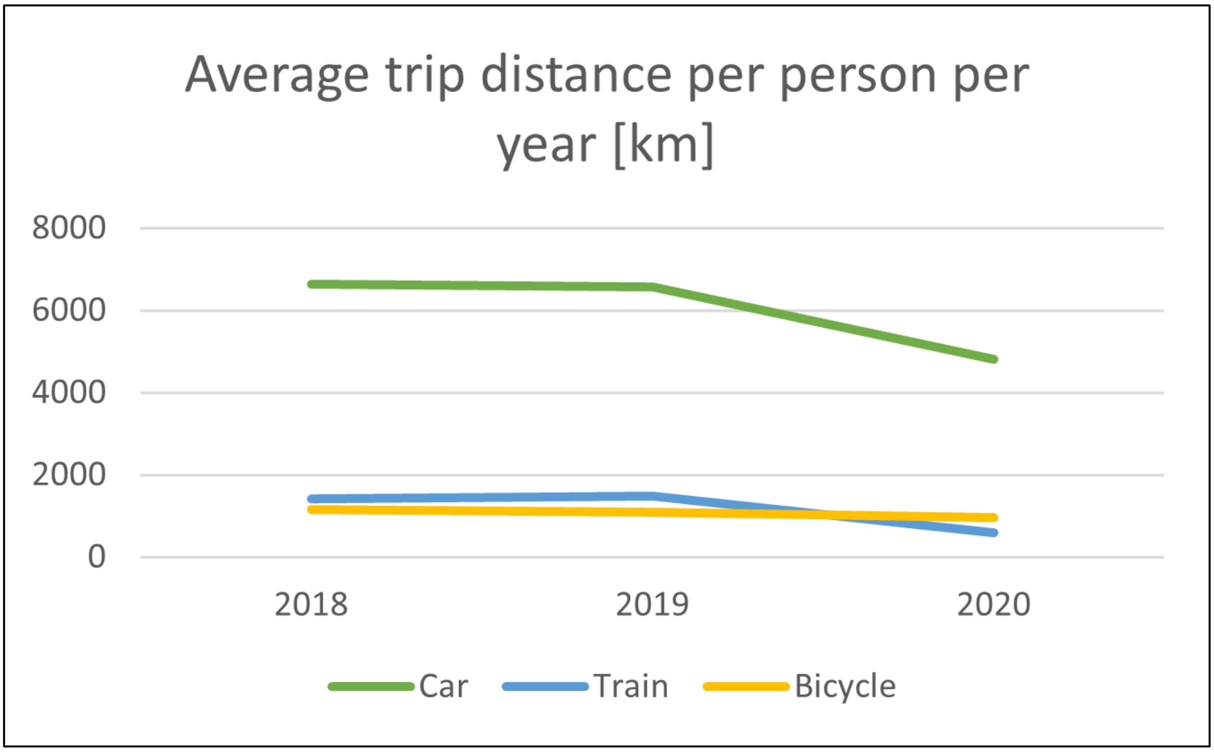

Image 63: Graph visualising the decrease of trip distance per means of transport (CBS, 2021).

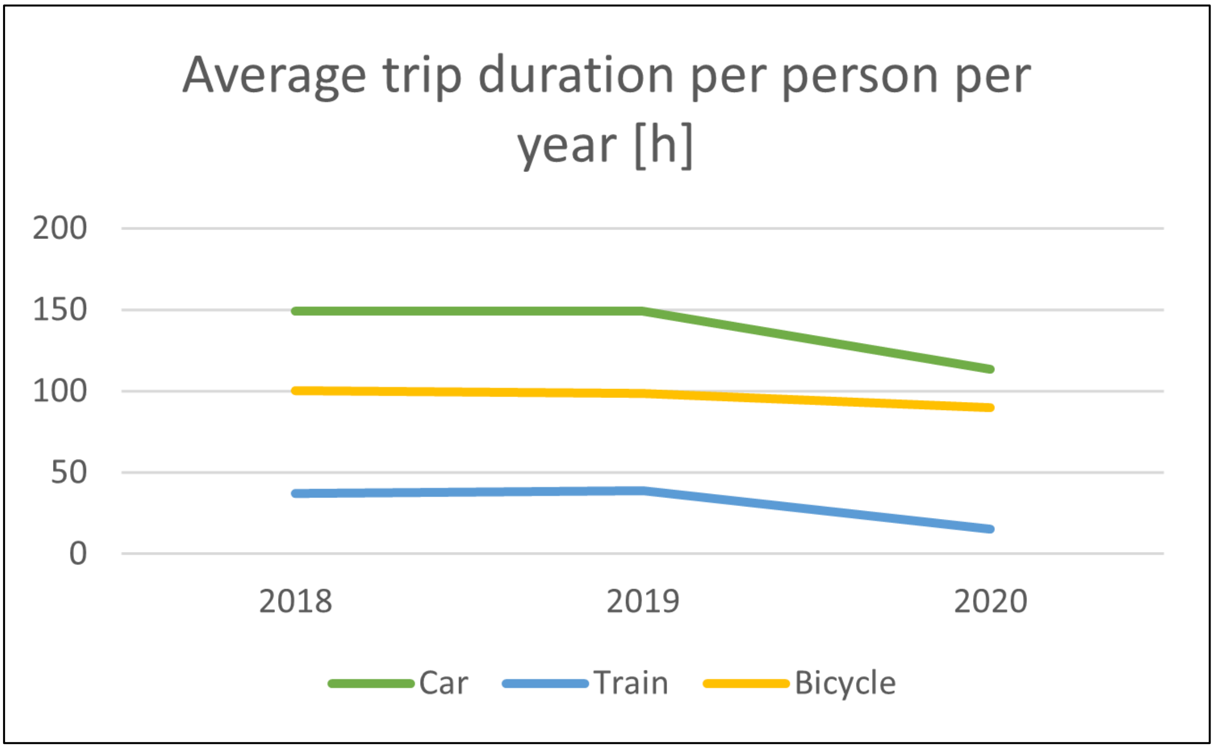

Image 64: Graph visualising the decrease of trip duration per means of transport (CBS, 2021).

C. GfK data 2021

This appendix contains graphs visualising sales numbers regarding bicycles in the Netherlands, generated by GfK (GfK, 2020–2021).

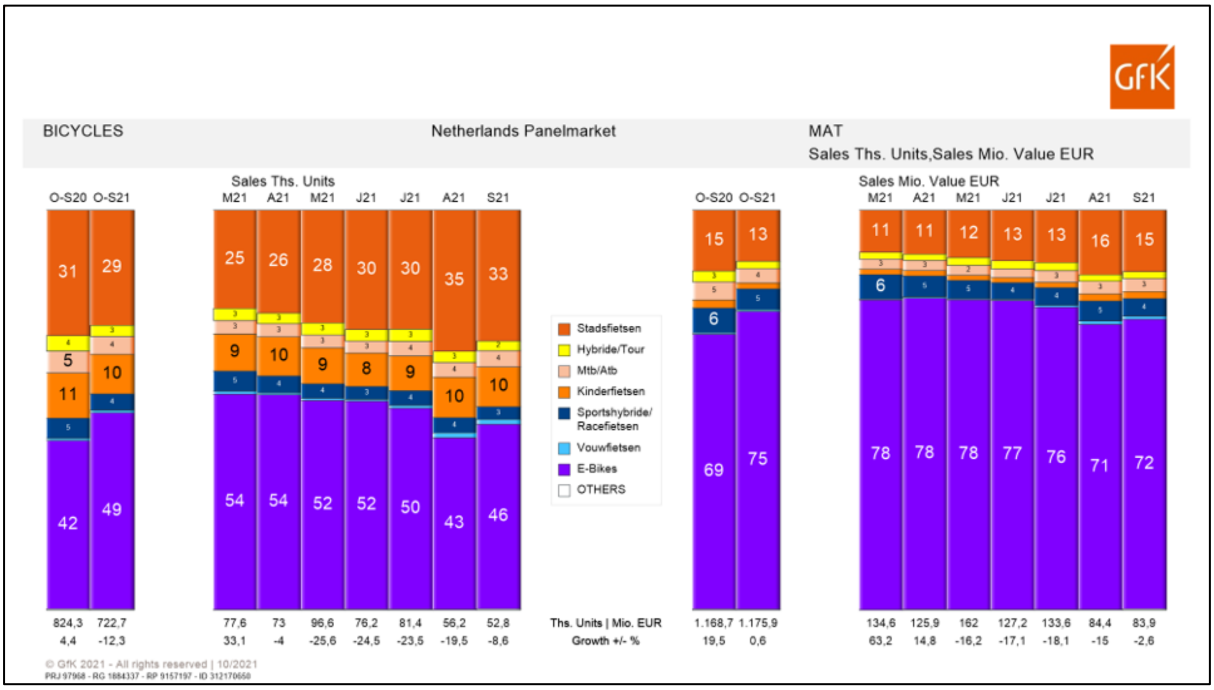

Image 65: Graph visualising sales as percentage per bicycle type in 2021 (March – September), expressed in quantity (left) and value (right) (GfK, 2020–2021).

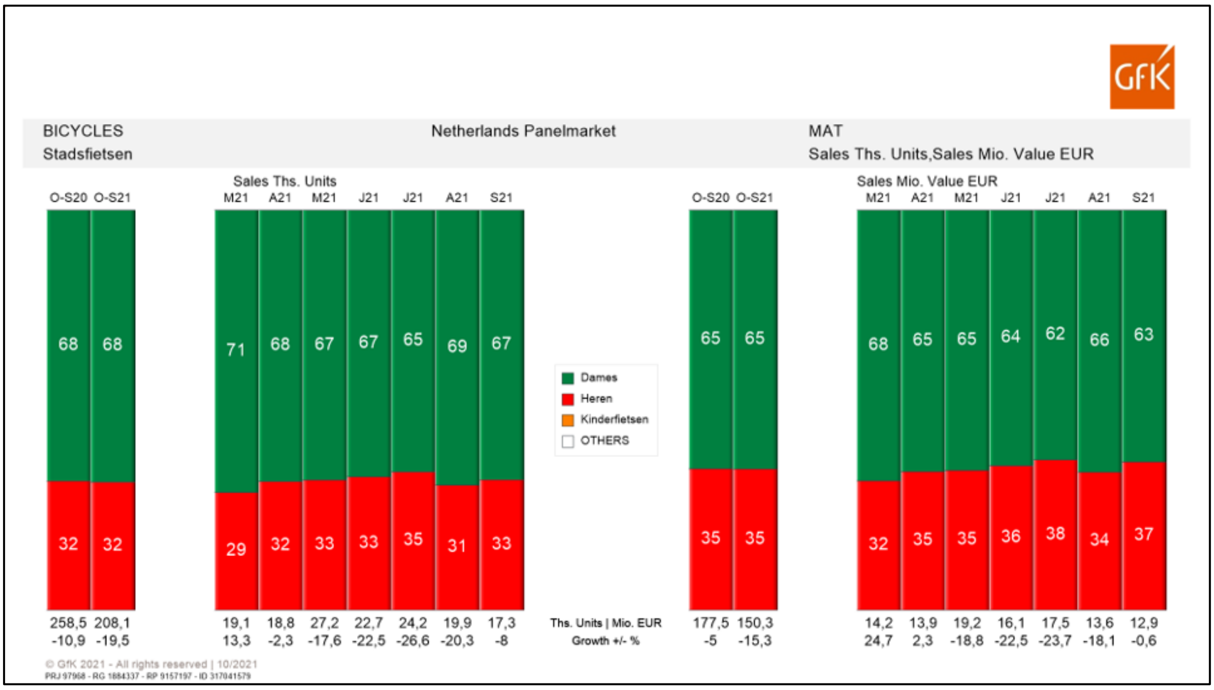

Image 66: Graph visualising sales as percentage per bicycle gender model in 2021 (March – September), expressed in quantity (left) and value (right) (GfK, 2020–2021).

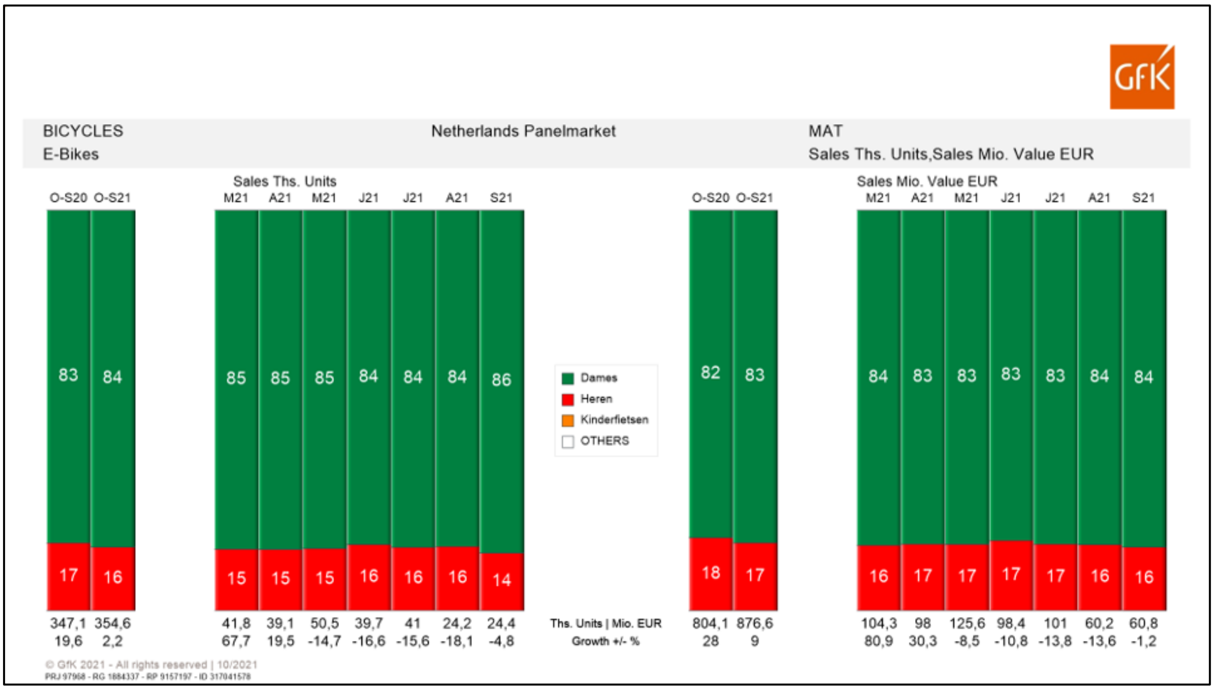

Image 67: Graph visualising sales as percentage per bicycle gender model (e-bike) in 2021 (March – September), expressed in quantity (left) and value (right) (GfK, 2020–2021).

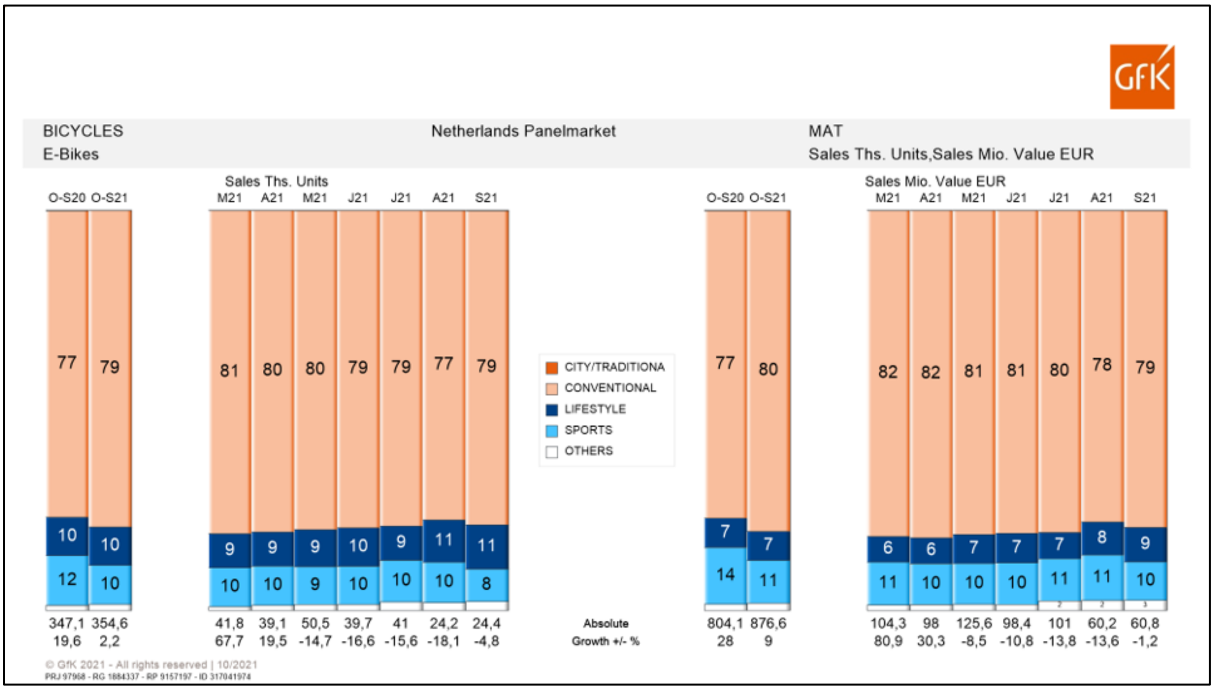

Image 68: Graph visualising sales as percentage per bicycle model (e-bike) in 2021 (March – September), expressed in quantity (left) and value (right) (GfK, 2020–2021).

BICYCLES Netherlands Panelmarket Oct 20-Sep 21
Stadsfietsen HITLIST TOP 25

No.	Brandname	MODELTEXT	Model	Type of bike	NUMBER OF GEARS	WHEELSIZE	SALES UNITS	SALES UNITS %	SALES TH.EURO	SALES EURO %	PRICE EURO
1	CORTINA	U4 TRANSPORT	Dames	Stadsfietsen	3 GEAR	28 INCH	12.579	6,0	7.150,8	4,8	568
2	GAZELLE	ESPRIT	Dames	Stadsfietsen	3 GEAR	28 INCH	4.801	2,3	2.789,3	1,9	581
3	CORTINA	U4 TRANSPORT	Dames	Stadsfietsen	3 GEAR	28 INCH	3.902	1,9	2.235,1	1,5	573
4	GAZELLE	BLOOM C7	Dames	Stadsfietsen	7 GEAR	28 INCH	3.898	1,9	3.328,0	2,2	854
5	GAZELLE	ESPRIT	Heren	Stadsfietsen	3 GEAR	28 INCH	3.666	1,8	2.122,5	1,4	579
6	GAZELLE	ORANGE C7+	Dames	Stadsfietsen	7 GEAR	28 INCH	3.577	1,7	2.926,8	1,9	818
7	GAZELLE	ESPRIT	Dames	Stadsfietsen	7 GEAR	28 INCH	3.426	1,6	2.192,2	1,5	640
8	GAZELLE	ESPRIT	Heren	Stadsfietsen	3 GEAR	28 INCH	3.251	1,6	1.926,6	1,3	593
9	GAZELLE	ESPRIT	Heren	Stadsfietsen	7 GEAR	28 INCH	2.709	1,3	1.765,1	1,2	652
10	CORTINA	U4 TRANSPORT	Heren	Stadsfietsen	3 GEAR	28 INCH	2.445	1,2	1.399,8	0,9	572
11	GAZELLE	HEAVYDUTYNL	Dames	Stadsfietsen	7 GEAR	28 INCH	2.438	1,2	1.825,1	1,2	749
12	CORTINA	U4 TRANSPORT	Dames	Stadsfietsen	7 GEAR	28 INCH	2.232	1,1	1.709,2	1,1	766
13	GAZELLE	ORANGE C7+	Heren	Stadsfietsen	7 GEAR	28 INCH	1.922	0,9	1.593,2	1,1	829
14	GAZELLE	CHAMONIX C8	Heren	Stadsfietsen	8 GEAR	28 INCH	1.917	0,9	1.838,9	1,2	959
15	GAZELLE	ORANGE C8	Dames	Stadsfietsen	8 GEAR	28 INCH	1.885	0,9	1.658,6	1,1	880
16	GAZELLE	CHAMONIX C8	Dames	Stadsfietsen	8 GEAR	28 INCH	1.850	0,9	1.793,7	1,2	970
17	CORTINA	COMMON	Dames	Stadsfietsen	7 GEAR	28 INCH	1.708	0,8	1.332,8	0,9	781
18	BATAVUS	PACKD START 3	Dames	Stadsfietsen	3 GEAR	28 INCH	1.678	0,8	815,9	0,5	486
19	GAZELLE	HEAVYDUTYNL	Dames	Stadsfietsen	3 GEAR	28 INCH	1.548	0,7	1.055,3	0,7	682
20	GAZELLE	PUURNL MIDNIGHT	Dames	Stadsfietsen	3 GEAR	28 INCH	1.534	0,7	904,3	0,6	589
21	BATAVUS	FONK 7	Heren	Stadsfietsen	7 GEAR	28 INCH	1.468	0,7	1.042,1	0,7	710
22	CORTINA	U4 TRANSPORT SOLID	Dames	Stadsfietsen	3 GEAR	28 INCH	1.436	0,7	995,2	0,7	693
23	BATAVUS	QUIP EXTRA CARGO	Dames	Stadsfietsen	7 GEAR	28 INCH	1.408	0,7	1.159,9	0,8	824
24	BATAVUS	PACKD 3	Dames	Stadsfietsen	3 GEAR	28 INCH	1.377	0,7	838,6	0,6	609
25	CORTINA	U4 TRANSPORT FAMILY	Dames	Stadsfietsen	7 GEAR	28 INCH	1.372	0,7	1.041,0	0,7	759
	SUBTOTAL						**70.027**	**33,7**	**47.440,3**	**31,6**	**677**
	TOTAL						**208.092**	**100,0**	**150.296,3**	**100,0**	**722**

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Image 69: List containing the top 25 sold non-e-bikes in category 4 in NL (October 2020 – September 2021) (GfK, 2020–2021).

BICYCLES Netherlands Panelmarket Oct 20-Sep 21
E-Bikes HITLIST TOP 25

No.	Brandname	MODELTEXT	Model	Type of bike	NUMBER OF GEARS	WHEELSIZE	SALES UNITS	SALES UNITS %	SALES TH.EURO	SALES EURO %	PRICE EURO
1	GAZELLE	GRENOBLE C8 HMB	Dames	E-Bikes	8 GEAR	28 INCH	16.031	4,5	43.530,1	5,0	2.715
2	GAZELLE	PARIS C7 HMB	Dames	E-Bikes	7 GEAR	28 INCH	10.274	2,9	18.607,7	2,1	1.811
3	GAZELLE	ORANGE LIMITED HMB	Dames	E-Bikes	7 GEAR	28 INCH	6.869	1,9	16.292,5	1,9	2.372
4	GAZELLE	ORANGE C8 HMB	Dames	E-Bikes	8 GEAR	28 INCH	6.627	1,9	16.311,0	1,9	2.461
5	GAZELLE	PARIS C7 PLUS HMB	Dames	E-Bikes	7 GEAR	28 INCH	6.405	1,8	13.365,1	1,5	2.087
6	GAZELLE	GRENOBLE C8 HMB	Dames	E-Bikes	8 GEAR	28 INCH	5.372	1,5	14.745,4	1,7	2.745
7	GAZELLE	ORANGE C8 HMB	Dames	E-Bikes	8 GEAR	28 INCH	4.819	1,4	11.951,5	1,4	2.480
8	GIANT	ENTOUR E+ 1 LDS	Dames	E-Bikes	7 GEAR	28 INCH	4.640	1,3	9.014,2	1,0	1.943
9	BATAVUS	FINEZ E-GO POWER	Dames	E-Bikes	8 GEAR	28 INCH	4.612	1,3	12.595,4	1,4	2.731
10	GAZELLE	MISS GRACE C7 HMB	Dames	E-Bikes	7 GEAR	28 INCH	4.589	1,3	9.265,3	1,1	2.019
11	GAZELLE	ORANGE C7+ HMB	Dames	E-Bikes	7 GEAR	28 INCH	4.320	1,2	9.730,6	1,1	2.253
12	GAZELLE	HEAVYDUTYNL C7 HMB	Dames	E-Bikes	7 GEAR	28 INCH	3.926	1,1	8.066,5	0,9	2.055
13	QWIC	PREMIUM I MN7+	Dames	E-Bikes	7 GEAR	28 INCH	3.628	1,0	10.000,6	1,1	2.757
14	GAZELLE	ULTIMATE C8+ HMB	Dames	E-Bikes	8 GEAR	28 INCH	3.018	0,9	8.670,7	1,0	2.873
15	GAZELLE	ORANGE C310 HMB	Dames	E-Bikes	INFINITELY VARI	28 INCH	2.977	0,8	7.715,8	0,9	2.592
16	KOGA	E-NOVA EVO PT	Dames	E-Bikes	8 GEAR	28 INCH	2.920	0,8	10.290,3	1,2	3.524
17	SPARTA	A-SHINE M8B	Dames	E-Bikes	8 GEAR	28 INCH	2.881	0,8	7.318,4	0,8	2.540
18	KOGA	E-NOVA EVO	Dames	E-Bikes	8 GEAR	28 INCH	2.804	0,8	8.971,1	1,0	3.200
19	SPARTA	A-LANE F8E	Dames	E-Bikes	8 GEAR	28 INCH	2.678	0,8	4.861,1	0,6	1.815
20	GAZELLE	ULTIMATE C8+ HMB BELT	Dames	E-Bikes	8 GEAR	28 INCH	2.641	0,7	8.108,4	0,9	3.071
21	BATAVUS	QUIP E-GO EXTRA CARGO	Dames	E-Bikes	7 GEAR	28 INCH	2.639	0,7	5.338,8	0,6	2.023
22	BATAVUS	FINEZ E-GO ACTIVE PLUS	Dames	E-Bikes	7 GEAR	28 INCH	2.601	0,7	6.662,0	0,8	2.561
23	GAZELLE	GRENOBLE C8 HMB CONNECT	Dames	E-Bikes	8 GEAR	28 INCH	2.497	0,7	7.089,0	0,8	2.839
24	PEGASUS	SIENA E7F PLUS	Dames	E-Bikes	7 GEAR	28 INCH	2.406	0,7	5.681,2	0,6	2.361
25	PEGASUS	RAVENNA E8F	Dames	E-Bikes	8 GEAR	28 INCH	2.404	0,7	6.042,2	0,7	2.514
	SUBTOTAL						**114.576**	**32,3**	**280.224,7**	**32,0**	**2.446**
	TOTAL						**354.567**	**100,0**	**876.590,8**	**100,0**	**2.472**

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Image 70: List containing the top 25 sold e-bikes in category 4 in NL (October 2020 – September 2021) (GfK, 2020–2021).

D. Field work

This appendix contains collages created by clustering photographs of the field work based on found characteristics and patters (see section 2.3).

Mounted the wrong way around

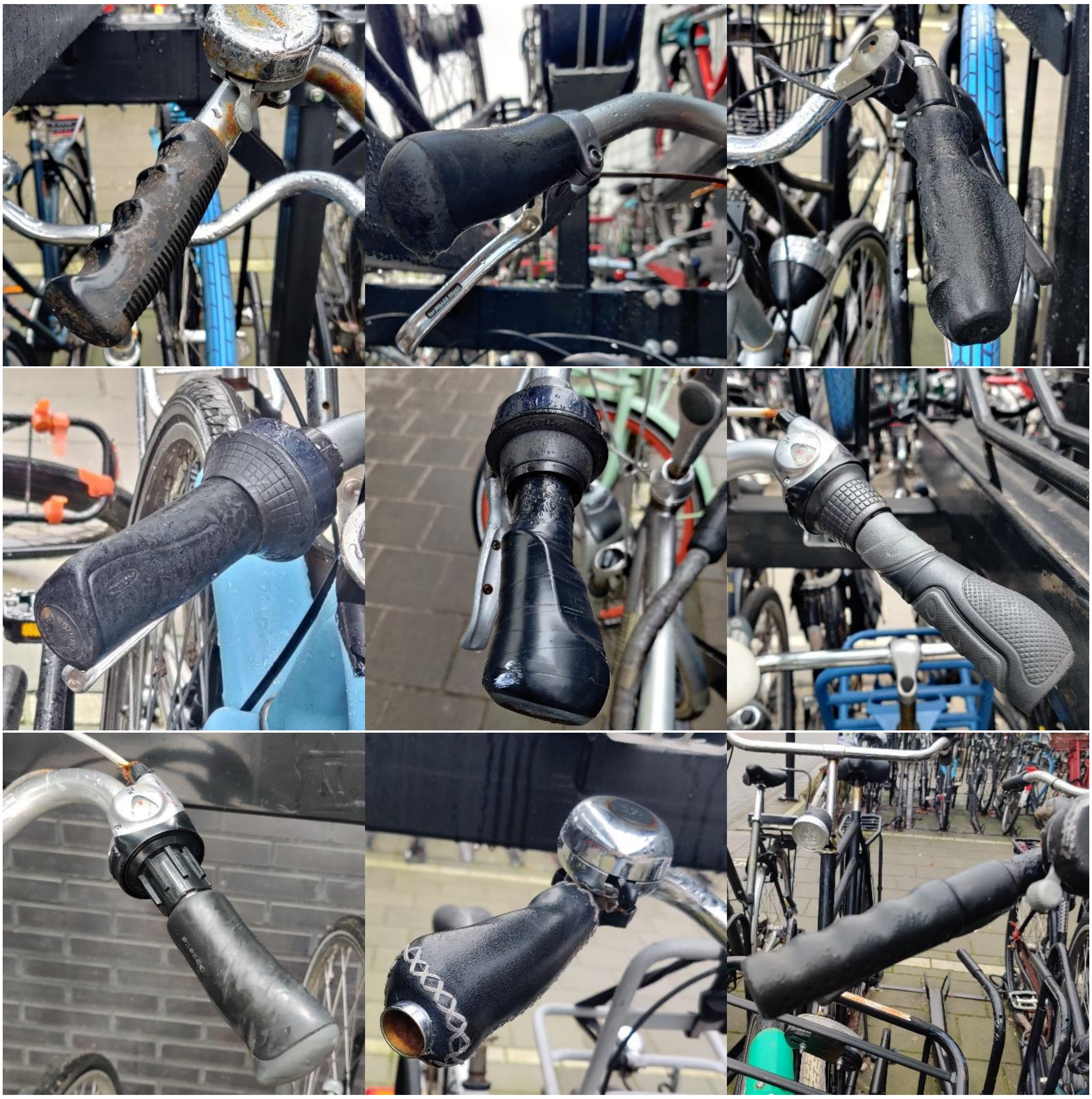
BHGs that are mounted the wrong way indicating a misinterpretation by the user or mechanic.

Dropped palm support

BHGs where the palm support has dropped downward, indicating BHGs are loose and twisted and a lack of knowledge or interest by the user for failing to fix this.

Mounted randomly

BHGs that are rotated randomly, indicating BHGs are loose and twisted and a lack of knowledge or interest by the user for failing to fix this.



Friction wear

BHGs showing surface wear indicating regions of peak pressure.

Damage by bicycle parking

BHGs with similar damage caused by features of the bicycle parking rack.

Impact damage

BHGs with damage caused by impact.

Mould and dirt

BHGs with mould or dirt.

Material decay

BHGs where surface is decaying due to external influences.

E. Survey

This appendix contains the fully transcribed version of the conducted survey (See section 2.4).

Experiences with BHGs

1) **Do you own a bicycle with BHGs (so not a handlebar with handlebar tape like a racing bike)? If you do not own a bicycle with BHGs, you can think back to the last bicycle with BHGs that you rode or had when answering the following questions.**

95.5% of the participants indicate that they own a bicycle with BHGs.

2) **How long have you owned this bike? The answer may be estimated in the number of years.**

Half of the participants have owned their bicycle for less than 3 years. The other half is evenly distributed between 3 and 8 years of ownership with an outlier at 21 years.

3) **What kind of BHGs are mounted on your bike now? Which of the examples in the picture is most similar to your BHGs? Describe the characteristics of your BHGs (shape, material, colour, etc.).**

Image 71: examples of BHGs produced by Widek: (a) ‘Heavy Duty’ (Widek BV, 2020d), (b) ‘Ergoline Tour’ (Widek BV, 2020c) and (c) ‘City Comfort’ (Widek BV, 2020b).

One third of the participants compare their BHGs with example (a) where two of those participants indicate additional features to increase grip and comfort. Two participants say they have BHGs comparable to example (b). Five participants say their BHGs look like example (c) and one of those indicates that the protrusion on their BHGs is smaller.

4) **Are you satisfied with the current BHGs on your bicycle? Justify your answer.**

Almost all participants state they are satisfied with their current BHGs. Reasons mentioned are that their BHGs stay in place, do not cause discomfort, and even feel nice to hold. Some participants indicate they do not cycle long distances and they think this is the reason they never experienced discomfort. Two participants state that they have never thought about discomfort caused by their BHGs or do not set high standards to how their BHGs feel. It was mentioned that the BHGs provide enough grip when being wet and that no material comes off and sticks to the hands.

Some participants indicate they are not satisfied with their current BHGs. They mention that their BHGs are loose and that they experience discomfort when cycling longer distances.

5) **Are you experiencing problems with the current BHGs on your bicycle? Explain these issues.**

Half of the participants indicate that they do not experience any problems with their BHGs. Of the participants that do indicate they experience problems; the majority suffers from loose BHGs. Other problems mentioned are material coming off and sticking to the hands, the experience of pressure peaks on the palm and an incorrect position of the wrists, feeling of numbness in hand and fingers, lack of support and comfort, metal parts that get cold in winter and noticeable wear after a short period of use.

6) **How did the current BHGs end up on your bike?**

Only one participant indicates that their current BHGs did not came with the bike, but that they were mounted on the bike by a bicycle mechanic.

7) **Have you ever bought BHGs (whether or not they are mounted)?**

Only 13.6% of the participants state that they ever bought BHGs.

8) **Where did you buy these handles? And why there?**

Three options are mentioned by participants: requesting new BHGs at the leasing company where they have a monthly subscription, purchasing online and looking for the cheapest option or going to the local bicycle mechanic shop to receive advice.

9) **Have you ever replaced or had the BHGs of a bicycle replaced?**

40.9% of participants state that they ever had their BHGs replaced.

10) **For what reason(s) did you do this, or have it done?**

Some participants state they replaced their BHGs because they were worn out (worn surface finish, material coming loose and being sticky). Another group participants indicate their BHGs coming loose was reason for replacement where one participant even lost their BHGs.

11) **List all the other reasons why you would replace your BHGs.**

The most frequently mentioned reasons by participants for replacing their BHGs are damage to the BHGs, loosening of the BHGs, the BHGs being so worn that friction spots appear, or sticky material coming loose. Less frequently named reasons are experiencing discomfort, reduced grip (both when dry and wet), noticeable pain in hands and wrists and when the BHGs are ugly or do not match with the rest of the bicycle.

12) **Are you satisfied with the range of BHGs at the place where you bought them or would buy them? Justify your answer.**

Half of the participants did not answer this question since they never looked into buying new BHGs. The ones that did answer this question, the majority is content with the range of BHGs, as well as online as in the large sports stores and local bicycle mechanic shop, where they experienced additional service and test options. Participants state that the range of ergonomic options may be increased since they hear nothing but good news, but the prices are still very high. Participants that lease their bicycle indicate they are not able to choose their BHGs when requesting new ones and that those services mostly offer the cheapest options.

13) What were your criteria when choosing between the BHGs offered?

The most important criterium according to the participants is the price of the BHGs. After this comes comfort, appearance and material. Comfort and material are based in initial contact and not extensively tested.

14) What do you think the lifespan of BHGs is compared to other parts and accessories on a bicycle? Justify your answer.

Most participants believe the lifespan of BHGs is longer than the lifespan of other parts and accessories on the bicycle. Participants believe that the BHGs have a longer lifespan than moving parts of the bicycles and that as long as they don't come loose, or the bike falls on them they will last as long as the rest of the bike. Even though some wear is expected, it is the last part that they would replace. Some participants expect the lifespan of BHGs to be similar to inner tubes and saddles, while others mention chains or lighting.

15) What do you think the lifespan of BHGs should be compared to other parts and accessories on a bicycle? Justify your answer.

Over half the participants think the lifespan of BHGs should be similar to that of the bicycle. 25% finds it acceptable to replace BHGs only once during the life of a bicycle. Other participants are satisfied with a lifespan similar to other parts and accessories so everything can be replaced or maintained during periodic service.

Cycling behaviour

16) Describe your cycling behaviour with the bicycle you have described (not a racing bicycle). How often do you cycle? How far are these rides? How long do these rides take?

Almost every participant indicates that they cycle several rides every day (back and forth) but that most of these rides are shorter than 20 minutes. Three participants state that once a week their rides exceed 30 minutes, and two others take regular tours of a couple hours in the weekend.

17) How often do you make bike rides that are longer than 20 minutes?

One third of the participants take bike rides that exceed 20 minutes once a week. 25% indicates that they do this once or twice every month and another 25% say they almost never take bike rides longer than 20 minutes. One participant states they only cycle longer rides in summer, while another does this daily.

18) During or after these longer rides, do you have different experiences with your grips compared to the short rides? Justify your answer.

One part of the participants does not experience differences between short and long bicycle rides. Another group notes that they do experience signs of discomfort on longer rides. The third group realised that they often change their grip during rides, and one participant even rides without their hands on the straights. Another participant stated that they experience numbness in their hand and sometimes even their forearm.

19) **Do you ever experience numbness, tingling or even pain in your hands during or after cycling? If so, describe what symptoms you experience and when they occur.**

Half of the participants indicate that they never experience numbness, tingling or pain in their hands. Some explaining that they cycle often (so are conditioned) or ride mostly without hands. Participants that do experience these symptoms indicate pressure on their wrists and forearms or weary arms and explain this by cold weather or very long rides.

Assessment of existing handles

20) **What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.**

Image 72: Example BHG Widek (Widek BV, 2020d)

Half of the participants indicate they do not find the shape of this BHG interesting and assume it has no ergonomic value. One third states they would not buy these BHGs with most frequently mentioned reason being it looks like they get loose easily. Some participants assume the BHGs are above average resistant to wear, and all price indications are lower than €10 per set. Half of the participants state they would buy these BHGs if the price is low enough, since these BHGs are sufficient for their bicycle use. One participant indicates that the frame, rims and handlebar are the most beautiful and coolest parts of the bike and the BHGs should not distract from the rest of the bicycle. According to them, the BHGs should be functional and discrete.

21) **What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.**

Image 73: Example BHG Widek (Widek BV, 2020c)

Half of the participants indicate they think this BHG has improved comfort and a better fit compared to BHGs with a cylindrical shape. Participants state that it looks like these BHGs come loose easily, and that the material looks like it is very sticky and makes your hands dirty. Lifespan is estimated to be very long, and all price estimates indicate less than €15. Some participants state that the BHGs have a natural or neutral look and that they think the material gives sufficient grip. Others indicate that the weird shape confuses them or makes the BHGs look less pleasant, they also state that the BHGs are too pointy and ugly.

22) **What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.**

Image 74: Example BHG Widek (Widek BV, 2020f)

For almost half of the participants, the function of the bolts on these BHGs is unclear. This makes them hesitant to be positive about the BHGs. The other half understands that the function of the bolts is to fasten the BHGs to the handlebar, solving the problem of BHGs getting too loose. Estimated prices are higher than the previous BHGs. Participants see these BHGs as for a higher segment with a very high lifespan. This is also due to the use of multiple materials and colours. Half of the participants expect these BHGs to be comfortable and to give additional support on the palms. A few think these BHGs are very ugly, and the lines make them look uncomfortable.

23) What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.

Image 75: Example BHG Widek (Widek BV, 2020b).

Half of the participants indicates that these BHGs look comfortable and like they offer support to the palm of the hand. They think the use of multiple colours adds a feeling of quality and the rough surface will provide increased grip. Despite its ergonomic shape, it still has a modest and neutral appearance. This group estimates the price of these BHGs around €20 and thinks they will last long enough.

The other half of the participants indicates they would not buy this BHG because it does not look very comfortable or have no high expectations of its lifespan. They state the material looks less premium and more prone to wear, and that the BHGs look like they get loose quickly. Participants also note that half of this BHG has an ergonomic shape, but the other half is still too geometric.

24) What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.

Image 76: Example BHG Ergon (Ergon Bike Ergonomics, 2021)

Half of the participants state that these BHGs look very comfortable, even for longer rides. But most of those participants indicate they would not purchase these BHGs since they are ugly, associated too much with sport bicycles and are over the top for the use on their city bicycles. The geometric design is seen as futuristic, which both deters as appeals to participants. Some participants do not see the added value of the bar-ends and others indicate they distrust bar-ends since the brake levers are not accessible. The lifespan of these BHGs gets estimated at as long at the bicycle itself, but it is mentioned that the bar-ends look vulnerable to impact since they stick out. Participants think these BHGs are mounted well and do not get loose but estimate their price higher than €35.

25) **What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.**

Image 77: Example BHG SQlab (Hoogstrate, 2018)

Most of the participant think this BHG is very comfortable and sturdy, it looks like they are indestructible and have a very long lifespan. With these BHGs users are able to tackle rough terrain and weather conditions and the user is able to switch between multiple postures. Participants associate these BHGs with expensive and high-end bicycles and think they are mounted very well. Estimated prices vary between €20 and €80, but for most participants this model is over the top for their city bikes. Some participants do not see the function for bar-ends and associate this kind of BHG with people that have special needs or the elderly. Others state that the inner bar-end is thought to be more comfortable than those at the end of a handlebar but note that the metal parts can get cold in winter.

26) What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.

Image 78: Example BHG Ergotec (Ergotec, 2020)

Half of the participants states these BHGs look very comfortable since they clearly provide additional support and multiple hand positions and even the bar-ends have an ergonomic shape. The material and surface finish indicate these BHGs to be the highest quality on the market and able to endure very rough conditions and usage. Most of the participants associate these BHGs with very serious cyclists that take very long rides at high velocity, and thus state these BHGs to be over the top for their use. Due to the multiple parts these BHGs look too complicated and very hard to mount on the handlebar. The price is estimated very high ranging between €40 and €100.

27) **What are your thoughts on, experiences with, and expectations of the BHG in the picture? (Function, shape, material, colour, mounting, price, lifespan, comfort). Would you buy this BHG? Justify your answer.**

Image 79: Example BHG butterfly handlebar (Denham, 2011)

None of the participants state they would purchase these handlebars for their current bicycle use, but some would consider them if they rode exceptionally far or long tours. One third of the participants associate these handlebars with elderly users or very specific situations and bicycles. These handlebars require a lot of modification to current systems on the handlebar and participants have some trust issues regarding the stiffness of this handlebar. Participants also state these handlebars are too bulky and due to the great amount of possible hand positions the brake levers are not always accessible. The foam sleeve of these handlebars gets wet and soggy in the rain and is very prone to wear and ripping. This increases the need for periodic maintenance and is not very sustainable for both the environment and the user's wallet. On top of that, these handlebars are estimated to have a very high purchase price.

F. Problem list

This appendix contains a description of the selection process for the order of the problem list in section 3.1.

The problems are listed below and their corresponding letters, with which they are indicated in images 80 and 81.

A. Pressure peaks
B. Incorrect wrist position
C. Loosening of BHGs
D. Misinterpreted features
E. Unappealing appearance
F. Surface finish and material – Weathering
G. Surface finish and material – Wear
H. Surface finish and material – Temperature
I. Surface finish and material – Impact
J. Price
K. Testing / range
L. Type of buyer

The problems are placed into the matrices based on the importance, urgency, impact, and effort of finding and implementing a solution. Importance looks at the magnitude of the value of a solution to the problem in question, while urgency describes in what timeframe action is needed. The impact is the size of the effect of the applied solution, and effort describes the time and work that is needed to develop and implement a solution.

The problem list ranked by priority is as follows:

A. Pressure peaks
B. Incorrect wrist position
C. Loosening of BHGs
L. Type of buyer
D. Misinterpreted features
J. Price
H. Surface finish and material – Temperature
K. Testing / range
E. Unappealing appearance
F. Surface finish and material – Weathering
I. Surface finish and material – Impact
G. Surface finish and material – Wear

The problems that have proven not to be solved within the scope of this project have been marked red. The R&W concerning these problems will be separated in the LoR to ensure this project will be completed within the scheduled time.

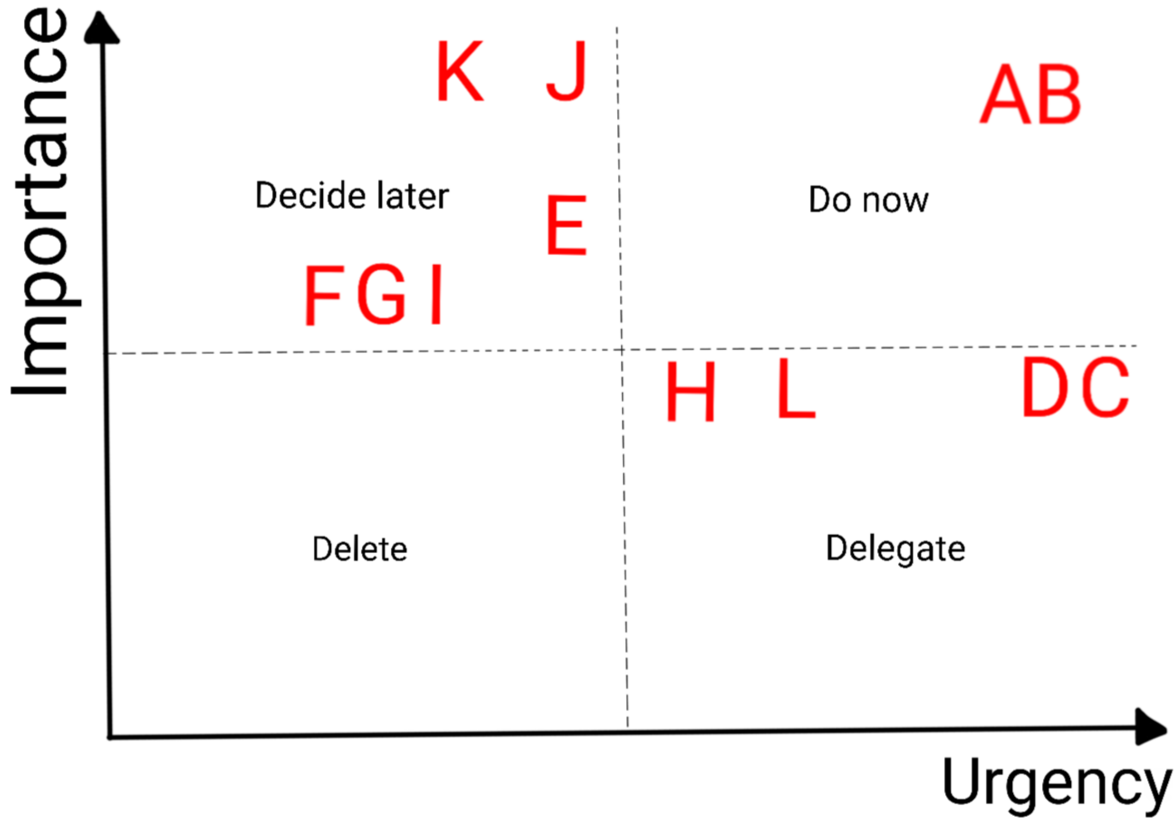


Image 80: Eisenhower matrix displaying the importance and urgency of solving the found problems.

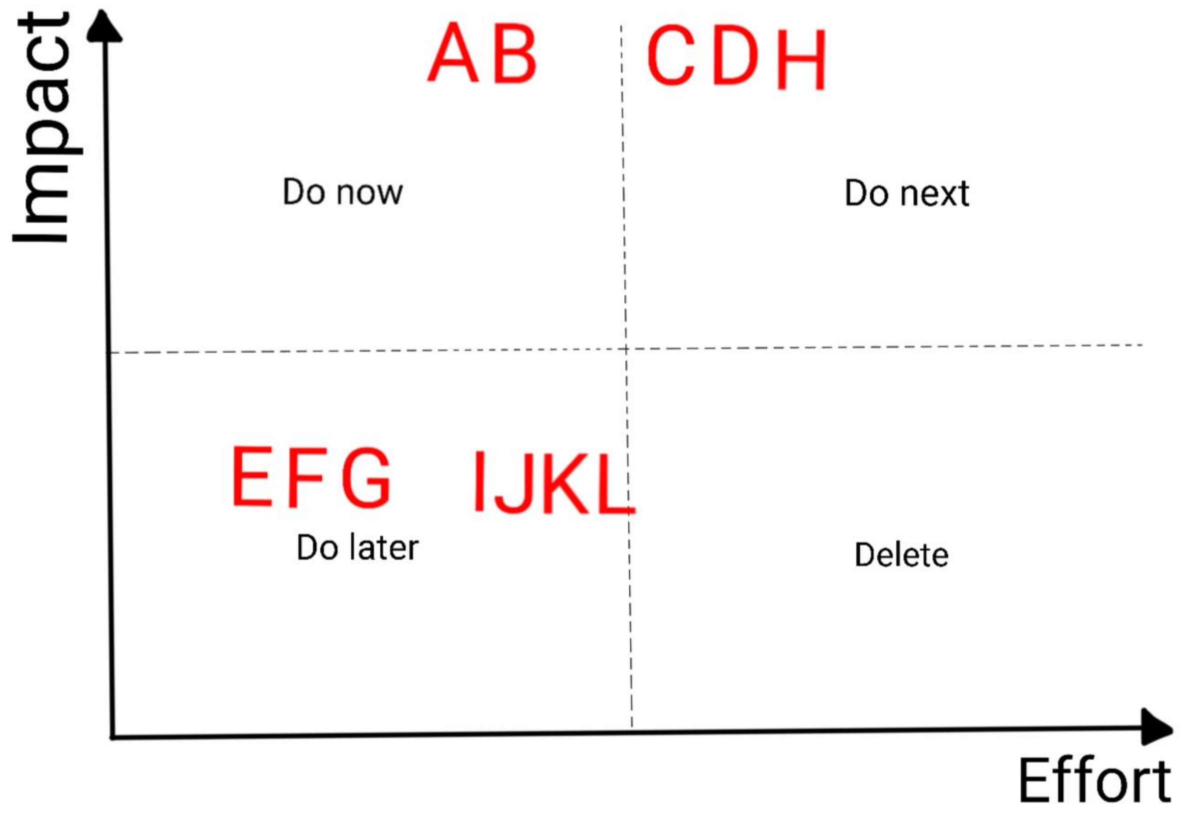


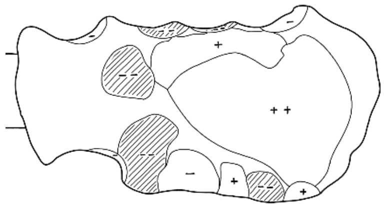
Image 81: Prioritisation matrix displaying impact and effort of solving the found problems.

G. Morphology

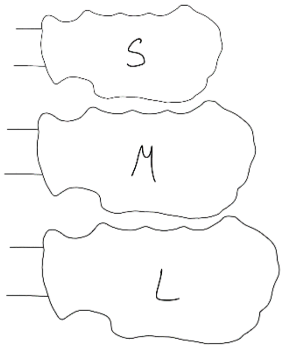
This appendix contains the morphological overview of the generated solutions to the listed problems in section 3.1.

Pressure peaks

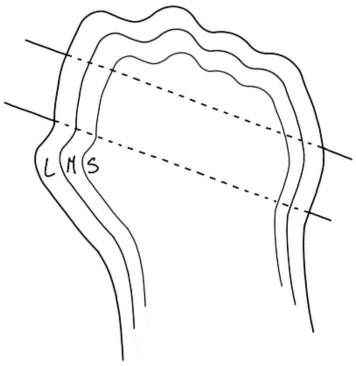
Shape BHG exactly after hand



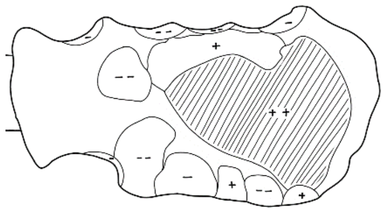
Include softer materials at low discomfort threshold regions



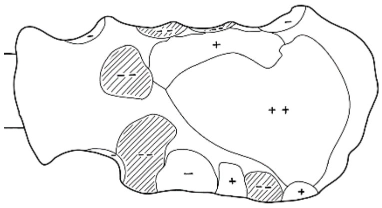
Make size categories (S/M/L) in accordance with available bicycle sizes



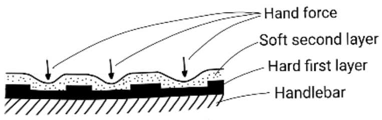
Make one general shape for all hand sizes



Add peaks at regions with high discomfort threshold

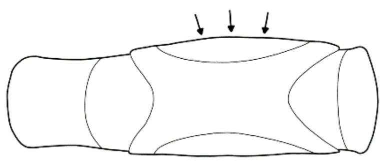


Add cavities at regions with low discomfort threshold / Focus on low threshold areas since those feel discomfort and pain first



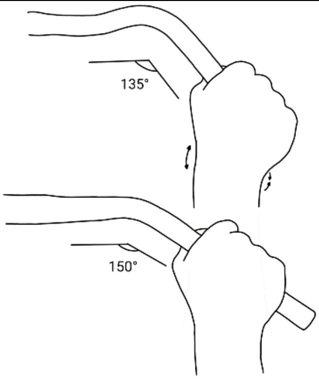
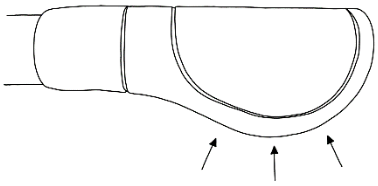
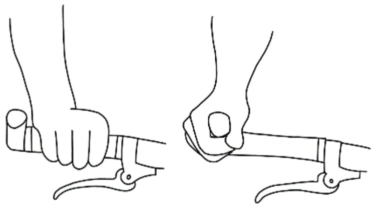
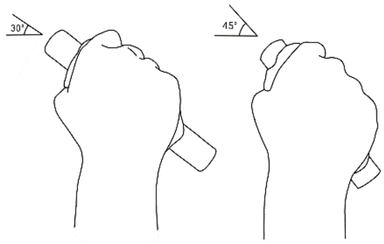
Cavities in first layer with a thin second layer on top so you feel the holes but not see them

First sight and first moment of touch must convince the buyer

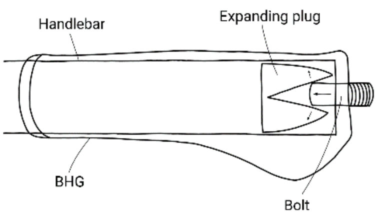
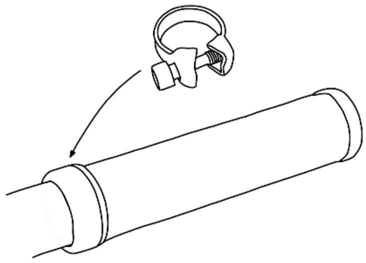
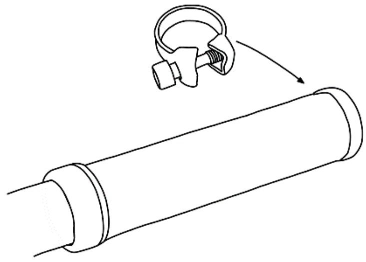
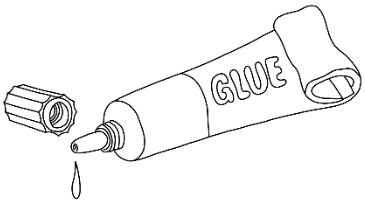
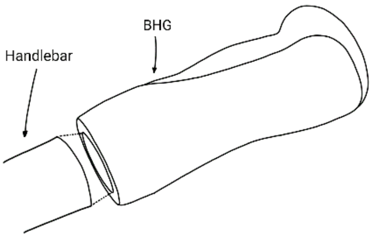
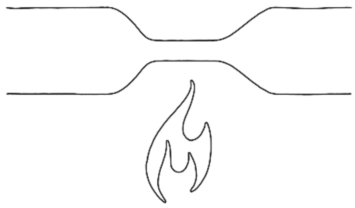
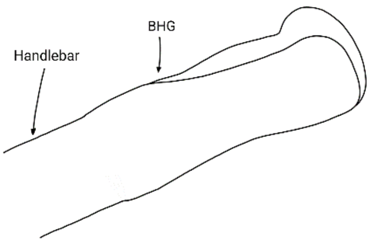
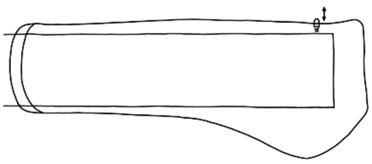
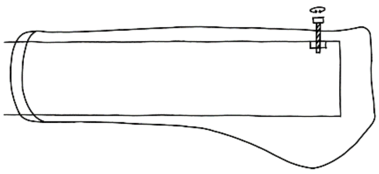
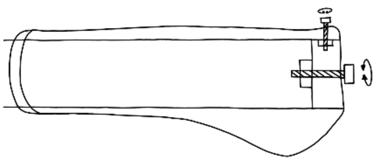
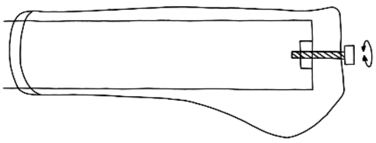


Bulge at fingers: middle finger and ring finger

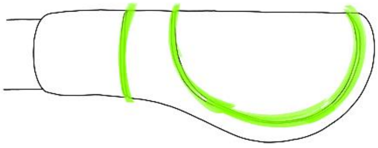
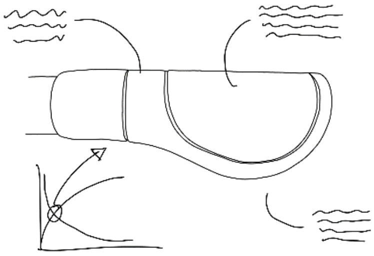
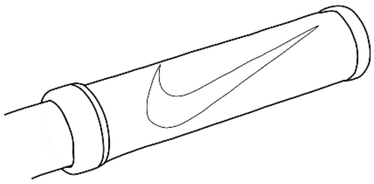
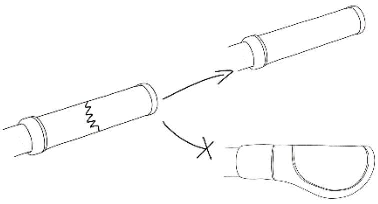
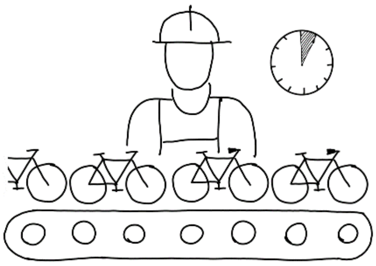
Incorrect wrist position

 Handlebar curve	 Palm support to prevent sagging wrist
 Multiple possible hand positions	 Focus BHG design on 1 specific handlebar angle (30° or 45°)

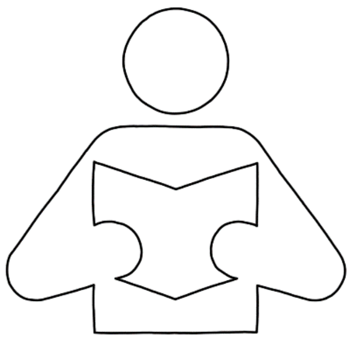
Loosening of BHGs

 Plug fastener in handlebar	 Clamp ring inside	 Clamp ring outside
 Glue / adhesive	 Friction: difference in diameter (BHG smaller than handlebar)	 Friction: Heat shrink tubing
 Incorporate BHG design into handlebar	 Spring-loaded push button	 Angle bolt
 2 bolts: one for securing fastener to handlebar, other one for securing BHG to fastener. This way error margin is smaller	 Axial bolt into threaded hole inside handlebar end	

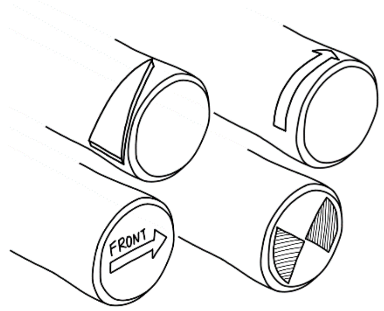
Type of buyer

 Use unique selling points to differentiate from competition	 Market scientific research and findings	 Include options to adopt brand identity (OEM)
 When BHG needs replacement, consumer tends to purchase something similar to the original	 Do not deviate from standard / current installation method (factory speed)	

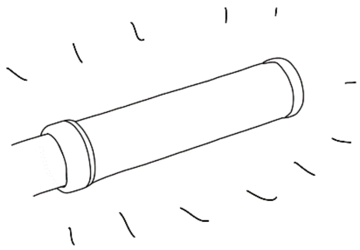
Misinterpreted features



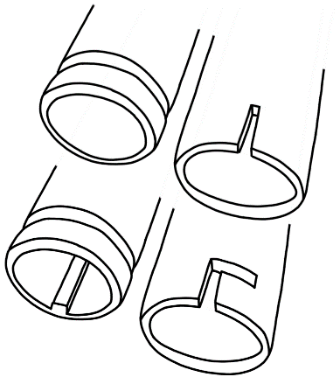
Installation manual



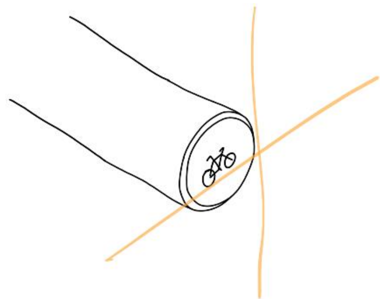
Use cues (arrow, colour, shape) for all misinterpretable functions



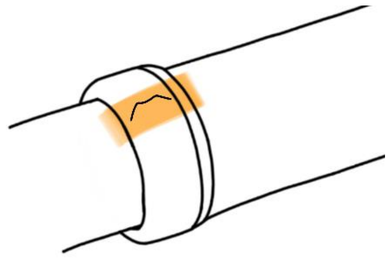
Minimise number of extended features



Only one possible installation fit

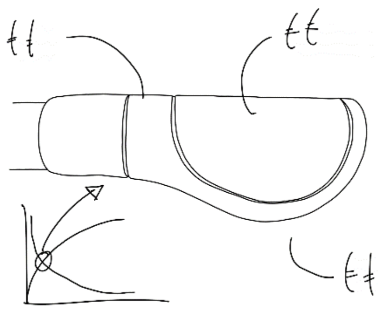


Bicycle icon on BHG end cap that indicates correct orientation

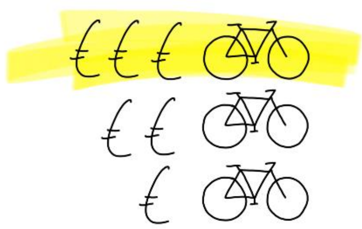


Handlebar icon on BHG that indicates correct orientation

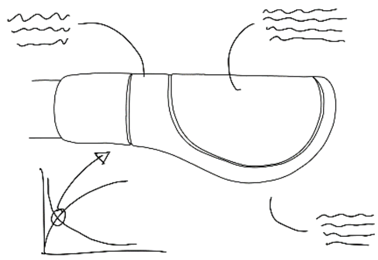
Price



Clarify reasoning behind price

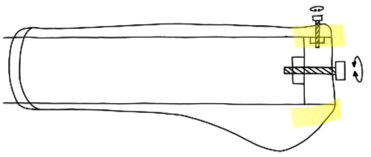
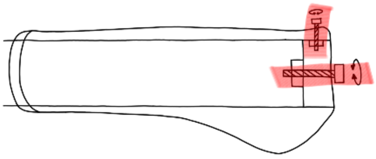
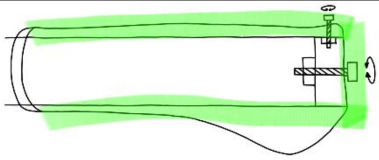


Focus on bicycles in line with price category (upper segment)

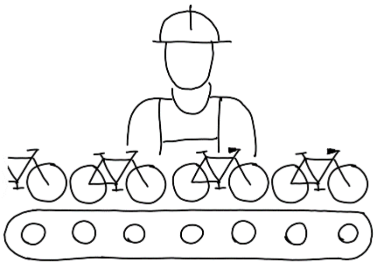
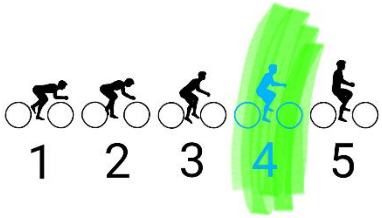
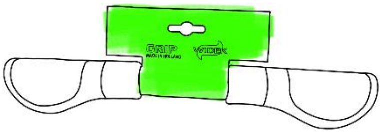


Clarify features / options / unique selling points

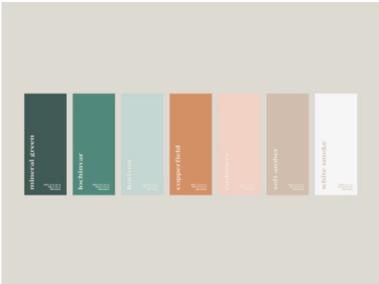
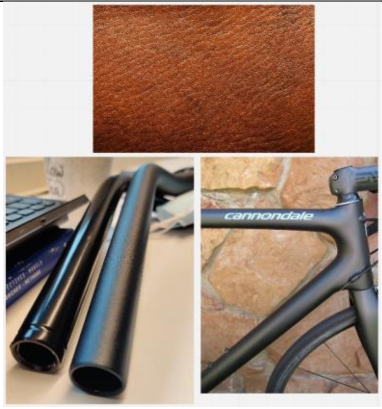
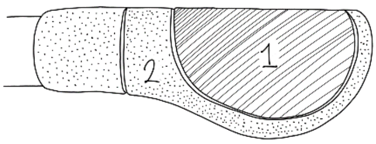
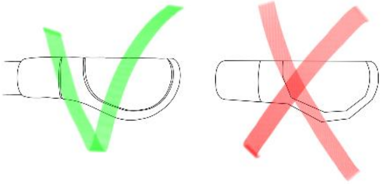
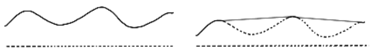
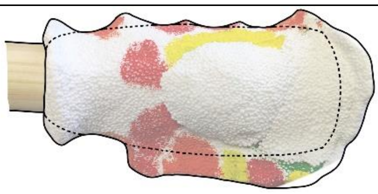
Surface finish and material (temperature)

 Make sure all metal parts (fasteners) are built-in and enclosed by insulating material	 Non-metal fasteners
 No fastener - no heat conducting material	 Extra layer of high-comfort finish material

Testing / range

 Include concept on factory bicycles (OEM)	 Emphasize use and target bicycle	 Salient packaging

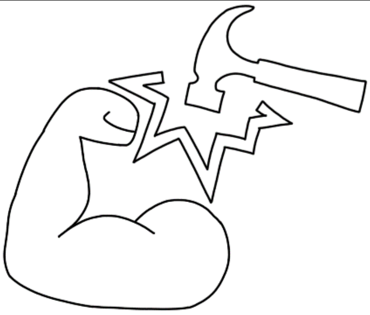
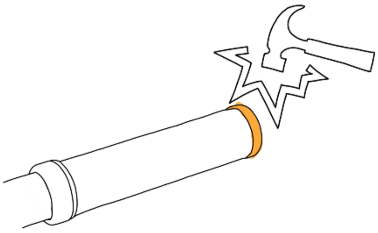
Unappealing appearance

 Use neutral colour(s)	 Do not use more than 2 colours	 Use material (finish) that is associated with high quality
 Do not use more than 2 materials	 Use organic shapes (exclude geometric shapes and angles)	 Make holes instead of bulges
 Flatten out protruding points		

Surface finish and material (weathering)

 Increase material resistance to corrosives

Surface finish and material (impact)

 Increase impact resistance	 Place impact-resistant part on end of BHG

Surface finish and material (wear)

 No surface texture - no noticeable wear	 Make surface texture of wear-resistant material

H. Anthropometrics

Frame size

This appendix contains research on the anthropometrics regarding BHG and bicycle frame sizes (see subsection 'Additional findings' in section 3.3). All definitions and images in this appendix are taken from anthropometrics website Dined (TU Delft, 2022).

First the body measurements regarding bicycle frame size are investigated. The dimensions concerned are stature (vertical distance from the floor to the top of the head (vertex)) and crotch height (vertical distance from the floor to the distal part of the inferior ramus of the pubic bone) (see image 82). When comparing these measurements, it appears that there is no linear relationship between stature and crotch height, meaning both these measurements must be used for selecting the correct bicycle frame size (see image 83).

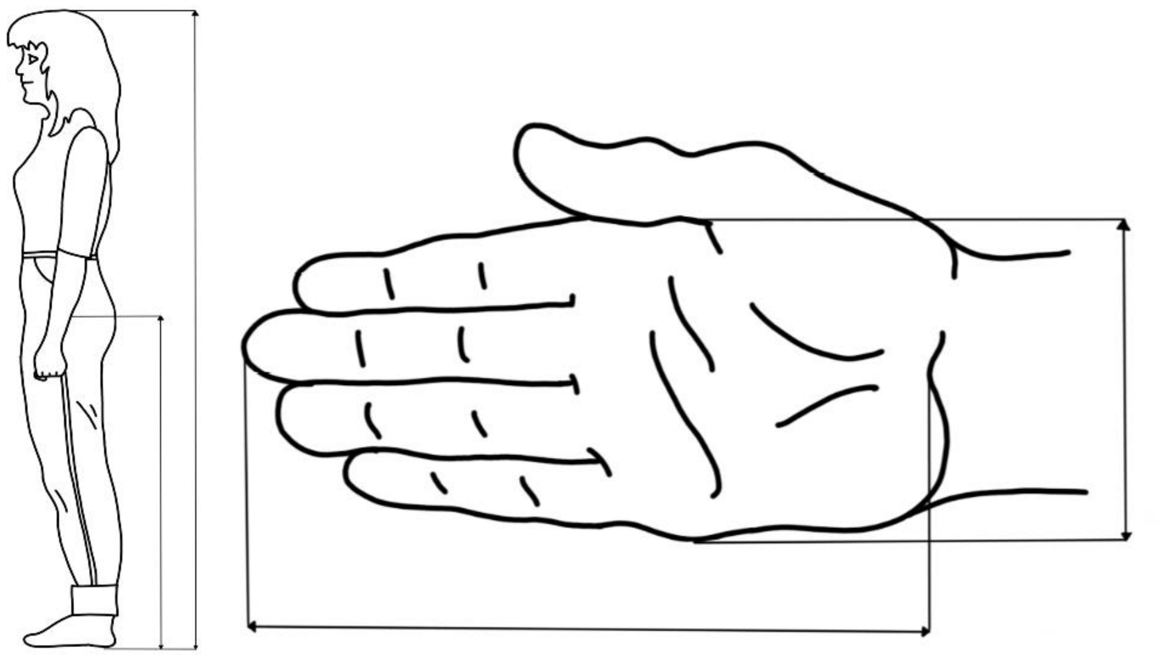


Image 82: Visualisation of the measurements (left) stature and crotch height, (right) hand length and hand width (TU Delft, 2022).

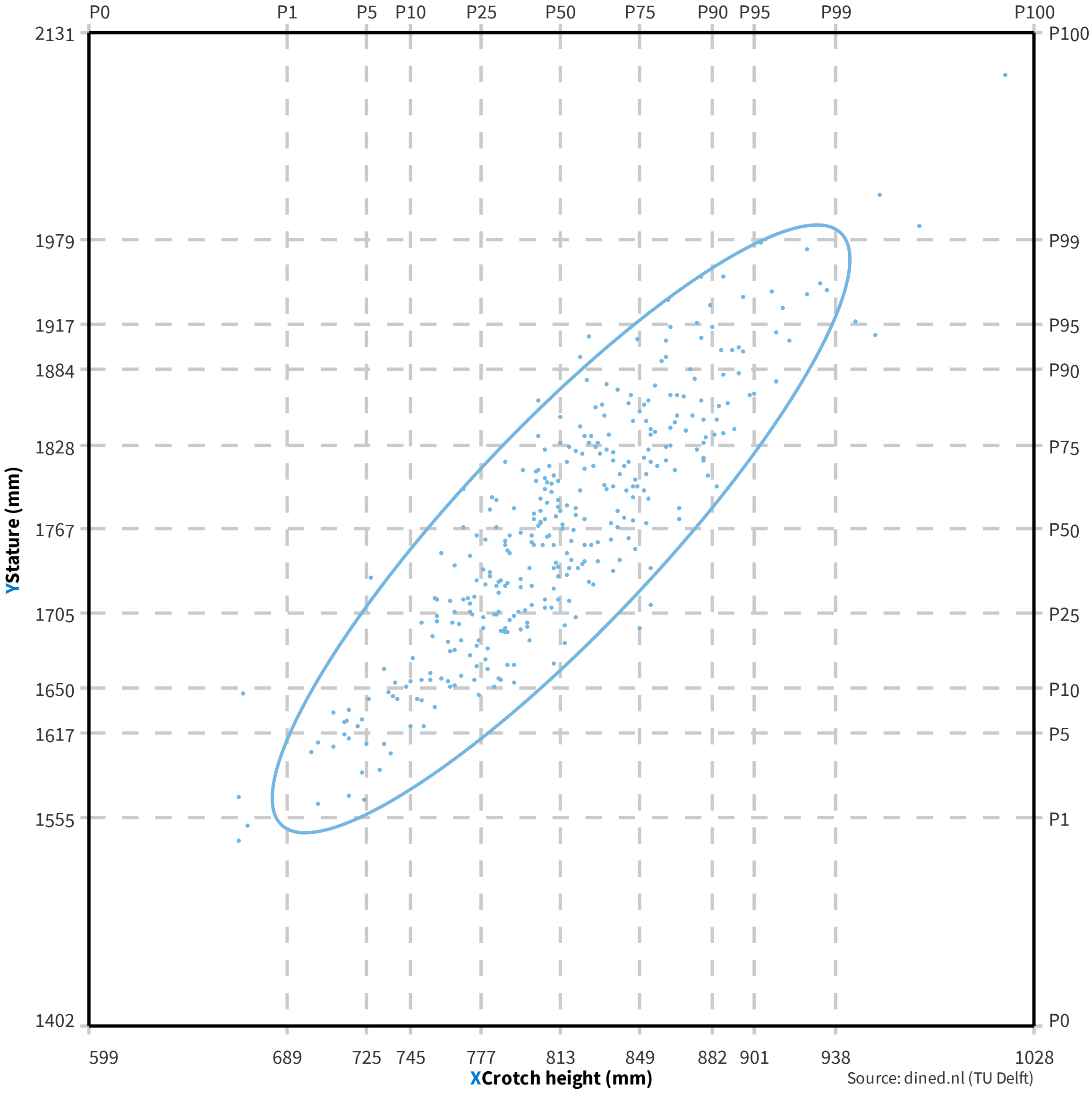


Image 83: Measurements stature and crotch height plotted (DINED, 2016).

Next, the body measurements regarding BHG size are investigated. The dimensions used here are hand length (The distance from the wrist crease to the tip of the middle finger, parallel to the fingers) and hand width (The distance from the radial to ulnar side of the hand, measured at the distal extremities of the metacarpals) (see image 82). This comparison proves that there is also no linear relationship between hand length and hand width, meaning both measurements must be used for selecting the correct BHG size (see image 84).

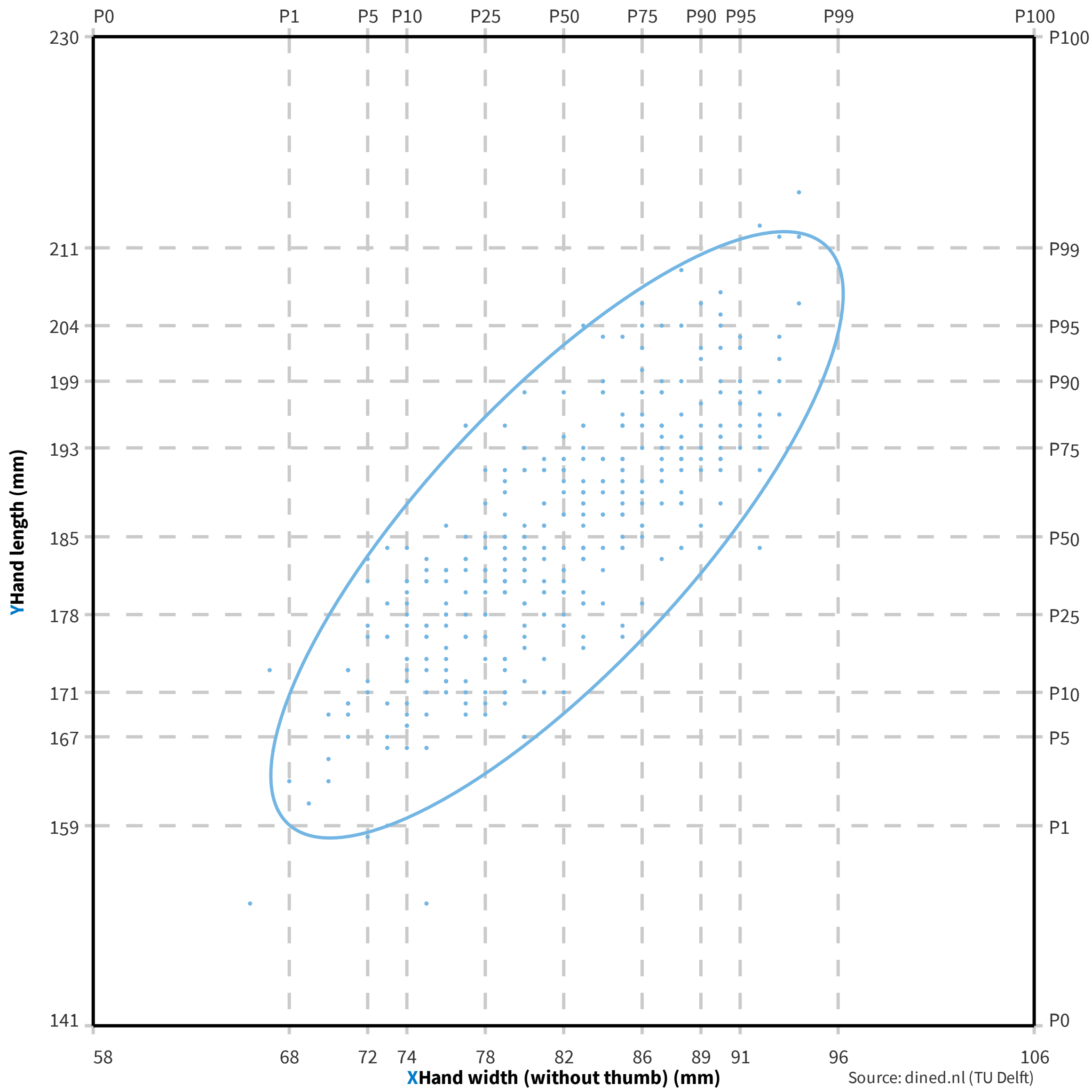


Image 84: Measurements hand length and hand width plotted (DINED, 2016).

Then, the two BHG measurements are compared to the frame size measurements. This resulted in four different plots: hand width x stature, hand width x crotch height, hand length x stature and hand length x crotch height (see images 85, 86, 87 and 88). These comparisons prove that there is no linear relationship in any of the situation, meaning that BHG cannot be related in any way to bicycle frame size.

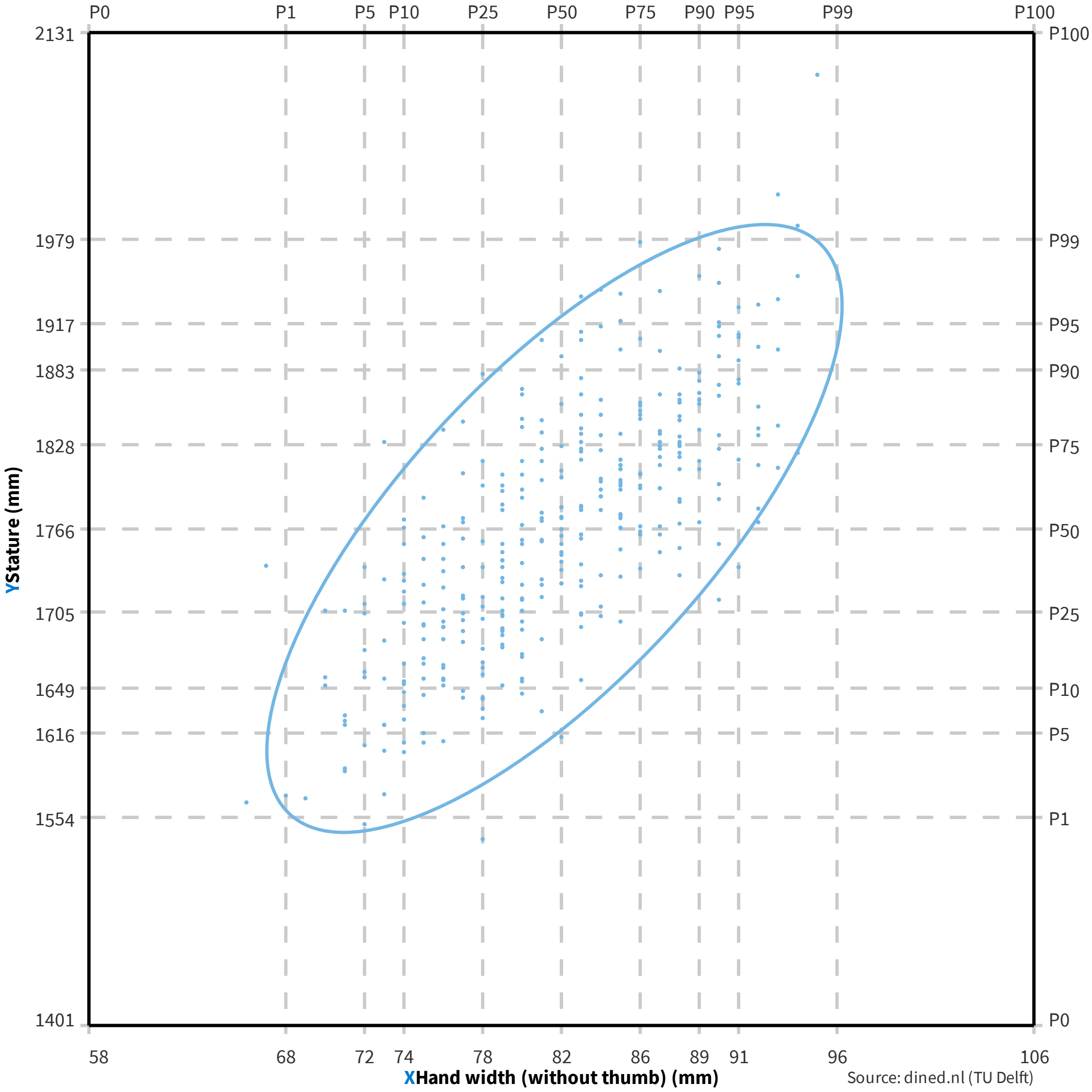


Image 85: Measurements hand width and stature plotted (DINED, 2016).

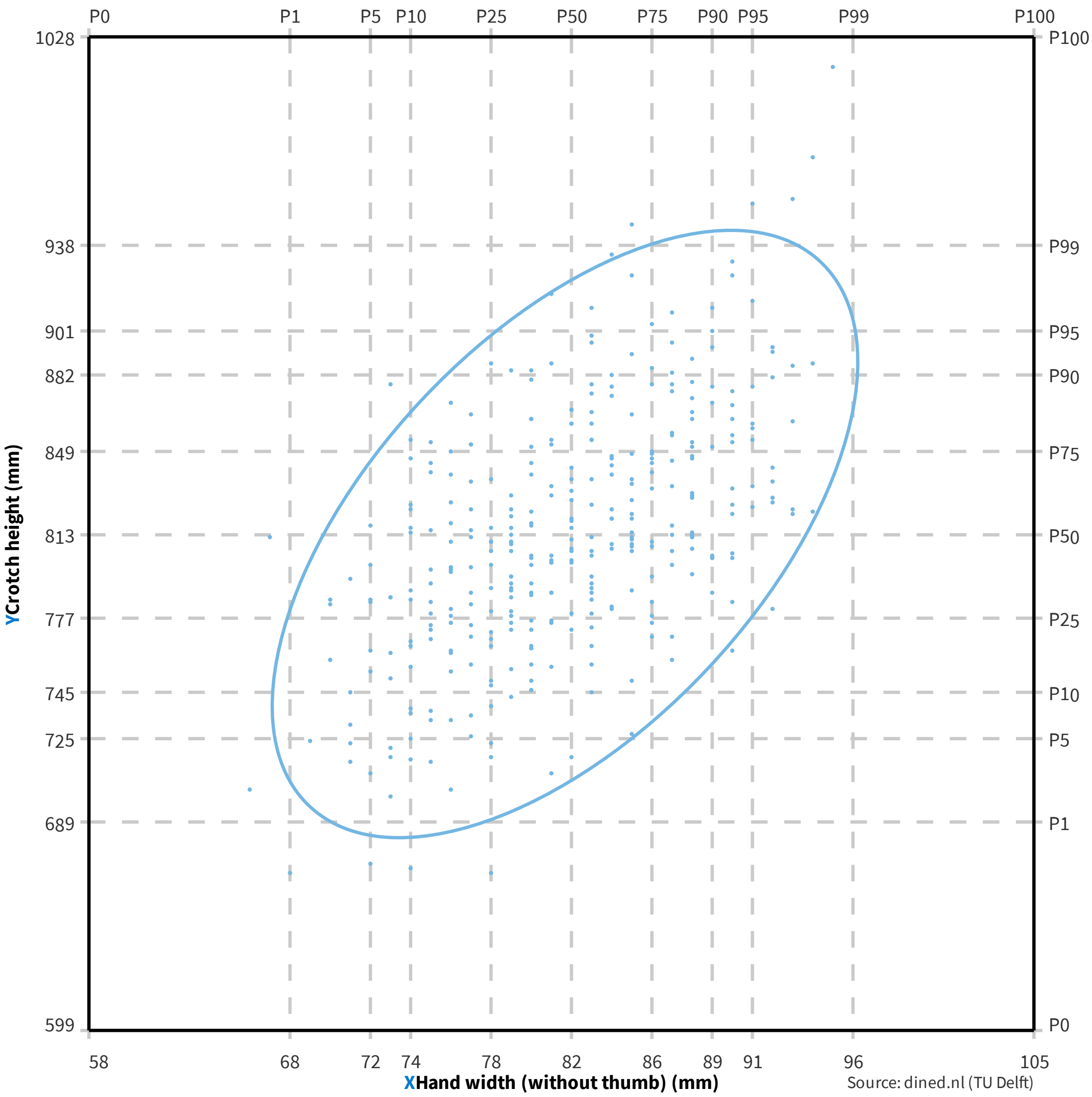


Image 86: Measurements hand width and crotch height plotted (DINED, 2016).

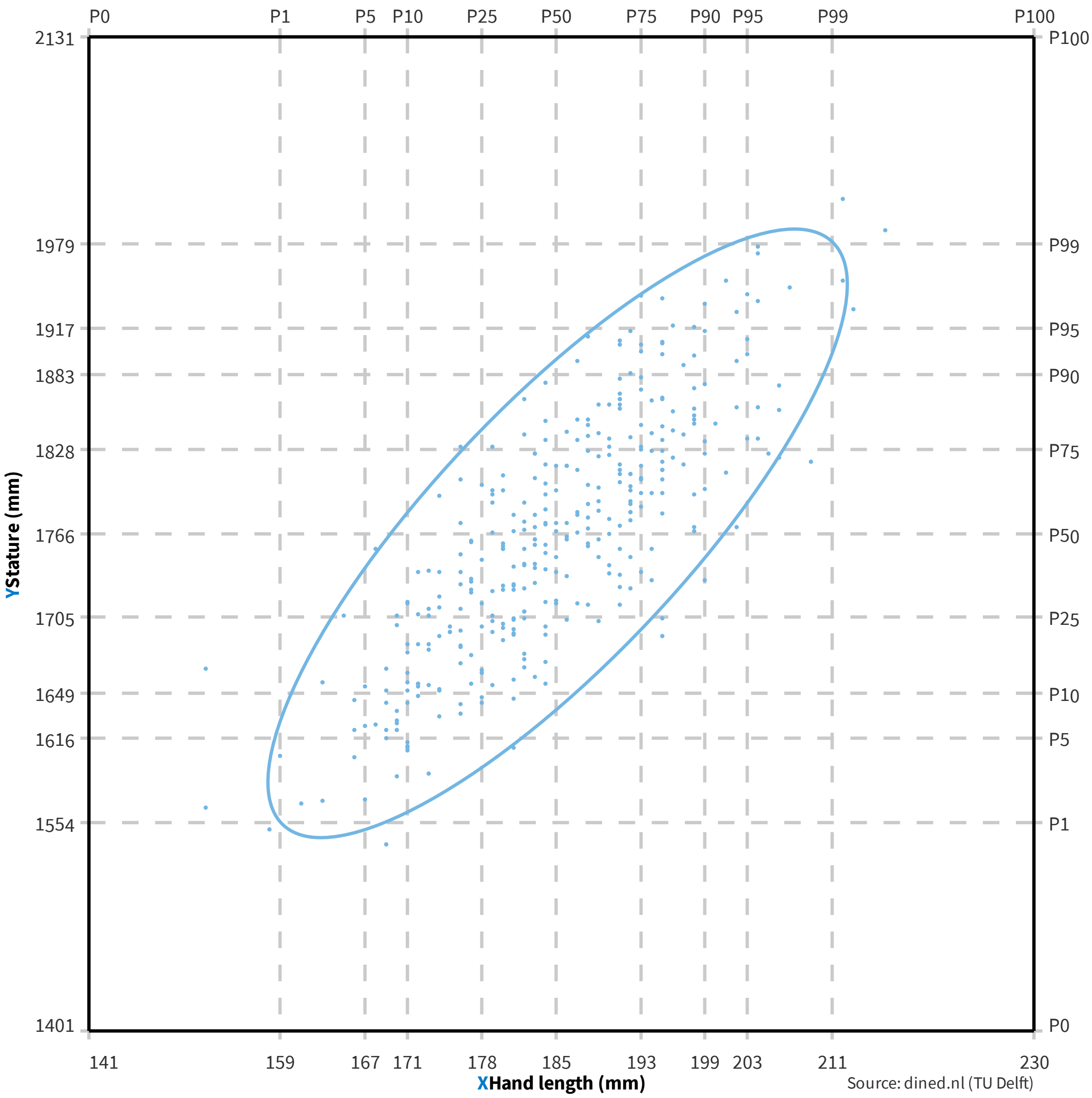


Image 87: Measurements hand length and stature plotted (DINED, 2016).

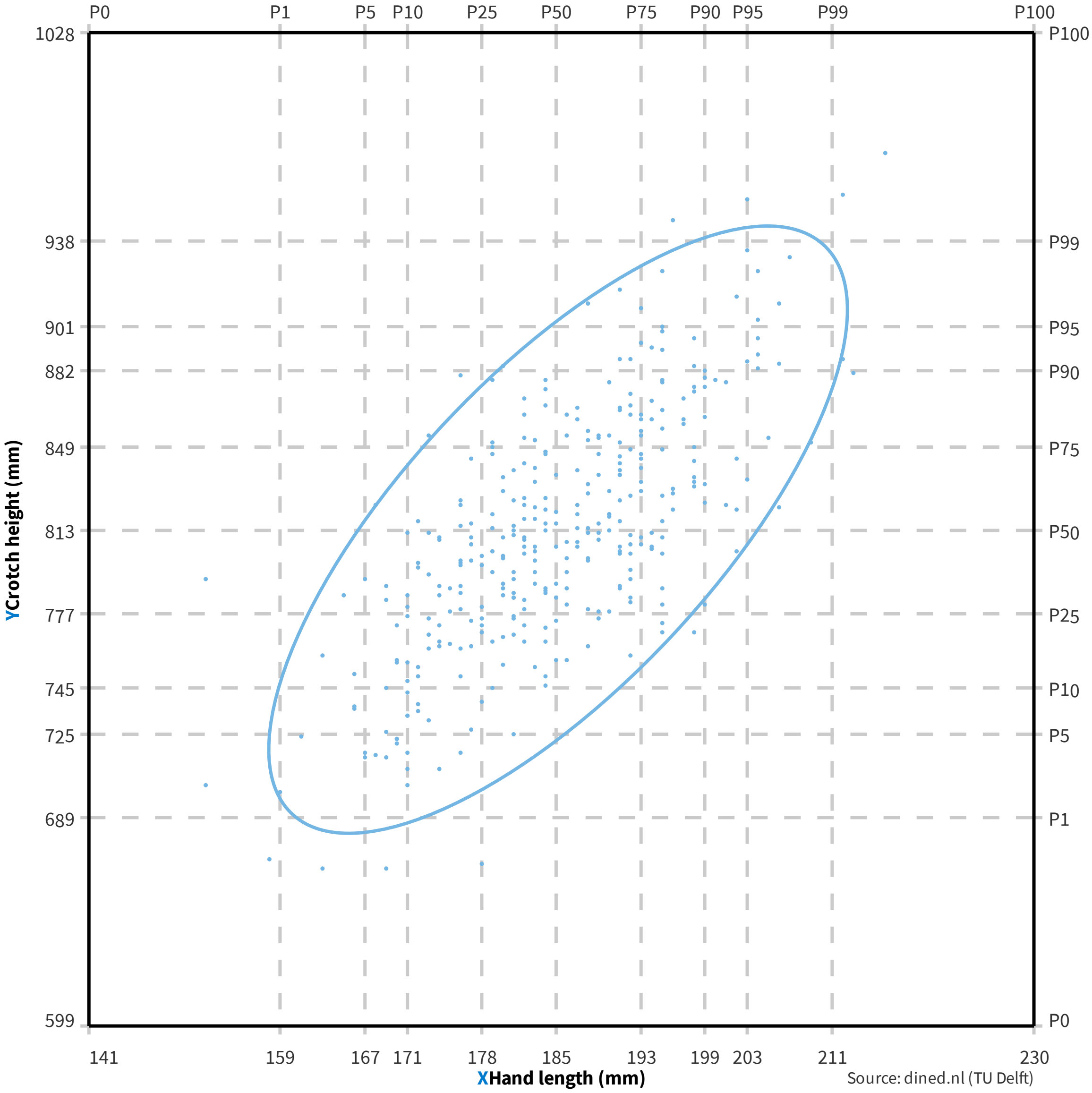


Image 88: Measurements hand length and crotch height plotted (DINED, 2016).

Female male

This appendix contains research on the anthropometrics regarding female and male hand sizes (see subsection 'Additional findings' in section 3.3). All definitions and images in this chapter are taken from anthropometrics website Dined (TU Delft, 2022).

First, hand length and hand width of both females and males are plotted. These plots are then superimposed to visualise the differences between females and males (see image 89).

Comparing these measurements shows that there is a difference between female and male hand sizes, but that the differences between the outliers and the average are so little that the disadvantages (higher production cost, machine adjustments per size, different packaging and marketing and potential errors by users and mechanics) outweigh the advantages (a BHG that fits just a little bit better for the outliers).

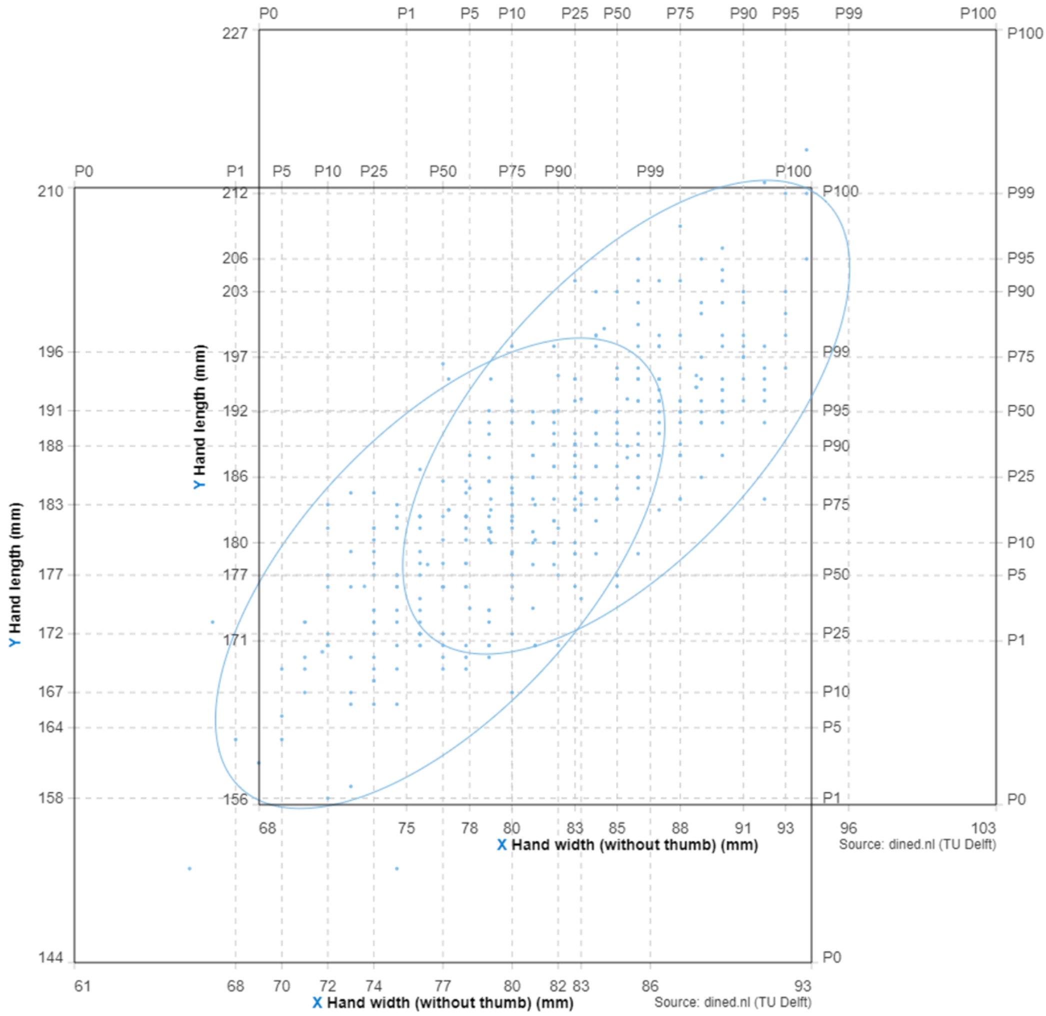


Image 89: Visualisation of the differences between females and males by superimposing their respective hand length and hand width plots (DINED, 2016).

I. Geometry

This appendix contains an overview of the geometry of the most sold category 4 bicycles.

Table 6: An overview of the most popular category 4 bicycles and their geometry (Giant bicycles, 2022; Koga, 2022; Koninklijke Gazelle, 2022a, 2022b) (Qwic customer service, personal communication, December 7, 2021).

		Gazelle Orange	Gazelle Grenoble	Giant Entour	Qwic Premium	Koga E-Nova	**Average**
A	Size [mm]	530	530	500	490	542.5	**518.5**
B	Top tube length [mm]	582	593	590	588	576	**585.8**
C	Head angle [°]	68.5	68.5	70	70.5	70.5	**69.6**
D	Seat tube angle [°]	69.5	69.5	72	71.5	73.3	**71.2**
E	Chainstay length [°]	482	482	470	464	476.8	**475**
F	Bottom bracket drop [mm]	60	60	60	65	69	**62.8**
G	Head tube length [mm]	165	165	160	165	180	**167**
H	Fork offset [mm]	55	55	43	42	45	**48**
I	Wheelbase [mm]	1120	1120	1105	1082	1102	**1105.8**
J	Stack [mm]	640	640	630	658	688	**651.2**
K	Reach [mm]	354	354	385	368	363	**364.8**

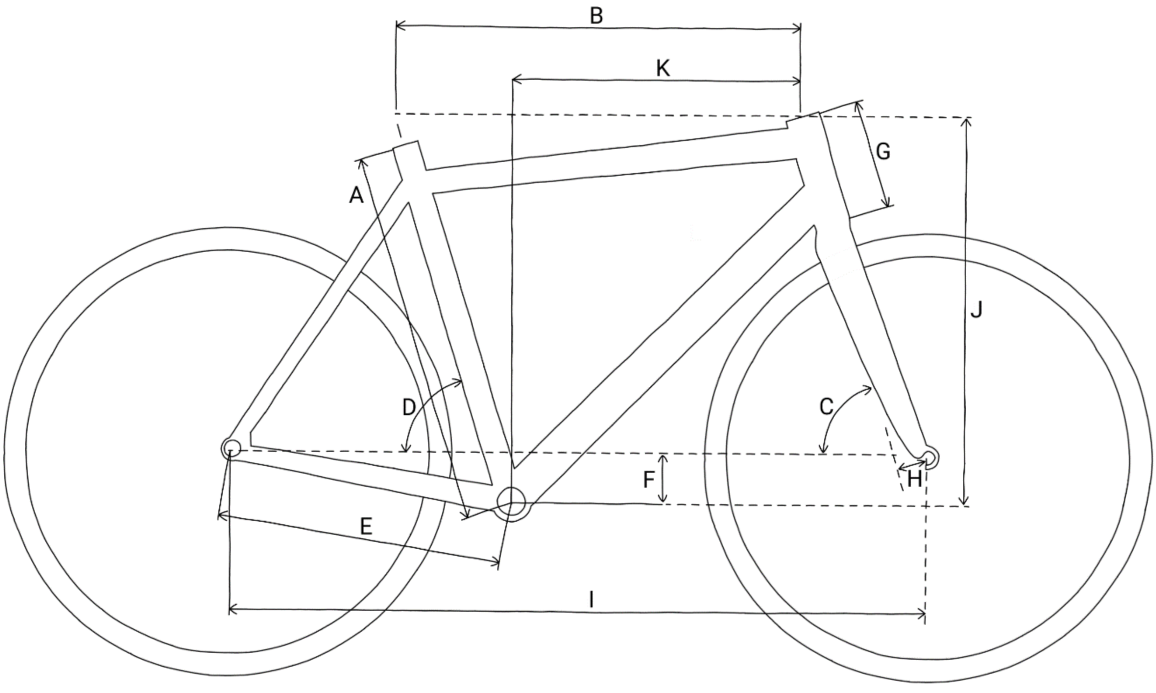


Image 90: Visualisation of the used dimensions and their locations on the bicycle.

J. Concept assessment

This appendix contains the fully transcribed version of the concept assessment interviews (see section 3.4).

Demographics

1) Gender at birth

50% of the participants indicate that they are male, the other 50% indicate that they are female.

2) Age

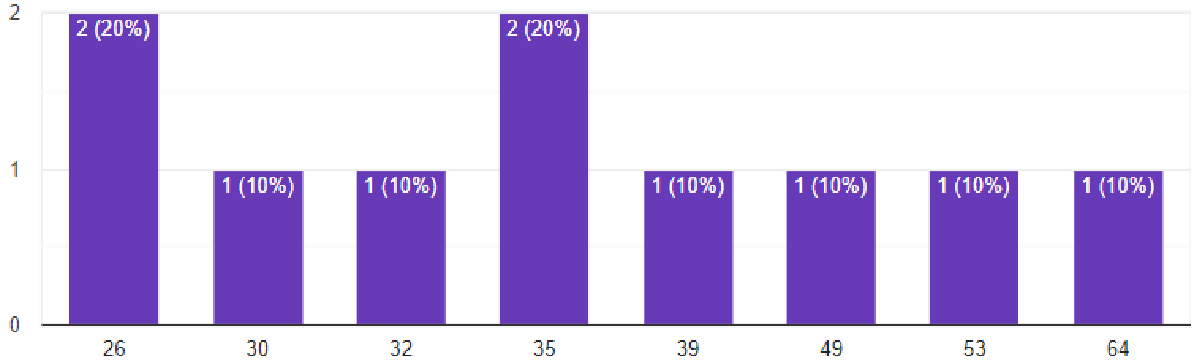


Image 91: Visualization of the age distribution of the participants

3) Hand length and hand width

Table 7: Hand lengths and hand widths of the participants.

Hand length [mm]	Hand width [mm]
210	96
189	84
199	93
181	82
194	81
191	78
193	86
186	83
172	75

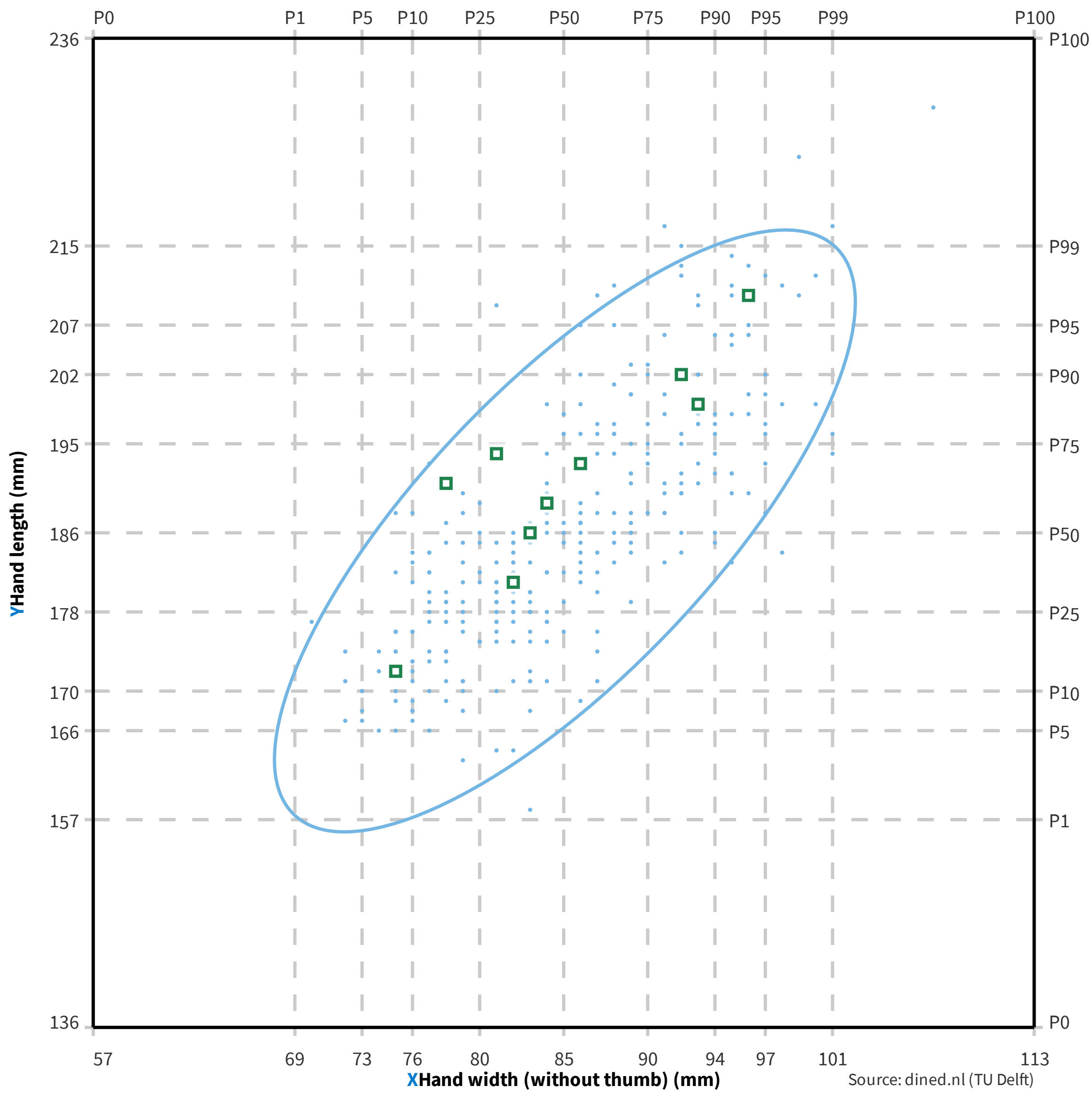


Image 92: Visualisation of the hand length and hand width of the participants compared to the hand length and hand width of the Dined 2004 Dutch adults 20-60 mixed dataset (Dined, 2004).

All three concepts (I)

4) Which concept do you like best? And why?

70% of the participants indicate concept 1 as the best looking. Given reasons for this are that it is seen as most traditional and associative with existing BHGs. They also think Concept 2 does not look like a BHG, that is looks like the region 1 bump is higher than on concept 1 or that the diameter of concept 2 looks too big.

20% of the participants choose for concept 3 as they distrust the region 1 bump and recognise the region 2 + 3 wing.

10% choose concept 2 with the reason that without the region 2 + 3 + 4 protrusions it has the calmest look.

5) Which concept do you think is the most comfortable? And why?

70% of the participants say concept 1 looks the most comfortable because of the wide region 2 + 3 wing, it seems to them this design will offer the most support. They also find this concept looking similar to the current BHGs on their bicycles.

30% of the participants indicate they expect concept 3 to be the most comfortable. Reason is that it has the most pronounced and recognisable shape, which is associated with a higher level of comfort because it looks like more thought went into the design.

6) Which concept do you think is the least comfortable? And why?

70% of the participants state they believe concept 2 looks the least comfortable. The main reason is that a region 2 wing is expected to be needed for the highest level of comfort. Another reason is that the region 1 bump looks a lot higher than at concept 1.

20% of participants designate concept 3 as looking the least comfortable because the shape of the wing (regions 2 + 3 + 4) looks too big and exaggerated.
Only 10% of the participants choose concept 1 as looking the least comfortable.

Concept 1

7) On a scale from one to ten, what do you think of the look of this concept?

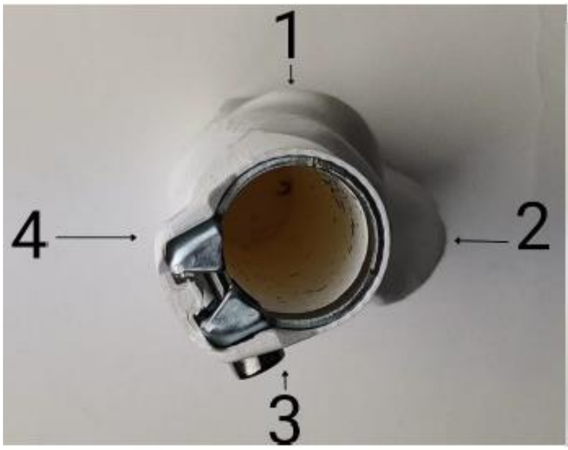
The average score for the look of concept 1 is 7.5/10 (SD = 1.08).

8) On a scale from one to ten, what do you think of the comfort of this concept

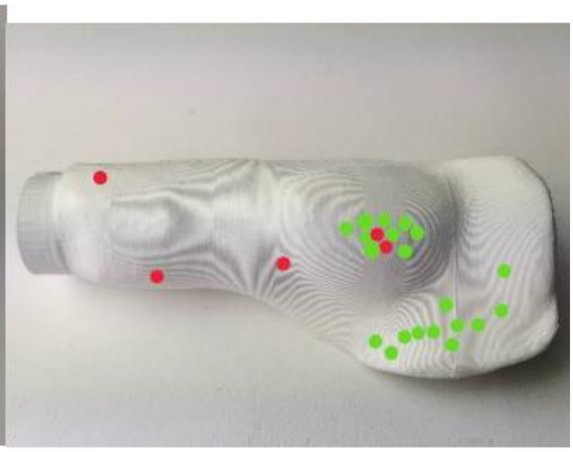
The average score for the comfort of concept 1 is 7.4/10 (SD = 1.82).

9) Indicate your favourite and least favourite area on this concept.

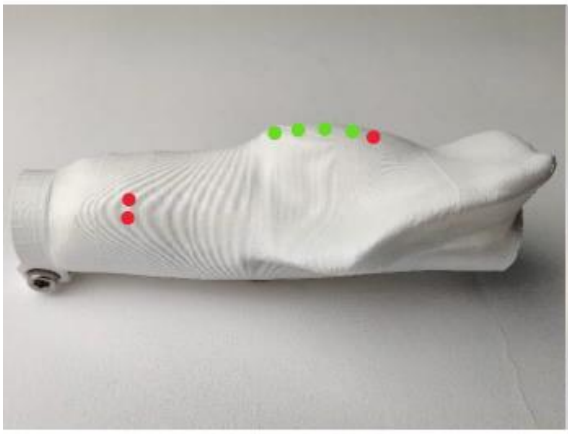
Concept 1



View 1



View 2



View 3

View 4

View 5

Concept 2

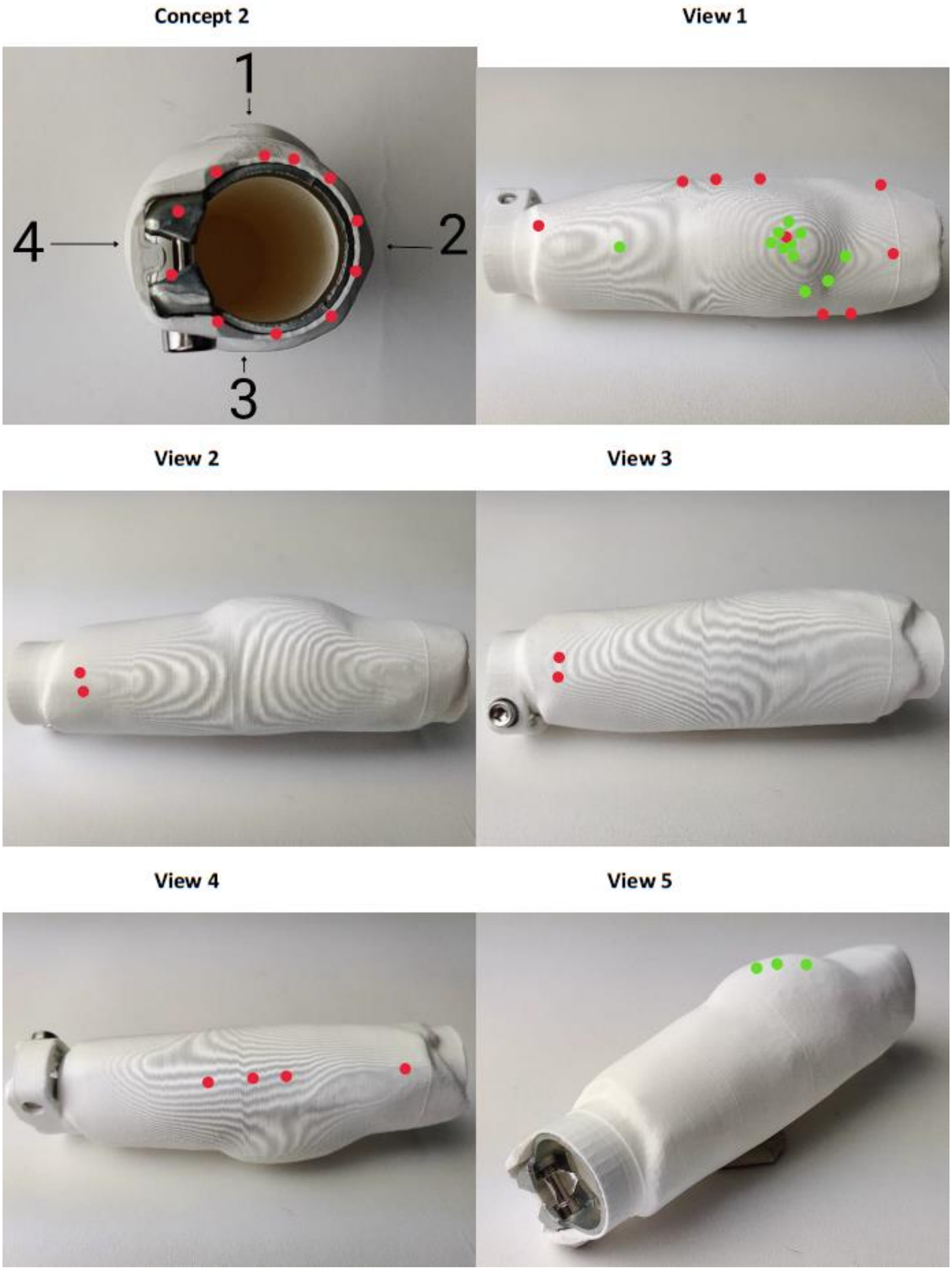
10) On a scale from one to ten, what do you think of the look of this concept?

The average score for the look of concept 2 is 6.4/10 (SD = 0.97).

11) On a scale from one to ten, what do you think of the comfort of this concept?

The average score for the comfort of concept 2 is 7.0/10 (SD = 1.26).

12) Indicate your favourite and least favourite area on this concept.



Concept 3

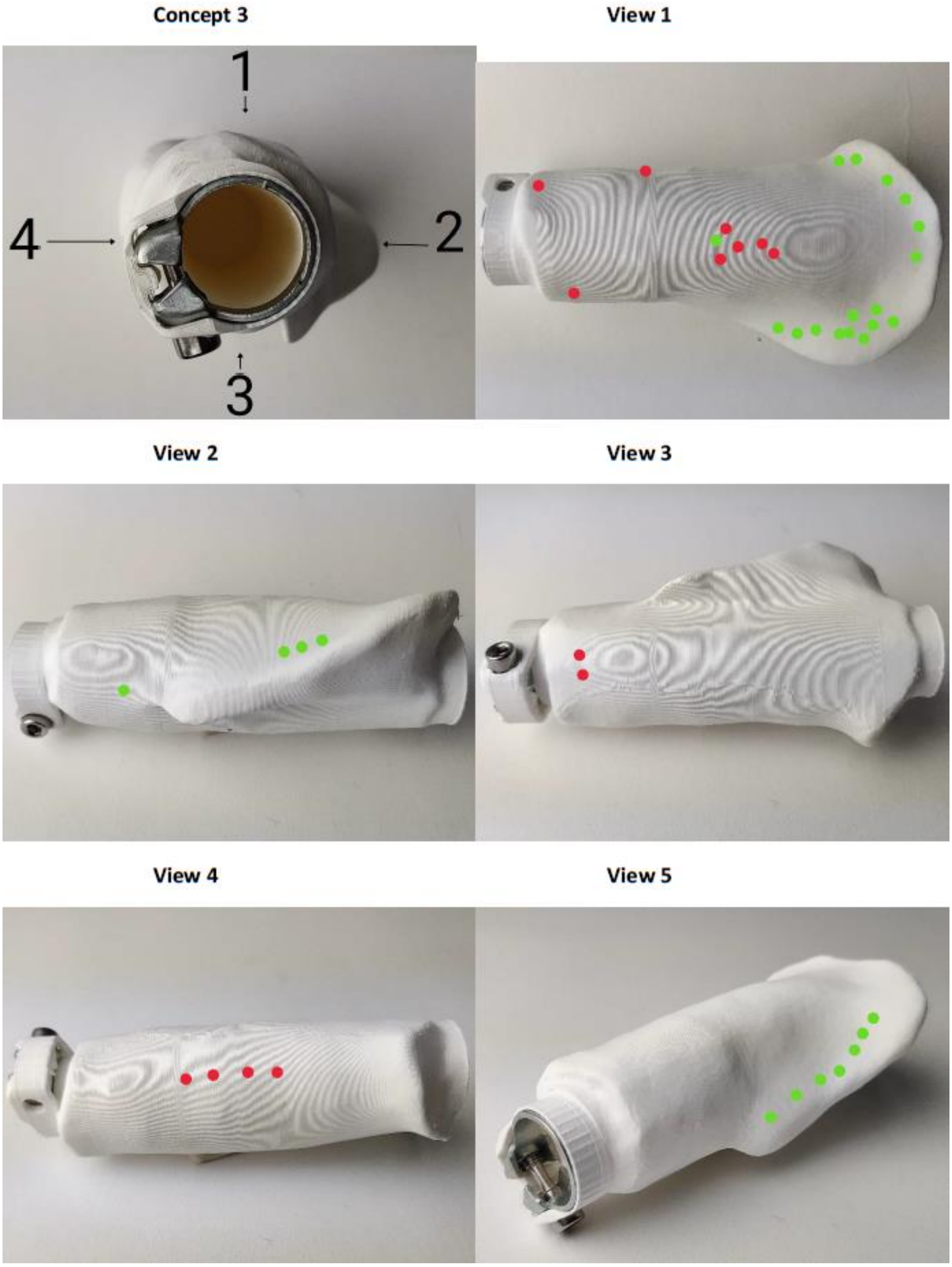
13) On a scale from one to ten, what do you think of the look of this concept?

The average score for the look of concept 3 is 7.1/10 (SD = 0.73).

14) On a scale from one to ten, what do you think of the comfort of this concept?

The average score for the comfort of concept 3 is 7.6/10 (SD = 0.85).

15) Indicate your favourite and least favourite area on this concept.



All three concepts (II)

16) Based on looks, which concept is your favourite? And why?

80% of the participants state that concept 1 is their favourite in terms of looks. Given reasons are that the region 1 bump looks smaller in combination with the region 2 + 3 wing and that the curves in the concept look similar to the curves in the handlebar. Participants also indicate that because the shape of the region 2 wing is familiar to them, it explains the orientation of the unknown region 1 bump (in contrary to concept 2 where a lone region 1 bump might be confusing). As point of improvement it is indicated that the region 1 bump could use a smoother finish or better integration with the rest of the concept.

20% of the participants prefer the appearance of concept 3. Reasons for this choice are that they like the wing feature and how it organically runs all the way from region 2 through region 3 into region 4. They also state that without the region 1 bump it looks relatively similar to existing BHGs, and this familiarity appeals to them.

17) Based on comfort, which concept is your favourite? And why?

60% of the participants prefer concept 1 based on comfort. They mention that the region 1 bump feels a lot better than expected, and that they notice a relief of pressure in the other regions of the hand. That in combination with the region 2 + 3 wing ensures optimal pressure distribution. They also notice that regardless of the position of the hand on the concept (during regular use when mounted on a handlebar) they always feel the extra support compared to a standard BHG, which is beneficial for using handlebars with different angles. Participants state that when the region 1 bump is the only feature (concept 2), the lack of the region 2 + 3 wing causes the pressure on region 1 to become too high. This causes an uncomfortable focus on region 1. When the region 1 bump is not present (concept 3) participants indicate they notice the decrease of pressure distribution which translates into a lack of comfort which they compensate by squeezing harder. This increases their discomfort even more.

20% of the participants choose concept 2, because they experience that this concept works better for users that are outliers in size, since it does not have the region 2 wing.

Concept 3 also received 20% of the votes. Participants state that they do not like the region 1 bump (yet) or think that it is too high, and that it feels like it is in the way. They also say that region 4 appeals to them because it gives additional support to the ring finger and small finger.

18) Would you buy your chosen favourite? Why/why not?

80% of the participants indicate they are willing to buy their chosen favourite concept because the increase in comfort, appearance and feeling of safety. They say that they will only purchase their chosen concept if their bicycle matches the use and appearance of the concept. Most participants indicate they have never bought BHGs and probably never will, unless their current ones are really worn out and need to be replaced.

Reasons for the 20% that are not willing to purchase their favourite concept are that they base their decision solely on appearance and their choice does not appeal to them enough, or that they rarely cycle and do not care about comfort for the minimum number of times they do.

19) How much would you pay for your chosen favourite?

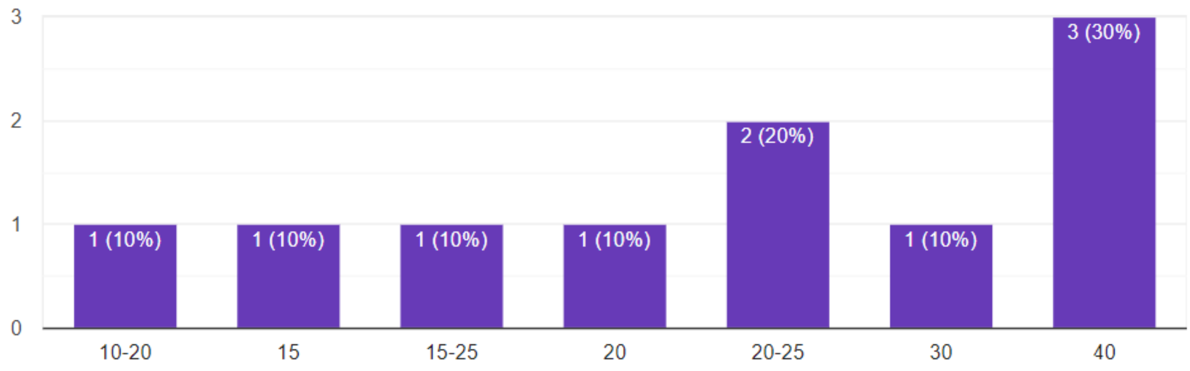


Image 93: The amount participants are willing to pay for their favourite concepts.

20) Would you recommend your chosen favourite? If so, to whom?

All the participants indicate they would recommend their chosen favourite concept, but not just to anyone. Stated intended users are daily bicycle commuters, cyclists that take longer tours or daytrips, more experienced cyclists (adults – elderly) who care more about comfort and safety. The advantages of these concepts do not apply to short rides. The named types of cyclists are also willing to pay more for a better developed product. And of course, their bikes must also fall within category 4, which is what these concepts are designed for.

K. Original project brief

DESIGN FOR our future

5401

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Schrijen

initials: RWH given name: Rob

student number: 4374738

street & no.: [redacted]

zipcode & city: [redacted]

country: the Netherlands

phone: [redacted]

email: [redacted]

Your master programme (only select the options that apply to you):

IDE master(s): (★) IPD ( ) DfI ( ) SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign

( ) Tech. in Sustainable Design

( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Peter Vink dept. / section: SDE

** mentor: Renate de Bruin dept. / section: AED

2nd mentor: Hanneke Laheij

organisation: Widek B.V.

city: Krimpen a/d IJssel country: the Netherlands

comments (optional): -

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Peter Vink date 10 - 11 - 2021 signature [redacted]

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 30 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

( ) YES all 1st year master courses passed

(X) NO missing 1st year master courses are:

ID4170 Advanced Concept Design (21,0)

name C. van der Bunt date 03 - 12 - 2021 signature [redacted]

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: (V) APPROVED ( ) NOT APPROVED

Procedure: (V) APPROVED ( ) NOT APPROVED

- the missing course ACD has been passed in the meantime

comments

name Monique von Morgen date 6/12/2021 signature

An ergonomic approach to the design of bicycle handlebar grips — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 10 - 11 - 2021 — 19 - 04 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

As a real Dutchman I grew up on and around bicycles. Even though I now live in the big city with all kinds of (public) transport methods available, I always prefer my bicycle as my main mode of transport.

The bicycle industry is growing bigger than ever. Between 2015 and 2020, average bicycle retail prices have increased from €914 to €1499 (+64%). The total turnover from bicycle sales has increased with 30% in 2020 and even doubled between 2010 and 2020 to a record height of €1.65 billion (Stichting Landelijk Fietsplatform, 2021). Next to this increase in spending on bicycles, the number of people preferring the bicycle to the train or car is also increasing. Between 2019 and 2020 (the first year of the COVID-19 pandemic) travel time and distance by car and train decreased with 25% and 60% respectively, while the decrease in bicycle use was only around 10% (CBS, 2021). Looking at these developments, Widek wants to seize this opportunity to increase the quality of handlebar grips and secure their position in the upper market segment. I also believe that this part of the bicycle can use improvement to make it more fit to the human form if we want to ensure the growth of the bicycle's role in European traffic.

Widek is a Dutch company that manufactures and sells bicycle accessories. Their main products are bells, spoiler straps and handlebar grips which are designed by their in-house team of designers. More than 95% of these products is manufactured in their factory in Krimpen a/d IJssel. Widek manufactures several different handlebar grips, all with a different focus (comfort, grip etc.). Widek has divided bicycles into the 5 categories below. These categories are based on body posture during use (see image 2 on page 4). The scope of this project includes category 4.
1 Aerodynamic (racing bike)
2 Aggressive (mountain bike)
3 Performance (tour bike)
4 Fitness (urban bike/e-bike)
5 Leisure (granny bike)

Main stakeholders:
Peter Vink - TU Delft project chair
Renate de Bruin - TU Delft project mentor
Hanneke Laheij - Widek project mentor (product designer)
Mike de Kwant - Widek project mentor (account manager)

Opportunities:
- Widek and their R&D department have a lot of experience with the design and manufacturing of bicycle grips.
- There are new developments in the research relevant to grip ergonomics (di Brigida et al., 2021).
- Widek offers customized products, and the factory specializes in flexibility. I may use all relevant tools and machines in the factory, allowing better prototyping.

Limitations:
- The Widek account manager is result-oriented, my design mentor however understands the design process and assists me in this classical conflict.
- Changing COVID-19 measures could restrict accessibility of the Widek office and factory and their facilitations.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: Current design of Widek ergonomic handlebar grips.

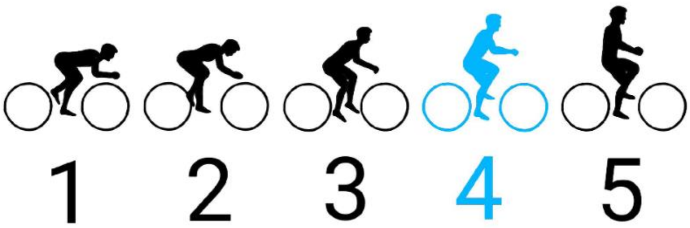


image / figure 2: Bicycle types categorized by posture.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Problem definition:
Existing handlebar grips fit the current use of bicycles. Looking at developments that indicate increasing use frequency and duration of bicycles, an increased level of ergonomic quality is desired.

Scope of the project:
The goal is to collect and distil current knowledge on grips (anthropometrics, biomechanics and experience) and to relate this knowledge to the design of bicycle grips. The next step is to bundle this knowledge into a program of requirements and develop a new handlebar grip design with a focus on the shape of the grip and the posture of the cyclist.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The main objective is to design the shape of a new handlebar grip concept design that fits the needs of the changing bicycle market by focusing on the ergonomics of the hand and the posture of the cyclist.

The first deliverable will be the report of a literature study on grip ergonomics and how this relates to bicycle handlebar grips in the established context.

The second part of this project will be the development and proposal of a new grip shape design by applying the collected insights to the defined context and scope. This shape design will contribute to Widek's goal of developing bicycle handlebar grips with a higher ergonomic quality.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 10 - 11 - 2021 | 19 - 4 - 2022 end date

Date	08/11	15/11	22/11	29/11	06/12	13/12	20/12	27/12 03/01	10/01	17/01	24/01	31/01	07/02	14/02	21/02	28/02	07/03	14/03	21/03	28/03	04/04	11/04	18/04
Calendar week	45	46	47	48	49	50	51	52 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project week	**01**	**02**	**03**	**04**	**05**	**06**	**07**		**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**		**18**	**19**	**20**	**21**
Events	**KO**							**Holiday**		**MT**								**GL**	**Holiday**				**G**
Research & Analysis																							
Ideation																							
Conceptualisation																							
Prototyping & Testing																							
Evaluation & Iteration																							
Documentation																							
Presentation																							

Notable events (concept):
10 November 2021 - Kick-off
18 January 2022 - Midterm evaluation
15 March 2022 - Green light
19 April 2022 - Graduation

27 December 2021 - 6 January 2022 - Holiday
21 March 2022 - 25 March 2022 - Holiday

Initials & Name RWH Schrijen Student number 4374738

Title of Project An ergonomic approach to the design of bicycle handlebar grips

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Motivation:
Projects that aim to result in a physical product always interest me more because of the need for physical work. I love to work with my hands and physically prove the effect and working of a concept. Since the goal of this project is to develop a product whose success depends on its physical properties and how it is adapted to its human user, this will be the ultimate test of my prototyping skills. One of my core values in product design is to help users in the most simple and effective way. I do this by creating products that are not open for interpretation and the chance of wrong use is minimized.

Competences:
I want to prove my technical skills as a designer by making prototypes that represent my design in the truest way possible. This will, among other methods, involve 3d-modelling and printing

Learning ambitions:
My learning ambitions involve peripheral matters like planning and reporting. Since most design projects are done in groups, my focus has mostly been with the designing itself.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.