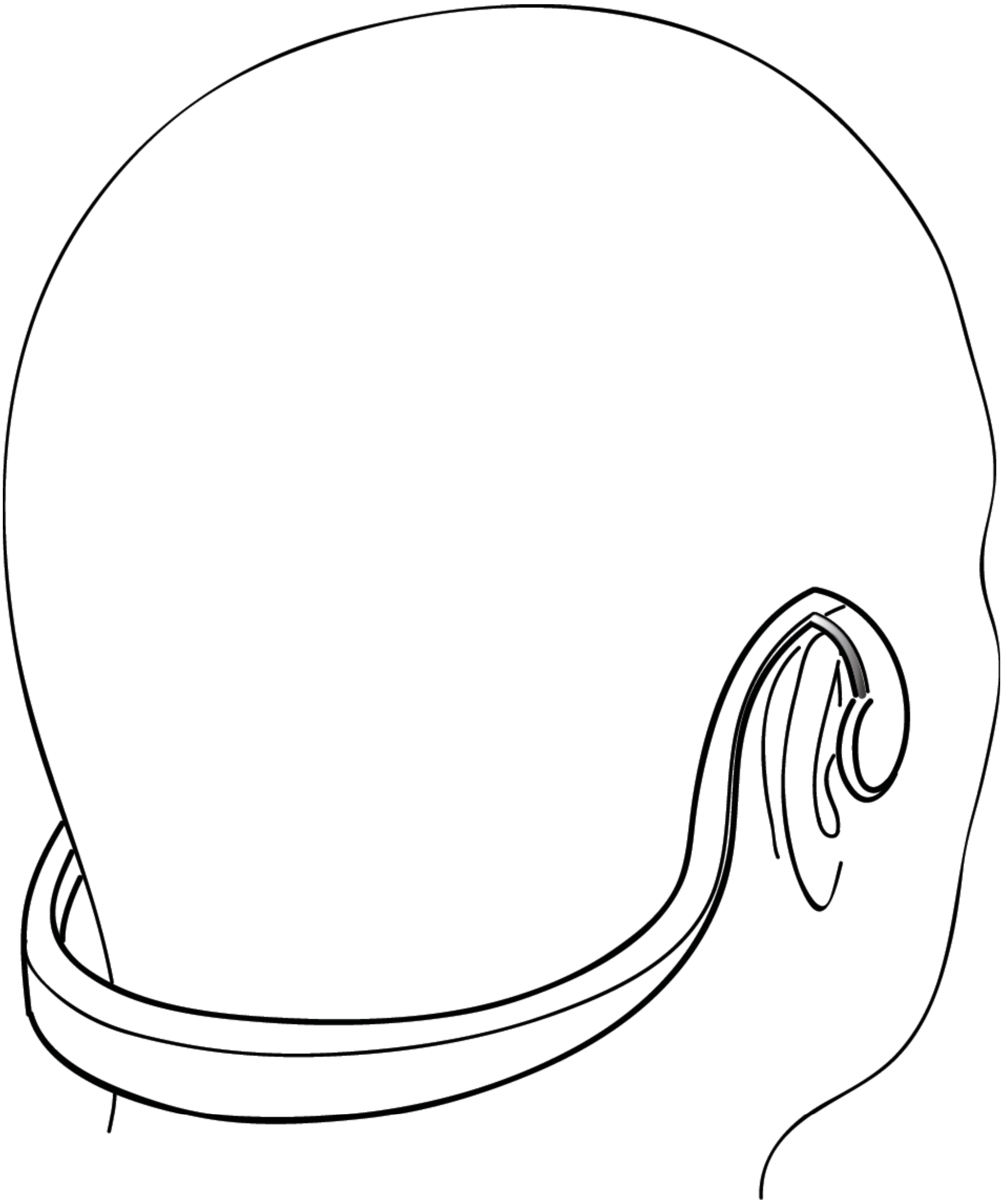
BitsLab

A smart product for weight loss through behavior change
With a focus on food intake



Master Thesis
by Anne Bekker
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Graduation Project
MSc Integrated Product Design
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DoBots

BitsLab

A smart product for weight loss through behavior change

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Preface

My goal in designing is to help people improve their lives. Due to the freedom I was given in creating the assignment, I have been able to do a project that I am passionate about.

Although I would have wanted to further elaborate on the design, I am happy with the results of this project. I have learned a lot, and met great people in the process.

This thesis describes the process and results of the final project of my master Integrated Product Design at Delft University of Technology. I am happy to have had the possibility to execute this project at DoBots; an interesting, dynamic company, consisting of great people.

Acknowledgements

I would like to express my gratitude towards the following people for supporting me during this project:

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Marc again, my wonderful boyfriend, for always being supportive, helping me create 3D printed models, and helping me relax when I needed it.

Joris Janssen, for our inspirational conversations about behavior change.

Finally, my friends and family, for being there for me. In particular, I want to thank my parents for supporting me through my whole education.

Anne Bekker, May 2015 ABekker

Abstract

Overweight prevalence has increased dramatically over the course of the last three or four decades. An increased caloric intake, partly induced by the food industry, is the main cause of this epidemic. Though activity trackers are widely available, no solutions are yet available for automatic food intake tracking. Current solutions for improving and reducing food-intake rely on manual tracking. This has been proven inaccurate, both for reporting on eating frequency and on dietary intake.

A study on human behavior resulted in the insight that, to make long-term changes, the focus should lie on on changing habits. Simplification is key to changing behavior. The slower the changes are introduced, they higher the chances of successful long-term changes. Slow changes are easy to introduce and build confidence in one's ability to change; a crucial element in achieving behavior change.

In order to change habits, it is essential to first analyze current habits. A design was created that facilitates behavior change by helping people analyze and improve their food intake patterns. The design, the BitsLab, consists of an add-on for smartphones and an accompanying app. The add-on is a chewing sensor, located on the zygomatic process.

The sensor measures chewing trough bone conducted audio. Audio data is sent from the add-on to a smartphone app using Bluetooth LE, where it is analyzed by an algorithm. This measured data will provide users with an unbiased overview of their intake pattern. A proof of concept of the technology is presented, along with an ergonomic study on shape design.

Contents

1. Introduction

A large part of the population lives an unhealthy life. According to the World Health Organization (2015a, n.d.), overweight and obesity, along with their consequences, are a rapidly growing societal problem. Overweight and obesity are not solely a problem for high income countries anymore. The problem is now also quickly rising in low- and middle-income countries, particularly in urban settings.

In the past decades, technology has been increasingly used to help people to tackle their health problems. For instance, sensors can track how many steps you take, how far you run, and how fast your heart rate is. Sensors combined with apps give people useful feedback and advice about their behavior. Yet the problem keeps growing.

Figure 1 *Illustration of a sedentary lifestyle (Rampazzo, 2010).*

1.1 ***Problem Definition***

Technologies hold high promises in aiding people in losing weight. Technological solutions are arising, though products on the market are mainly focused on activity levels up until now. Sensors can provide useful feedback which can motivate people to change their behavior. It is problematic however that even if people manage to increase their activity level for a longer period of time, they often counter their efforts by consciously or unconsciously increasing their food intake. Even when intake stays the same, the loss of weight due to increased activity levels tends to be minimal.

When it comes to food intake, a good solution is not yet available. There are apps on food intake, which usually revolve around calorie counting. Although calorie counting is an effective method of realizing and applying a proper food intake, for most people it is too much of a hassle and too time-consuming. It is simply too intrusive on their lives. An application which makes the monitoring of food intake less intrusive would be of great help for many.

Largely due to influences of the food industry, many people today have a distorted image of what a normal daily food intake looks like. In the last decades our diet has changed drastically. Regular snacking and eating junk food is the norm for many. Tempting foods are widely available all around in developed countries and urban areas, as are ways to persuade people into buying food. People are constantly being reminded of (mostly unhealthy) food. This makes it very difficult for them to stop themselves from eating more than they should. Many people try a variety of diets to improve or reduce their food intake. However, these diets seldom result in long-term changers and/or weight loss since generally these diets are not based on permanent changes in their (eating) habits.

The main factor that determines weight is food intake (Comstock, 2014; Mullin, Cheskin & Matarese, 2014), though it should be kept in mind that food intake is linked to other factors such as activity, stress and sleep. Activity trackers can definitely be a valuable addition to many people's lives. It is important for people to keep a check on their activity levels, especially with today's sedentary lifestyle. Increasing activity levels is very beneficial to the health of a sedentary person. However, there should be more emphasis on developing technological products addressing food intake in the light of the high overweight prevalence.

1.2 *Assignment*

After initial research, the following assignment was composed:

Develop an add-on for smartphones which is able to help people to attain and maintain a healthy weight.

The main purpose of the assignment is to permanently change people's behavior towards food. The challenge of this assignment lies in achieving this purpose in a manner that fits people's lives based on in-depth study of human behavior and advanced technology.

DoBots

This thesis was executed at startup company DoBots (from 2013). DoBots is one of the daughter companies of Almende (from 2000), a research company that performs research in a diverse range of disciplines building on principles of self-organization. DoBots, specialized in robotics, works on applying this knowledge into commercial products.

This thesis, for DoBots, was meant to explore possibilities of Bluetooth add-ons for smartphones. In addition to DoBots, communication also existed with Sense (from 2009), another daughter of Almende. Sense creates solutions which help people take control over their health and well being. These solutions vary from minimizing jet lag to increasing activity levels. Solutions on tracking and changing food intake however are still absent. Therefore, this thesis was also interesting for Sense.

1.3 *Approach*

Figure 2 illustrates the approach of this project. The project consists of three main phases: the analysis, conceptualization and embodiment phase. The analysis phase starts with literature research on overweight and human behavior. In order to explore possibilities and verify parts of the literature research, this research will be supplemented by brief field research(es) and self-testing.

While aimed at maintaining, this project is not long enough to enable testing of this aspect of the assignment. Therefore, information will mainly be gathered through literature research. The performed research will lead to a List of Requirements and a Design Vision, which will be the starting point of the ideation and conceptualization.

Due to the broadness of the subject's material, a heuristic approach will be taken within this project, combined with action research. Research will be performed parallel to idea/concept generation. Additional literature and field research, aside from that on overweight and human behavior, will be executed when necessary. Simple models or prototypes will be created to evaluate the feasibility of concepts if necessary.

The chosen concept will be embodied and prototyped in the third phase. The prototype will be tested and evaluated. Based on the results, recommendations will be presented for improving the design and potentially continuing research.

The business aspect of this assignment has been executed before starting the assignment itself. The assignment given by DoBots was to design an add-on for smartphones which is connected through Bluetooth. A very broad external and a brief internal analysis were performed in order to find a need in the market, and to thereby compose an interesting and meaningful assignment. This research will not be shown in the report.

1.4 *Structure of this Thesis*

This thesis is divided into three main phases: the analysis, conceptualization and the embodiment phase. Starting with the analysis, relevant findings of the literature research concerning overweight and human behavior will be presented, supplemented with field research. Consecutively, literature research on automatic intake tracking will be presented; research that has been performed later in the process.

The concept phase starts by presenting the formed Design Vision and List of Requirements. Next, the general process of the ideation will be shown. Three selected concepts will be presented of which one will be chosen with the aid of additional field research.

The embodiment phase starts with a study on the technology of the design. The testing and selection of the sensor and functioning of functional chewing recognition will be presented. Consecutively, the different aspects of the design will be explained. After some more detailing concerning shape and production, the evaluation and recommendations will be presented.

Green text boxes in the text represent a recap of the previous information or design implications.

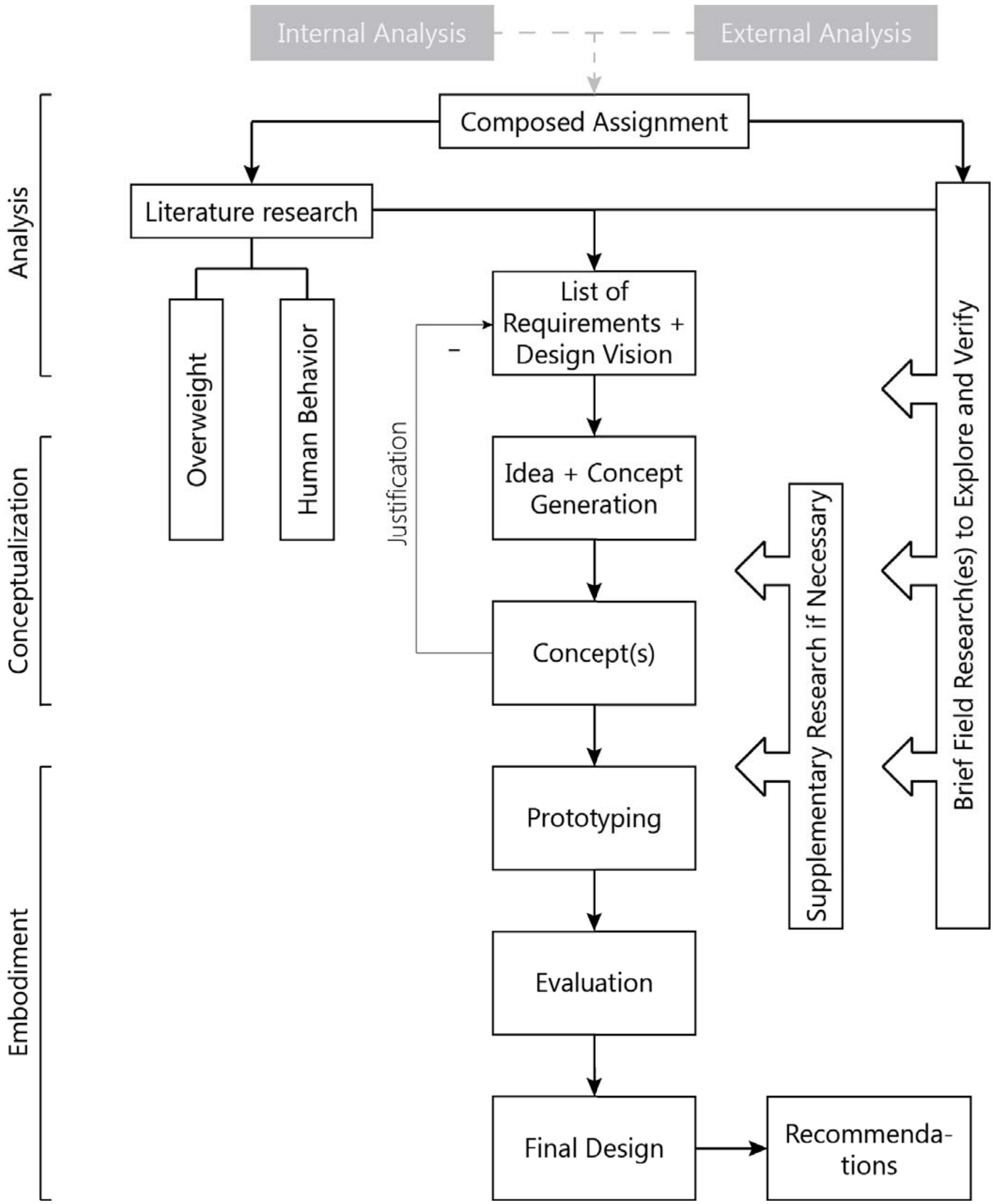

Figure 2 *Illustration of the approach of this project.*

Analysis

The Analysis section presents an overview of relevant information found during the analysis phase of this project. The research mainly consists of literature research in order to address the long-term aspect of the assignment. Alongside this literature research, some field research has been performed to test certain aspects of the performed literature research and in order to get additional insights into the target group.

The goal of the analysis was to gain insight into the problem of overweight, the target group and relevant technologies, in order to find possibilities to help people normalize their food intake permanently within the scope of this assignment.

The analysis will start with a chapter providing information about overweight. Next, human behavior and how it can be changed will be discussed. Finally, relevant technologies will be explored.

2. Overweight

This chapter presents results of the research performed concerning overweight. It provides information on the prevalence and recent history of overweight. Note that the term overweight includes obesity.

2.1 *Project focus on food intake*

A person´s weight is determined by his or her energy expenditure versus intake, commonly measured in kilocalories (kCal). The daily caloric need of an average healthy adult is said to be around 2000 kCal for women and 2500 kCal for men. When one´s intake is higher compared to one´s expenditure for a period of time, that person will gain weight, and vice versa.

+ A person's intake is dependent on what that person eats and drinks.

- A person's expenditure is mainly dependent on that person's activity, gender, age, body composition and weight.

While it seems like simple mathematics, complex physiological systems are behind this. Stress and sleep for instance are indirectly affecting a person's weight (Mullin, Cheskin & Matarese, 2014).

Food intake is believed to be the main determinant factor of a person's weight (Comstock, 2014; Mullin, Cheskin & Matarese, 2014). Overeating 600 kCal is much easier for the majority of people compared to burning 600 kCal extra on a day. To give an idea, Figure 3 shows a couple of examples of intaking and expending 600 kCal.

Figure 3 *Indicative comparison between intake and expenditure of 600 kCal for a 70kg adult. Overeating 600 kCal per day is much easier for the large majority of people compared to burning 600 kCal extra on a day, indicating the importance of monitoring and/or reducing food intake in weight loss and maintenance.*

Additionally, although activity affects the amount of calories expended, it takes a substantial amount of exercise to induce or maintain even a minimal amount of weight-loss when not coupled with intake restriction; typically above the recommended amount of exercise (Mullin, Cheskin & Matarese, 2014). Additionally, odds are that, when not tracking dietary intake, this small energy deficit will be compensated by consciously or unconsciously increasing intake.

Currently a variety of activity trackers is on the market, whereas products with sensors to track food intake appear to be non-existent. The reason for this absence, especially considering its potential, is probably attributable to the fact that sensing activity is much easier compared to sensing food intake.

Due to the importance of food intake in weight control, combined with the lack of products concerning food intake, ***the choice was made to focus this project on helping people to monitor and adjust their food-intake***.

2.2 *Overweight Prevalence*

Overweight and obesity are an indication of an excessive body fat percentage that may impair health. They are commonly defined using a weight-height ratio called body mass index (BMI). A person's BMI is measured by dividing a person's weight by the square of his/her height (kg/m^2).

- A BMI greater than or equal to 25 is defined as overweight
- A BMI greater than or equal to 30 is defined as obesity

Worth noting is that BMI is a rough measure and is not without controversy. It does not take into account factors such as body composition, gender and age (Wyatt et al., 2006). A fit bodybuilder with a low fat percentage might be classified overweight or even obese in extreme cases by BMI standards due to a high muscle mass. Vice versa, a person with a normal BMI can also have a fat percentage considered unhealthy. The reason BMI is used as standard is due to its easy and inexpensive attainability. Additionally, in general it is still a decent indication of overweight and obesity that proves effective for the majority of the population; a high correlation exists between a deviating BMI and obesity related disease risk (Dalton, et al. 2003). Waist measurement provides a better guide to excess body fat compared to BMI however (Haslam, Sharma & Le Roux, 2014). BMI combined with waist circumference or waist to hip ratio measurements would provide more meaningful data due to the high risk abdominal fat poses to diseases associated overweight. These measurements are still inexpensive and quite easy to acquire.

According to the Central Bureau of Statistics (2014a), 48,2% of Dutch adults (aged 20 and above) was overweight and 11,8% obese in 2013, compared to 33,4% and 5,3% respectively in 1981, as can be seen in Table 1 and Figure 4. Worldwide, overweight and obesity have increased rapidly in the last decennia. Data of the WHO (2015a) states that the prevalence of obesity has more than doubled worldwide since 1980. In 2014, 39% of the adult population aged 18 and above was overweight, of which 13% was obese. The following graph shows the rapid growth of overweight and obesity in the Netherlands through the last decennia.

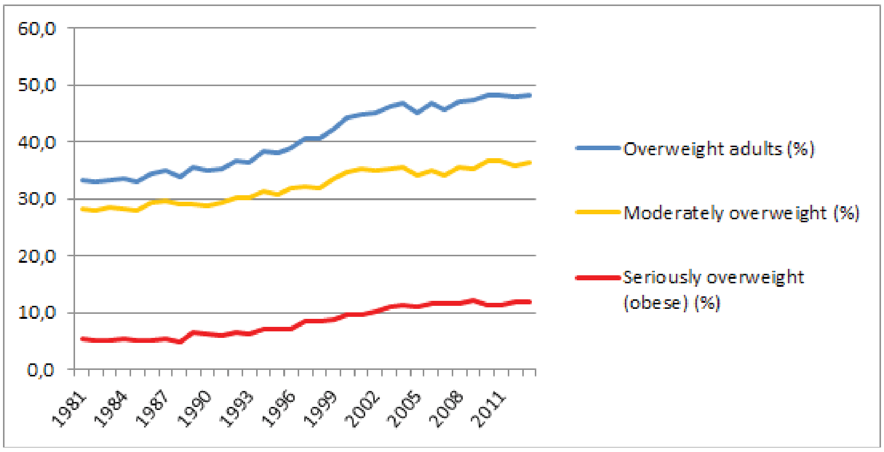

Figure 4 *Overweight and obesity of Dutch adults aged 20 and above; from 1981 (CBSa, 2014)*

This data also shows a correlation between education levels and overweight prevalence. The higher the education of the concerning person, the lower the chance he or she is overweight or obese. Another aspect strongly correlated with overweight prevalence is age. As can be seen in Figure 5, the older the age group, the higher the overweight prevalence (Centraal Bureau voor de Statistiek, 2012). This effect seems to reverse after reaching the age of 75. This might be caused by shortened lifespans of overweight individuals.

Overweight and obesity levels are even higher in other locations on the world. For instance, the World Health Organization (2015b) estimates that in the United States in 2015, over 80% of the population aged 15 and above was overweight and over 50% obese.

Childhood obesity is a rising problem as well. Worldwide, childhood obesity is growing, with most obese children living in developing countries (WHO, 2014).

Table 1 *Overweight and obesity; from 1981 (Centraal Bureau voor de Statistiek, 2014a; 2014b)*

Year / Education level	Overweight persons (%)	Moderately overweight (%)	Seriously overweight (obese) (%)
1981	33,4	28,2	5,3
1991	35,2	29,3	5,9
2001	44,9	35,3	9,6
2011	48,2	36,8	11,4
2013	48,2	36,4	11,8
Primary eduction	62,8	40,9	21,9
Lower vocational education	58,2	41,9	16,3
(Senior general) Secondary & intermediate vocational education	51,5	39,2	12,3
Higher vocational education	43,6	36,2	7,4
University education	34,4	28,8	5,5
Unknown education	57,6	39,7	17,9

The prevalence of overweight and obesity has rapidly risen to alarming rates in the last three or four decennia.

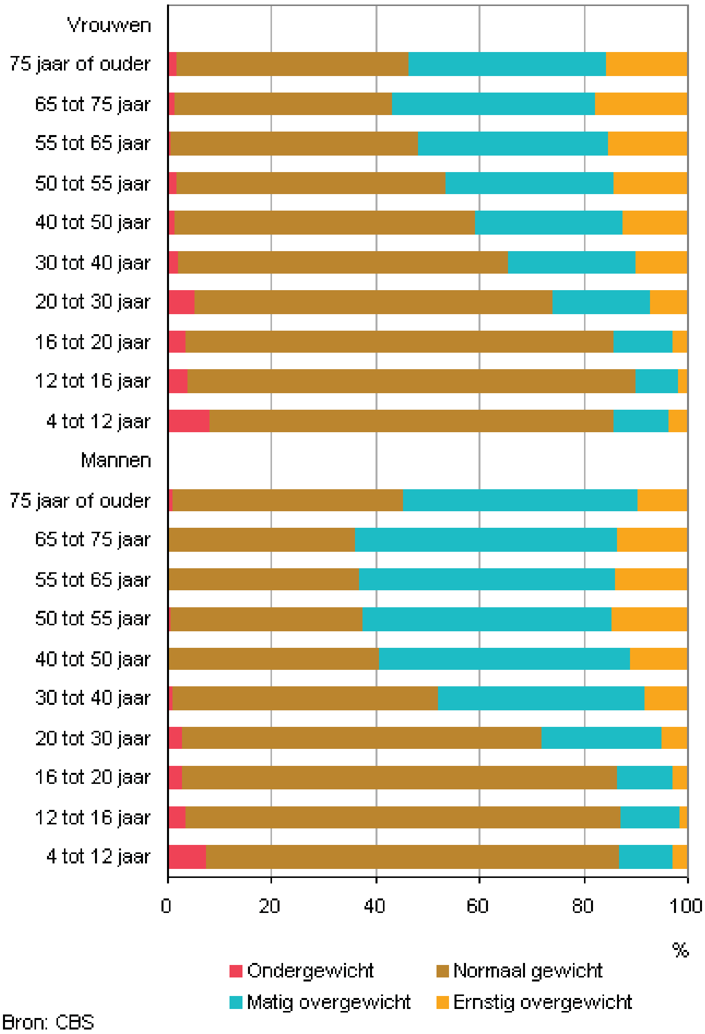

Figure 5 *Overweight by age, 2009/2011 (Centraal Bureau voor de Statistiek, 2012). Generally the older the age group, the higher the overweight prevalence.*

2.3 Consequences

The high prevalence of overweight and obesity has a harmful effect on the health of the population, its psychosocial functioning, people's quality of life, and the economic situation of the affected countries. This section shows a brief overview of these consequences.

Health

Wyatt et al. (2006) mention that a variety of studies have shown causal relations between overweight and a number of serious health conditions. An elevated BMI has been linked to cardiovascular disease, hypertension, diabetes, dyslipidemia, metabolic syndrome, gallstones, osteoarthritis, sleep apnea, and certain forms of cancer. The higher someone's BMI (≥25), the higher someone's risk to get affected by these conditions. Abdominal or visceral fat (fat accumulated around the organs) is of particular risk of morbidity associated with overweight.

Being overweight also significantly reduces life expectancy. The estimated number of years of life lost is dependent on the degree of overweight. A higher BMI corresponds with more years lost.

Psychosocial

Being overweight has a negative effect on the quality of people's life. There is a social stigma on being overweight which may cause higher rates of anxiety, depression, and low self-esteem (Wyatt et al., 2006). Overweight adolescents are less likely to marry, are less educated (as can be seen in 2.2 as well) and have a lower household income in adulthood. Researchers speculate about the correlation between the growing depression and obesity prevalence. Obesity is also associated with mental disorders. Figure 6 shows hypothesized relationships between obesity and psychosocial factors.

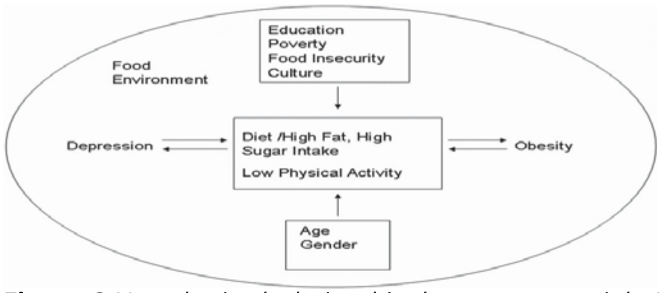

Figure 6 *Hypothesized relationships between overweight/ obesity and pschosocial factors (Wyat et al., 2006).*

More research is necessary to explore the causality between obesity and psychosocial factors. Whether for instance a lower education level is a cause or consequence of being overweight remains uncertain up to this point. There are many variables at play here with complex interrelations, which have yet to be unraveled.

Economical

Additionally, the high overweight prevalence also has a negative effect on the economy of affected countries. Conditions related to being overweight include the most expensive health care problems due to the high cost of health services associated with their treatment. In the US, the treatment cost of obesity related health problems is estimated to be $92.6 to $117 billion, which is approximately 5.7% to 9.1% of the total US health care expenditures (Wyatt et al., 2006). In 1998 in the US, the mean annual health care expenses per person was $2970 for an adult of healthy weight, compared to $3038 for overweight adults, and $4333 for obese adults.

Aside from these direct costs, indirect costs caused by obesity also harm the economy. For instance absenteeism and shortened lifespan as a result of obesity leads to lost value of income for employers, businesses, and the government. This loss will be passed on to taxpayers indirectly, meaning the population's disposable income will decrease. The decrease in disposable income caused by direct and indirect costs associated with obesity leads to lower spendings, with is harmful for the economy.

Childhood obesity

Childhood obesity is especially harmful, since they are not fully developed yet. Often it will lead to a poor development of their motoric skills due to diminished movement in a critical phase of their lives. Aside from an elevated risk of various health problems, obese children also have a higher risk of developing social and psychological problems such as low self-esteem, which can continue in adulthood (Centers for Disease Control and Prevention, 2012).

Obese children have a higher risk of turning into obese adults. Additionally, obesity in adulthood is likely to be more severe when the concerning person is obese during childhood.

The high overweight prevalence has a significant negative impact on the health, psychological and economical situation of the affected people and countries.

2.4 *Causes of the High Overweight Prevalence*

The fundamental cause of weight gain, ultimately leading to overweight, is a prolonged positive imbalance between energy intake and expenditure. However, the problem is not as simple as this seemingly suggests. If being overweight has this many negative consequences on people themselves and society (as described in 2.3), then why would such a large percentage of the population be overweight? In order to attempt to combat the high overweight prevalence it is important to understand its causes.

Most people, even many health care professionals, blame the people themselves for being overweight. They assume overweight people behave irresponsibly and make bad lifestyle choices, thus causing them to be too heavy. "*The problem of overweight and obesity cannot be completely explained by this seemingly simple relationship. Overweight and obesity involve a complex interplay of biologic, genetic, environmental and psychosocial factors that influence the efficiency with which some people store food and mobilize fat stores* (Wyatt et al., 2006)." This complex interplay of factors and how exactly they influence weight has not yet been unraveled by scientists.

Environmental and psychosocial causes

The environment has changed significantly in the past decades. Industrialization and increase of bodyweight appear to be causally related. Possibilities for physical activity have diminished dramatically: the number of sedentary jobs has increased; products have taken over or eased many tasks that demand physical activity, such as washing the dishes; commuting by foot and by bicycle is less common due to longer commuting distances; leisure activities are increasingly passive, often in front of a screen; cities have become less suited for outdoor activities. In the Netherlands, 47% of adults aged between 18 and 54 don't fulfill the minimal requirements for sufficient movement, which is to perform a minimum of half an hour of moderate activity a day at least five days a week (CBS, 2010).

While energy expenditure has decreased, the ease in which tasty, inexpensive food requiring little effort to prepare can be acquired has increased dramatically. Additionally, in today's society, eating (and drinking) does not solely fulfill a biological function. It also serves a social and emotional function. Food is often consumed when people are not hungry due to social events and emotional states.

In the US, the food industry spends billions of dollars on advertising and consumer promotions on foods high in calories, sugar, and fat, encouraging unhealthy eating at the cost of healthy eating (Wyatt et al., 2006). Through the years, the food industry has slowly distorted people's perception on a healthy, proportional diet through media. TV advertising for unhealthy foods support unhealthy eating behavior by reinforcing and normalizing it (Dixon et al., 2007). Additionally, research has shown that exposure to food advertising triggers automatic eating behaviors irrelevant of hunger levels and thus contributes to the high overweight prevalence by stimulating increased intake (Harris, Bargh & Brownell, 2009). This effects persists also after viewing these advertisements. When abstaining from snacking during watching tv, the effects of the food advertising can cause the viewer to eat more during a subsequent snack or meal.

Wyatt et al. mention that studies indicate that the quality of diets improve with a higher household income, containing healthier and higher quality foods. Unhealthy food is cheaper per calorie compared to healthy food. Especially for people living on a low budget, the temptation of buying this inexpensive, easy to come by, tasty (fast)food is very tempting. While many of these people ingest too many calories, the diets of these people may still contain an insufficient amount of certain nutrients due to the low nutritional values of the ingested food.

Another problem is the large amount of contradictory information available on food, health and dieting. The confusion this causes makes it hard for people to choose, and stick with, a successful approach for their health or weight-loss goals.

Genetics and biological causes

Many unknowns and uncertainties still exist in this area of research. Genetics influence the susceptibility for weight gain and the body's preferred size. However, genetics are rarely the sole cause of obesity. For instance environmental factors, such as the availability of high caloric foods and the habits one is taught in childhood, play a large role.

More than metabolism, the reason for a higher BMI is related to appetite. Overweight people generally eat more compared to people with a normal BMI (given the same activity level, body composition and size). This weight difference, however, is still (partly) attributable to genetics. While one group of people loses interest in food when they are not hungry, another is almost constantly aware of, and interested in food. This is related to hormonal systems in the human body.

Today's environment makes it a lot harder for those with an improperly functioning appetite to control food intake. Desired high caloric foods are readily available at most places and people are constantly being reminded of eating. It can be said that today's environment is built for supporting obesity.

Cultural difference

There are significant racial/ethnical differences in overweight prevalence. One explanation for these differences, aside from genetics, is body weight preference and acceptation of overweight (Wyatt et al., 2006). Something else that might be influential is differences within eating habits and traditions amongst cultures.

Childhood obesity

As with adults, advertising triggers automatic eating behaviors in children (Harris, Bargh & Brownell, 2009). Children are very sensitive to advertisements. Research performed by Dixon et al. (2007) shows the adverse influence of TV advertisements for unhealthy foods on children's

Variable	No. of Subjects Obese as Adults/ Total No. (%)	Odds Ratio (95% CI)*
Subject's age and obesity status		
1–2 yr		
Not obese	106/702 (15)	1.0
Obese or very obese	14/73 (19)	1.3 (0.7–2.5)
Very obese	5/19 (26)	2.0 (0.7–5.7)
3–5 yr		
Not obese	80/664 (12)	1.0
Obese or very obese	31/86 (36)	4.1 (2.5–6.7)
Very obese	14/27 (52)	7.9 (3.6–17.3)
6–9 yr		
Not obese	59/558 (11)	1.0
Obese or very obese	44/80 (55)	10.3 (6.2–17.3)
Very obese	24/35 (69)	18.5 (8.8–38.8)
10–14 yr		
Not obese	62/634 (10)	1.0
Obese or very obese	46/61 (75)	28.3 (15.0–53.5)
Very obese	24/29 (83)	44.3 (16.3–120)
15–17 yr		
Not obese	48/522 (9)	1.0
Obese or very obese	37/55 (67)	20.3 (10.4–39.6)
Very obese	23/30 (77)	32.5 (13.1–80.6)
Subject's age and mother's obesity status		
1–2 yr		
Mother not obese	73/575 (13)	1.0
Mother obese	29/85 (34)	3.6 (2.1–5.9)
3–5 yr		
Mother not obese	77/597 (13)	1.0
Mother obese	36/104 (35)	3.6 (2.2–5.7)
6–9 yr		
Mother not obese	76/611 (12)	1.0
Mother obese	42/131 (32)	3.3 (2.2–5.1)
10–14 yr		
Mother not obese	73/594 (12)	1.0
Mother obese	53/177 (30)	3.1 (2.0–4.6)
15–17 yr		
Mother not obese	65/549 (12)	1.0
Mother obese	64/233 (27)	2.8 (1.9–4.1)
Subject's age and father's obesity status		
1–2 yr		
Father not obese	55/455 (12)	1.0
Father obese	28/98 (29)	2.9 (1.7–4.9)
3–5 yr		
Father not obese	56/475 (12)	1.0
Father obese	34/123 (28)	2.9 (1.8–4.6)
6–9 yr		
Father not obese	60/497 (12)	1.0
Father obese	40/149 (27)	2.7 (1.7–4.2)
10–14 yr		
Father not obese	62/505 (12)	1.0
Father obese	46/184 (25)	2.4 (1.6–3.7)
15–17 yr		
Father not obese	54/491 (11)	1.0
Father obese	56/221 (25)	2.7 (1.8–4.1)

*For all odds ratios, the nonobese group served as the reference group. CI denotes confidence interval. The subject's obesity status during childhood is based on the mean z score for the child's body-mass index during the age interval, as follows: not obese, $z<1.036$ (corresponding to the 85th percentile for a normal population of the same age and sex); obese, $z \geq 1.036$ (85th percentile); and very obese, mean $z \geq 1.645$ (95th percentile).

Figure 7 *Odds ratios for obesity in young adulthood according to the child´s age and the obesity status of the child and the parents (Whitaker, 1997).*

food intake and preference. On the other hand, when showing advertising for healthy foods to children instead, they show improved attitudes towards these healthy foods. Regulating food advertisement aimed at children could be a powerful tool in combating childhood obesity.

Whitaker (1997) shows that childhood obesity, especially among older children (above 10 years old), is an important predictor of adult obesity, regardless of the weight of their parents. The higher the age of the obese child and the higher the degree of obesity, the higher the odds of the child being obese as a (young) adult, as can be seen in Figure 7. An obese child more than six years old has a fifty percent probability of adult obesity, versus ten percent for a non-obese child.

Obese and non-obese children under the age of ten with at least one obese parent have more than double the risk of becoming obese as adults compared to children with non-obese parents. Aside from genetics, this will largely be attributable to the lifestyle they are taught as a child. Food should be taught to be a source for energy; not a reward or punishment, as it is often nowadays.

The best method to counter the rising prevalence of overweight would be to return society to one with less temptations, more movement, and less of the food industries influences (think of advertising). What a product can do in this context is to create awareness and to help people lower temptations by slowly making them change their environment, including the social aspect, to one with less temptations.

It is important for parents to teach their children to be healthy. The odds of a child becoming an obese adult are more than doubled when at least one of the parents is obese. In order for the high and rising overweight prevalence to reverse, it is important to teach children a healthy lifestyle.

2.5 *Influences on Intake*

Environmental factors influence the quantity of food intake much more than most people realize (Wansink, 2004). External factors such as social and physical surroundings, sound, smell, temperature, time, color and distractions affect food intake and food choice, though the influence is not yet fully understood (Stroebele & De Castro, 2004).

Visual cues have a large influence on how much people eat. In a study by Wansink, Painter & North (2005), a group of participants was divided into two groups. The first group saw an accurate visual representation on a food portion, while the second group's visual representation was biased: their bowls slowly and unnoticeably refilled themselves while the participants were eating. The participants of the second group ate a significantly larger quantity of soup compared to the control group. They ate 73% more, whilst believing they had consumed the same amount of food as the other group and indicating the same level of satiety. People's vision appears to be an important aspect of self-regulating the quantity of food intake. This might also explain much of the mindless (over) eating done behind the tv for instance. This study rises the question whether slowly draining soup from the bowl would also induce the same feelings of satiety and perceived consumption compared to the control group.

Another interesting study is an example of the influence of portion size on intake. In this study by Wansink & Kim (2006), participants would randomly be handed a medium or a large sized container of free popcorn that was either fresh or stale, while they were going to see a movie. Those given fresh popcorn ate 45.3% more popcorn when given a large container compared to a medium one. For those who received stale popcorn, even though they disliked the taste, the ones who received a large container still ate 33.6% more compared to those who received a medium container. This leads to the conclusion that large packages lead to increased intake, even when the food is not palatable.

When people are made aware of these influences, they can make small structural changes in order to change their personal environment, and thereby reduce their intake with little effort. The same method can also be applied to increase their intake of healthy foods such as raw vegetables. The following points give a couple of suggestions of changes that can reduce intake in this manner:

- **Downsizing portion sizes**

  This can be reached by preparing smaller portions, eating from smaller plates and buying smaller packaged portions.
- **Mindfulness**

  Focus on the food while eating. Try to avoid distractions and mindless eating such as eating while watching tv.
- **Slow down eating pace**

  Eating slower gives one's body time to realize it is full before overeating. This can be reached by eating with smaller spoons for instance.

Another method of helping the body in managing its intake quantity properly is to start eating healthier. Reducing junk food and increasing intake of nutritious foods is known to help the body (re) gain a more normal regulation of food intake. On top of that, eating more healthy makes most people feel better rapidly and increases their energy.

3. Understanding the Target Group

This chapter will show results of the research performed concerning human behavior. It provides an overview of the theories found most relevant and applicable; those that have been applied in the final design, or helped to inspire in the process. Figure 8 shows the most applicable theories and how they are connected, along with their location within this thesis.

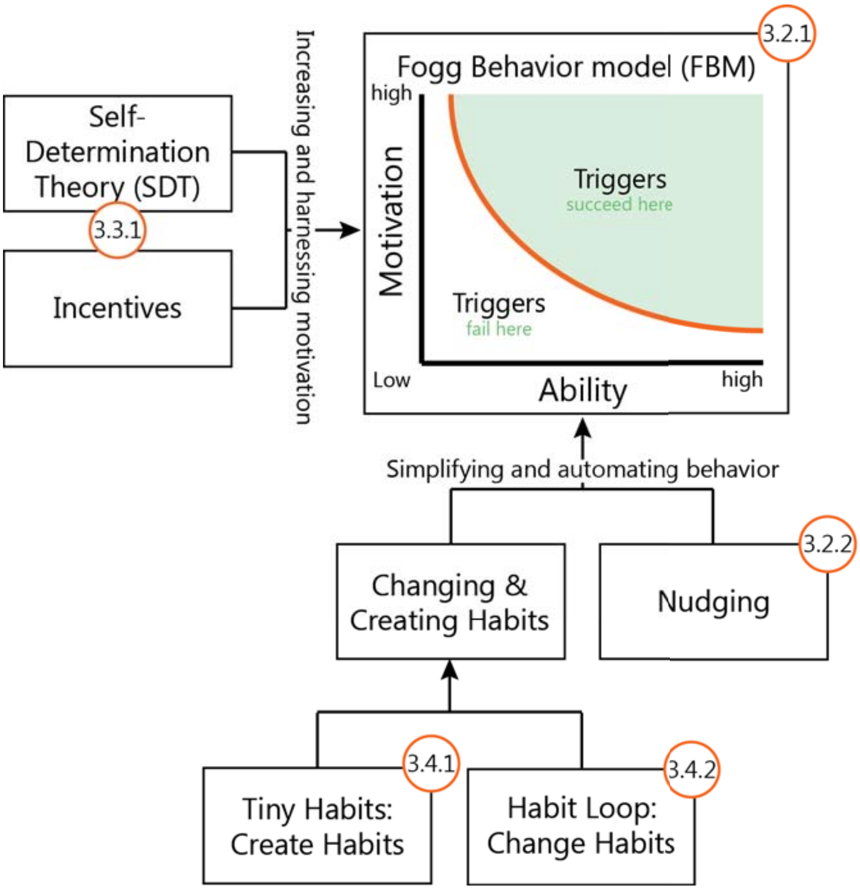

Figure 8 *An overview of the most applicable theories and how they are connected, along with their location within this thesis.*

3.1 *Target Group*

The target group of this project is overweight Dutch adults who have the desire to decrease their weight and are willing to make changes in order to accomplish this goal. During the ideation phase this group has been specified to Dutch adults aged 20 to 40 that live alone, in order to reduce the amount of external factors. As can be concluded from 2.2, people tend to grow heavier when they grow older. As the saying goes, prevention is better than cure. This is the main reason for targeting younger adults.

As mentioned before, childhood obesity is a serious problem. The reason to target adults instead of children is mainly because of the following: as shown in 2.4, children with at least one obese parent have a significant larger risk on staying or becoming obese as adults. Reducing the number of obese parents will lead to a reduced number of obese children. When the parents have a healthy weight and lifestyle, they will teach the children healthy habits, and set a good example. Children, especially those before entering puberty, take over the habits of their parents. When these are healthy habits, these children will have great odds of becoming healthy adults.

Parents are largely responsible for their children's weight. When teaching (future) parents how to live a healthy life, this will positively reflect on their (future) children's health.

Dutch adults aged 20 to 40 that live alone are chosen to be the target group for this project.

3.2 *Understanding human behavior*

This section will show how behavior can be broken down and changed.

3.2.1 *Behavior Model for Persuasive Design*

Behavioral expert Fogg (2009) created a model for understanding human behavior: the Fogg Behavior Model (FBM). The FBM is especially useful in analyzing and designing persuasive technology systems. The term "persuasion" in this model refers to attempts to influence people's behavior, not their attitudes.

First, the basics of this model will be explained. Subsequently, the use and application of the FBM in persuasion will be discussed.

The FBM assumes it takes a combination of three factors for a behavior to take place: ***motivation***, ***ability*** and ***trigger***. In order for a a person to perform a certain target behavior, he or she must:

- be sufficiently motivated
- have the ability to perform the behavior
- be triggered to perform the behavior

These three factors must occur at the same time for the behavior to take place. Figure 9 is a visualization of the FBM.

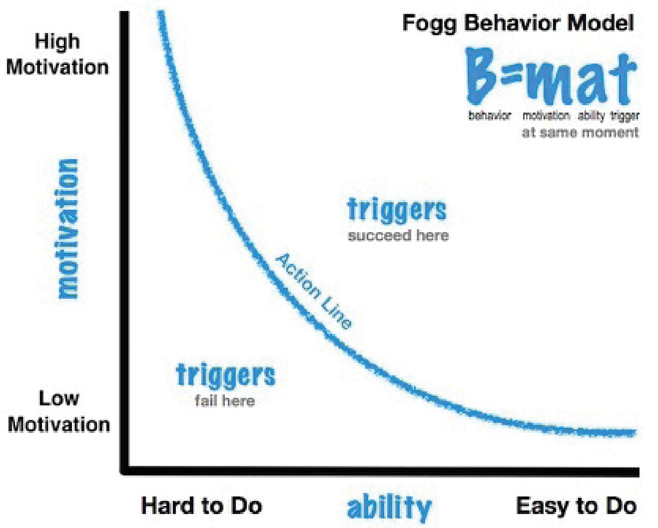

Figure 9 *The Fogg Behavior Model explains how behavior takes place (Fogg, 2014).*

When motivation and ability levels for a certain behavior are sufficient (so that the behavior ends up above the 'action line' as seen in Figure 9) and a trigger occurs, this behavior will take place. With one of three variables missing, the behavior will not occur.

The FBM describes different elements of motivation, ability and triggers. These elements will be briefly explained next.

Motivation

The FBM provides a framework for motivation consisting of three core motivators, with each two sides:

- **Pleasure/pain**

  These motivators are based on sensations. Little thinking or anticipation occurs here; people respond (nearly) immediately to these motivators.
- **Hope/fear**

  This dimension is characterized by the anticipation of a good or bad outcome.
- **Social acceptance/rejection**

  This dimension controls a large part of social behavior. It is driven by people's desire to be socially accepted and to not be rejected.

Section 3.3 includes further information on motivation.

Ability/Simplicity

The ability factor in the FBM, also called simplicity, represents to what degree something is easy or hard to do at a certain point in time. The framework provided by the FBM to define simplicity consists of six elements which are linked together. If one of these elements proves too difficult, the simplicity will be lost.

- **Time**

  The simplicity of the time aspect of a behavior depends on the amount of free time someone has.
- **Money**

  Whether the aspect of a target behavior that costs money is simple depends on that person's financial resources.
- **Physical Effort**

  A behavior that requires physical effort may not be simple dependent on the level of physical effort and the concerning person.
- **Brain Cycles**

  The simplicity of his aspect depends on the level of thought required for performing the target behavior.
- **Social Deviance**

The meaning of social deviance in this model is going against the norm; breaking the rules of society. Whether a this aspect of a target behavior is simple depends on how socially accepted that behavior is and how much the concerning person cares about what people think of him or her.

- **Non-Routine**

  When a behavior is not routine for people, they tend to not find it simple.

Note that what is defined as simple is very person dependent. For one person time might be the most difficult aspect, while for another it can be brain cycles for instance. The simplicity of a behavior depends on the person's scarcest resource at the moment a behavior is triggered.

Trigger

An often missing, or improperly implemented factor in persuasive design is the trigger. A trigger is something that tells people to perform a certain behavior now. Many other terms are used for the concept trigger, such as cues, prompts and calls to action.

The FBM shows three types of triggers:

- **Spark**

  A trigger combined with a motivational element, such as inspiring videos.

- **Facilitator**

  Triggers a behavior while also making it easier to do. An example is a software update that indicates that one click will get the job done.

- **Signal**

  Serves purely as a reminder or indicator, such as a traffic light turning red or green.

Persuasion using the FDM

Persuasive technology systems generally focus on increasing motivation, increasing the ability (simplicity), and/or triggering behavior in order to activate a target behavior in the user. The other, less used side of changing behavior using persuasive technology is preventing a behavior from occurring. By removing or reducing the motivation, ability or trigger, a behavior can be stopped or changed.

Stopping a behavior from happening is much more difficult compared to activating a behavior. When attempting to prevent a behavior from happening, the behavior might still take place but in a different pattern for instance.

Triggers

In persuasive design, the often missing or lacking factor is the trigger. Even if both motivation and ability are high, a behavior will not take place when a trigger is missing. An often occurring problem with triggers is the crucial factor of *timing*. Poorly timed triggers rarely initiate the target behavior and can lead to frustrations. A trigger should be used at a time when a person's motivation and ability lie above the action line threshold.

A wrong type of trigger can also be detrimental. When a 'signal' would suffice but someone is given a 'spark' or 'facilitator', that can be perceived as annoying or condescending.

Simplicity versus Motivation

Generally, increasing the simplicity of a behavior in persuasive design is more successful compared to rising motivation. The reason for this is that people love simplicity, and are often resistant against attempts at motivation. Increasing ability in persuasive design is usually done by making a target behavior easier to do. Designs relying on people increasing their ability by teaching and training often fail, since those generally require too much effort.

When designing for increasing simplicity, it is important to take a close look at the target group. If there is a common ability element problematic for the target group, that element will be an essential point to start designing for since it will strengthen the weakest link.

Ability (simplicity) is an important factor to work with. If one manages to make bad choices more difficult and good choices easier, one would need less motivation to keep making the right choices (see Nudging also, 3.2.2). In other words, changing/ managing one's environment in a clever manner can greatly reduce the level of motivation that he or she needs to keep performing the target behavior.

For instance, when someone does not have unhealthy food in the house, the barrier to eat unhealthy food is a lot higher (and therefore the ability lower) compared to when it would be available in the house. Conversely, when someone for instance pre-cuts fresh vegetables into snack-sized pieces right after having bought them, it is easier for them to grab it later. This greatly reduces the barrier to have a healthy snack or to eat a healthy meal later on.

This also explains a lot about how people's confusion over weight loss and a healthy diet can be so detrimental for many, as stated in 2.4. Those people have the motivation to lose weight and are determined to eat healthier. However, the confusion on how they should approach it with all the contradictory information they encounter greatly increases the difficulty, and thereby the likeliness of the desired behavior to fail. It will require much time and thought for many to make a decision on what they think is the best way. Even if they have made a choice, they might constantly doubt it and invest more energy into looking at the options and consider whether they should take a different approach. This makes it much harder to sustain the desired behavior.

Social

Social elements are usually added for motivational purposes, though they can also have different functions (Fogg, 2015). For instance, a triggering function: seeing someone performing an action one already intended to do but didn't think about yet, will trigger him or her to perform the action. For instance, when one sees colleagues leaving the room to eat lunch, he or she will be reminded that it is lunchtime and go have lunch as well.

Social elements can also have a simplifying function. Seeing someone performing an action one wants to do simplifies the behavior, because he or she has seen it being done before. An example is seeing someone cooking a certain dish one wants to (learn to) cook.

Social elements can also induce thoughts about behaviors one did not think of before, but could be doing. For instance, seeing someone using a shortcut on the computer one is not familiar with, for an action he or she often performs, might trigger the idea of using the shortcut oneself.

Simplicity is the key to successfully changing behavior.. Triggers are an important, often disregarded factor within persuasive design. Timing of triggers is crucial.

3.2.2 *Nudge Theory*

The term nudge, as used in this theory, is "*any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid* (Thaler & Sunstein, 2008)." An example is placing fruits and vegetables at eye level in a supermarket instead of candy. Nudging is a way of lowering the ability necessary to perform desired behavior and vice versa.

The concept of nudging has been studied and has been used for inspiration.

3.3 ***Motivation***

"*Motivation is defined as the process that initiates, guides and maintains goal-oriented behaviors. [...] It involves the biological, emotional, social and cognitive forces that activate behavior*" (Cherry, 2013). Motivation is a topic studied by many due to its importance in daily life and people's desire to increase their levels of it. Many theories exist on motivation and how to induce it for instance, though most of these theories only provide partial explanations. Among the theories studied, the Self-Determination Theory was found most accurate and applicable.

3.3.1 *Self-Determination Theory*

The Self-Determination Theory (SDT) by Deci & Ryan (2000) is widely used in motivational research, which can be seen by the large number of times its papers are cited. The SDT states that different kinds of motivation exist. The drive of motivation can be caused by internal (intrinsic motivation) or external factors (extrinsic motivation). ***Intrinsic motivation*** is a drive purely from within a person. It originates from curiosity, interest and joy, without the desire for a reward. It is a critical element in development. ***Extrinsic motivation*** is a drive originating from the expectation of known external rewards; both tangible and psychological.

People are born with a tendency to learn and grow. Intrinsic motivation is inherent in all healthy new-born children. Environmental and social factors in life can either facilitate or undermine its development. The SDT believes in behavioral self-regulation, and focuses on factors that either facilitate or prevent the natural process of self-motivation. The following needs have been identified essential for facilitating self-motivation, social functioning and personal well-being:

- **Autonomy**
  The need to have control and choice over one's actions, and act in harmony with one's integrated self.
- **Competence**
  The need too improve one's skill and feel competent at, and in control of, what one is doing.

- **Relatedness**

  The need to feel connected to, interact with, and experience caring for others.

A high level of fulfillment of these three needs correlates with a high level of well-being.

Cognitive Evaluation Theory (CET), a subtheory within the SDT, states that the value of autonomy and competence on intrinsic motivation has been clearly demonstrated. Autonomy is critical for inducing intrinsic motivation. It is important to keep in mind however that intrinsic motivation can only be induced in people if it corresponds with their intrinsic interests.

The SDT suggests that different levels of extrinsic motivation exist, depending on the relative autonomy. A sub-theory of the SDT, the Organismic Integration Theory (OIT) describes different forms of extrinsic motivation, based on the level of internalization and integration of the extrinsic motivation. For instance, extrinsic motivation can be fully externally regulated. In this case, the person who is being motivated purely performs the activity because of compliance, external rewards and/or punishments. An example of a more self-determined type of extrinsic motivation is identified regulation. With this form of extrinsic motivation, the values of the activity are internalized, so that they are perceived as important by the person him- or herself.

Compared to those being purely extrinsically motivated, those intrinsically motivated typically have more interest, excitement and confidence, which results in better performance, persistence and creativity.

Incentives

An incentive is something that externally motivates a person to perform a desired behavior. Incentives do not always work as expected. For instance, providing a reward for non-standard or creative behaviors or performances has a negative effect on performance according to Pink (2009); rewards narrow our focus. Expected rewards on tasks requiring little brain power such as running for 3 km are effective. However, rewards greatly reduce the creativity/problem solving ability of how the concerning person handles a problem. The larger the reward, the worse cognitive problems are solved. On the other hand, random, unexpected rewards, such as unexpected praise can be very effective in stimulating the individual.

Additionally, giving people extrinsic rewards for already intrinsically motivated behavior can undermine their autonomy and thereby reduce their motivation for the behavior (Deci & Ryan, 2000; Deci, Koestner & Ryan, 1999). This phenomenon is called the overjustification effect.

People can become self-motivated through (initial) extrinsic motivation, when they internalize and integrate the behavior with their own values and needs. Though this can be difficult to accomplish, the building blocks for achieving this is by fostering people's needs for autonomy, competence and relatedness. Fostering these aspects will facilitate self-motivation if the behavior corresponds with their intrinsic interests.

Incentives should be used with care. They can work counterproductive when cognitive tasks are involved. Unexpected rewards however do have a positive influence on one's self-motivation. The reason why unexpected reward work is that these do not undermine the autonomy of the individual in contrary to expected rewards.

Fun theory

The Fun Theory (Volkswagen, 2009) states that people can be persuaded to perform desired actions by making those actions fun to do. In terms of the FBM, the Fun Theory increases motivation. An example is the piano stairs, see Figure 10. When changing the the stairs into one that looks and functions as a piano, 66% more people compared to normal chose to take the stairs over the escalator.

The aspect of fun will usually diminish in time. However, it can be a powerful method to help someone initiate a behavior. As part of an approach, it can be very powerful.

Figure 10 *An example of the Fun Theory: the piano stairs. The fun element realized a 66% increase of stairs usage over the escalator (Volkswagen, 2009).*

3.3.2 *Motivation versus Willpower*

Motivation and willpower are both ways to take action. Motivation is the desire to take action, which means getting motivated equals to increasing your desire to take action (Guise, n.d.). Using willpower means forcing yourself to take action.

When people start their attempt to lose weight, they are usually motivated to take action. This motivational force drives them to start and (temporarily) stick with their preferred diets and/or exercise programs. In time however, this motivational force will drop. People's motivation levels naturally fluctuate over time (Fogg, 2012), causing people relying purely on being or getting motivated to ultimately fail at reaching their weight-loss goals.

Another reason why many things people try in order to lose weight do not work in the long run is that their manners require too much willpower. Willpower can be seen as a limited resource. Every day a person has a certain supply of willpower, of which the amount fluctuates naturally. Willpower can be amplified by practicing, though it will still be quick to run out. At times motivation for a target behavior is high, little willpower is necessary to perform the desired behavior and vice versa. The difficulty arises when there are multiple tasks that, together, require too much willpower. For instance, after a difficult day at work that required a lot of willpower, a target behavior someone is not particularly motivated for at the moment will likely fail to occur.

Both motivation and willpower on their own are not effective for permanently changing behavior. However, when motivation and willpower are used together in order to create habits, they can be very effective. This will be explained in 3.4.

3.4 ***Habits***

Successfully changing behavior permanently revolves around habits. Habits are behaviors that are intertwined in our routine and that occur semi-automatically. They are our default actions and require next to no willpower or mental activity to perform. Habits are a method for our brain to reduce the capacity it needs to function in daily life, and thereby freeing resources for more demanding tasks.

The key in lasting behavior change for better health is to step by step shape a habitual pattern that leads to a healthy lifestyle. This requires one to create new habits and to change old, bad habits into better ones.

As explained in the previous section, motivation or willpower by themselves are usually insufficient to create habits. Creating habits requires consistency. In order to create habits, it is best to combine motivation and willpower. The low consistency of motivation can be supplemented with willpower to create a consistent pattern. This means that at days motivation is low, one should force themselves to do the target behavior using willpower. When done consistently, a habit will be formed, making it many times easier to sustain the target behavior.

The most difficult part in shaping a new behavioral pattern is changing (old) habits. Through years of repetition, habits become hard-wired in people's brains. It is hard to break this cycle, especially since habits happen mostly unconsciously. The longer one has been performing a habit, the more difficult it is to change it.

The next section explains a method for creating new habits. Consecutively, a section will present how to change habits.

3.4.1 *Creating habits*

There are several theories/models around habit formation. Foggs 'tiny habits', similar to research by Gardner, Lally & Wardle (2012), provides a very practical approach for forming new habits that appears to be effective.

Tiny Habits

With 'tiny habits', Fogg (2013) provides an effective framework for forming new habits. Instead of training the target behavior, Tiny Habits focuses on training a habitual pattern, a routine. The key lies in breaking down a target behavior in tiny steps. This framework consists of three parts, which will be explained below.

1. Tiny steps

The steps to the target behavior should be made as small as possible. These steps should be so easy one can hardly refuse to do it, in order to overcome one's initial resistance to do the behavior. For instance, start by flossing only one tooth. Or put on running shoes when the target behavior is to start running. This corresponds to keeping the simplicity (ability) in the FBM very high, causing motivation for the behavior to be virtually unnecessary. When the first step starts to become more automatic (and therefore easier), the difficulty of the behavior can slowly be raised with incremental steps. Additionally, one's motivation will likely rise due to success momentum. The mechanism of this process is demonstrated in Figure 11. Starting at 1, the behavior gradually becomes easier to do (counting up to 2 and 3), plus motivation will likely rise. After some days, the difficulty of the behavior can be increased a bit (in Figure 11, the blue rounds). Continuing in this way will steadily form the desired habit without needing much motivation.

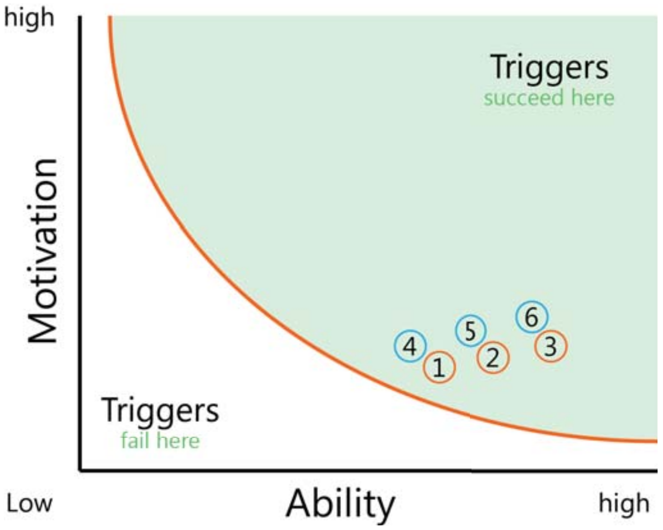

Figure 11 *Tiny Habits explained through the FBM. By starting with a very easy behavior, the motivation required to perform the behavior is low and therefore very likely to occur. From there, the difficulty can incrementally be increased, aided by the gained success momentum.*

Note that it is important to keep taking small steps. It can be very tempting to skip to a more difficult behavior when the tiny step feels too easy, especially when motivational levels are high due to the initial success momentum gained. However, the purpose of the tiny steps is not to train a behavior, but to create a habitual pattern. When increasing the level of difficulty too much, the behavior might fail on a day of lower motivation levels. This is not desirable since forming habits requires ***consistency***. Additionally, this can induce negative feelings in the individual towards him- or herself and thereby further reducing the motivation for the task.

2. Find an anchor

It is important to find the right spot in your day for the target behavior. Fogg suggests introducing a new habit after an existing, emotionally neutral habit. He suggests using the following format: *"After I.... (existing habit), I will.... (new tiny behavior)"* For instance: "after I go to the toilet I will do two push ups". This way, the existing behavior will act as trigger for the new behavior. Due to the trigger already being a part of one's life, forming the habit will be much easier.

3. Celebrate immediately

An important, often overlooked and underestimated factor in creating habits is celebrating the small accomplishments immediately after having performed them for behaviors. When celebrating a behavior of any scale immediately after performing the behavior, a positive association starts to form in the brain. This positive association speeds up formation of the habit and reinforces the behavior. As described by Charles Duhigg (2012), a behavior only becomes truly automatic (as in habit) when the brain starts to crave for the reward when the trigger occurs. The celebration, or reward, can be as small as giving yourself a thumbs up, or saying "good job" to yourself, depending on what feels natural. A good manner of celebration might be found by imagining how one would behave after scoring the winning goal in a football match for instance.

The feeling of accomplishment this propenses generates success momentum, making it easier to maintain and expand the efforts. Fogg states that our brains are not good at estimating the magnitude of our accomplishments. Tiny accomplishments have a disproportionally large positive effect on the brain compared to large accomplishments. When using the right approach, such as with ´tiny steps´, this information can be a really useful tool in order to create success momentum.

The small changes induced by 'tiny habits' grow into larger changes. Even the small changes, and the feeling of accomplishment it is accompanied by, increase the practitioners' confidence. They start to believe they can actually change themselves. This confidence is crucial in making lasting changes.

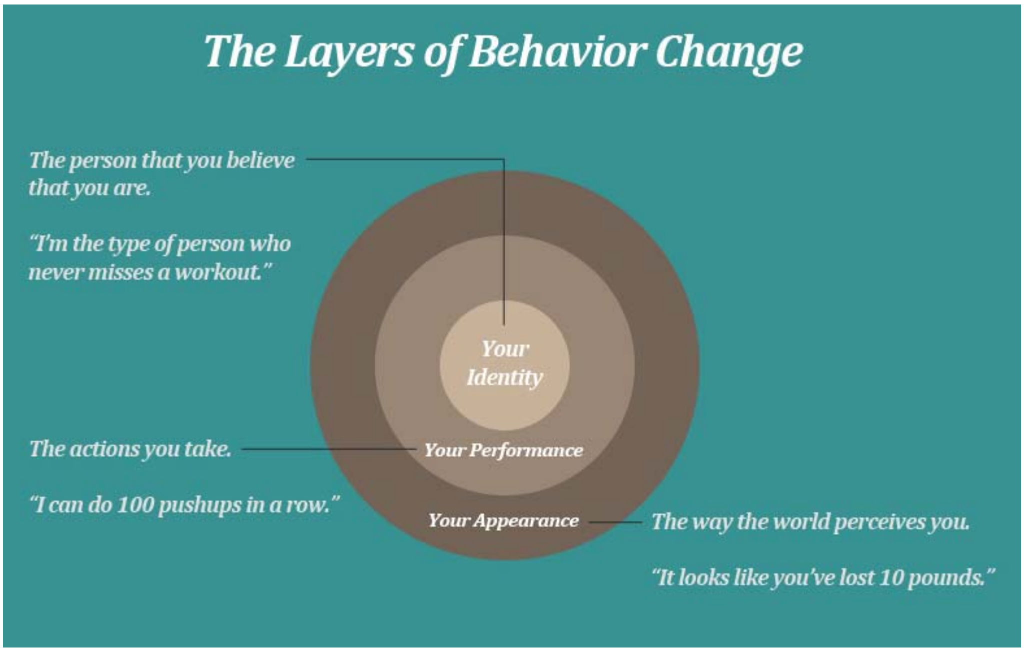

Figure 12 *How people see themselves has a large impact on their behavior, as illustrated in this figure. Transforming their view on themselves into something positive or something they desire to be will help them attain their goals (Clear, 2012.).*

Identity

As James Clear's 'Identity Based Habits' (n.d.) suggests, people's behaviors are a reflection of their current identity; the type of person they, consciously or unconsciously, believe they are.

Overweight people seeing themselves as fat, unfit people, will have a very difficult time changing themselves into a fitter, healthier version of themselves. When instead they start seeing themselves as people who take care of their health, or people able to change themselves for instance, this will positively radiate into their lives. When one believes to be a person who takes care of his or her health, one will start to think, talk, and act it out. In time, this will start to be visible in that person's appearance.

This explains part of the detrimental influence of many diet programs. Aside from the fact that most people gain back their weight (often plus extra) after their efforts, each of these failed attempts diminishes the confidence those people have that they can change themselves and thereby the chances of them succeeding in their goals in the future. They will feel as if they are people who cannot change themselves, while that is, in fact, untrue. However, as long as they retain that feeling, it is unlikely for them to change.

Forming Habits

Fogg advises to take up a maximum of three tiny habits at a time. The following three steps are used to get started with Tiny Habits:

1. Determine a specific behavior you want to learn
2. Break it down in small steps, and simplify it to the easiest level
3. Decide what will trigger the behavior

Research performed by Lally (2010) tested the time it takes for people to attain a certain level of automaticity in a new behavior. Creating habits occurs in the shape of an asymptote; it will approach the line of 100 percent (or lower percentage depending on the difficulty of the behavior) automaticity in time. With a habit defined as 95% automaticity, the median time it took participants to acquire a new eating or drinking habit was 66 days, varying between 18 and 254 days.

This duration of turning something into a habit varies depending on the person, the difficulty of the target behavior and the consistency of performing the behavior. Some behaviors might even take years to fully turn into habits.

Testing Tiny Habits

Self-testing plus testing Tiny Habits on a friend, by teaching him the method, gave the impression that Tiny Habits is indeed a very effective method that is low on mental resources. The feeling of success momentum was also clearly present. Months later, both he and I have made a couple of changes that we perform (semi-) automatically. More on this testing can be found in Appendix 1.3.

3.4.2 Changing habits

Through life, everyone forms an individual pattern of habits. Scientists are starting to get a grasp on behavioral patterns. However, individuals differ; analyzing and changing habits differs between people and behaviors.

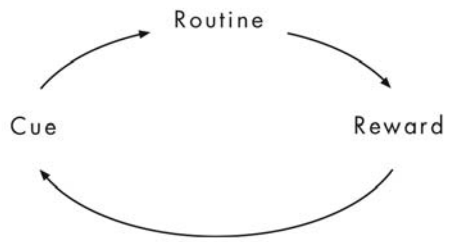

Figure 13 *Charles Duhigg's habit loop (2012), showing the process of how habits occur.*

The 'habit loop' of Charles Duhigg (2012), as can be seen in Figure 13, shows a simple neurological loop that is at the core of every habit. The habit loop consists of three components: a cue (or trigger), a routine and a reward. The cue is the same as the trigger in the FBM:

The following list explains the components of the habit loop.

Cue	What triggers the routine
Routine	The behavior itself
Reward	Something that satisfies a conscious or unconscious craving

A routine will become automatic when the brain starts to crave the reward once the trigger occurs.

As mentioned in 3.4.1, people have to believe they are able to change themselves in order for the habit changing to be effective.

With the habit loop, Duhigg provides a framework for changing behavior. He suggests replacing the existing, bad routine with a better, healthier one. Simply taking away the trigger will usually not suffice; in most cases the habit will still occur, though in a different configuration. There are exceptions: for instance, if stress triggers you to binge eat on unhealthy foods as coping mechanism, avoiding stress will likely prevent this routine from occurring. It is however still very wise to develop an alternative routine for the inevitable case one will be unable to avoid the trigger.

Duhiggs model for behavior change consists of the following four steps:

1. Identify the routing
2. Experiment with rewards
3. Isolate the cue
4. Have a plan

These steps will be explained next.

Step one: identify the routine

The first step consists of deciding what routine someone wants to change.

Step two: experiment with rewards

People are usually unaware of the cravings that drive their behavior. It can be difficult to discover what reward one/one's body is craving. Finding out what craving drives the unwanted behavior requires some experimentation. One should experiment with rewards by substituting the undesired behavior with alternative behaviors which potentially satisfy this craving (see Figure 14). This first phase is analysis. One should not feel pressured to make any change during this phase.

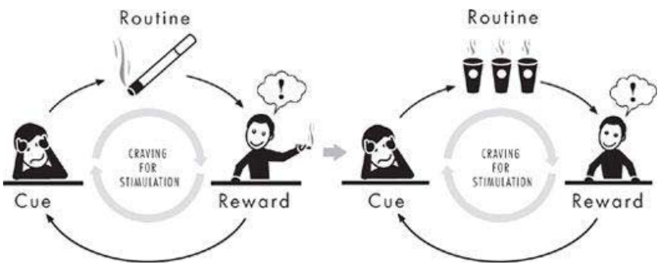

Figure 14 *Change habits by replacing the routine in the habit loop; one which satisfies the same craving (Duhigg, 2013).*

Directly after each alternative routine one has been substituting one's initial behavior with, it is helpful to write down the first three things that come to mind. Writing down those three things creates a momentary awareness. Additionally, later on these few words will help you recall what you were thinking or feeling at that time.

Fifteen minutes after performing the alternative routine, if the craving to perform the initial behavior has disappeared, one has likely discovered the reward he or she was craving. The next step is to isolate the cue.

Step 3: isolate the cue

Due to the large amount of information people have to process constantly, it can be difficult to identify what really triggers the behavior. Categorizing triggers can help identifying triggers. Almost all triggers belong to one of the following categories:

- Location
- Time
- Emotional state
- Other people
- Immediately preceding action

In order to identify what triggers the behavior, one should fill in the following questions each time he or she feels the urge to perform the routine:

- Where are you?
- What time is it?
- What's your emotional state?
- Who else is around?
- What action preceded the urge?

Analyzing the answers to these questions will provide insight into the trigger. Depending on the complexity of the habit, discovering the true trigger may take a couple of days or weeks.

Step four: have a plan

Once the trigger of the routine has been identified, it is time to make a plan for redesigning the habit. The plan should consist of a substitute behavior which provides the reward one is craving when the trigger occurs. It will take time and effort at the start to make this happen. In time however, it will become more and more automatic, and eventually it will become natural (a habit).

Creating a pattern of healthy habits is crucial for long-term behavior change and will eventually lead to a healthy body and weight. Willpower and motivation can be used to create habits when utilizing them to create a consistent pattern. Taking small steps increases the odds of the behavior change to succeed long-term. Additionally small steps are easier to initiate. People should rely on motivation only for initiating new behavior or for making changes.

An effective approach to changing habits is to change the routine within the habit loop, with something that satisfies the same craving.

3.5 *Explorative Interviews*

In order to gain more insight in potential users and their weight (-loss) related problems, a brief field research was performed during the analysis phase. First, an initial interview was done with someone known to struggle with his weight. The purpose of this interview was to gain insight on those who wish to lose weight in addition to providing input for the further interviews.

Next, 5 strangers were interviewed while they were waiting at the train station. Note that this data is likely quite biased. The most important points that came forward are the following:

- Food intake provided the largest difficulty for all participants.
- Those who had tried a variety of diets always failed after some point in time.
- Those who successfully lost and maintained weight had (created) a set eating pattern, and rarely snack in between.
- Those who successfully lost and maintained weight exercised in order to keep healthy and fit.

More on this research can be found in Appendix 1.

4. Automatic Food Intake Tracking

This section of the analysis has been performed during and after conceptualization. It has been placed at this location in the report for the sake of readability and overview.

Automatic Food Intake Tracking

Current products on food intake tracking consist of electronic food diaries, which help users in tracking their daily caloric and nutritional intake. However, there are several disadvantages for long-term self-reporting. Research by Sazonov et al. (2008), Sazonov & Fontana (2012), Amft (2010), and Liu et al. (2012) shows that self-reporting tends to be inaccurate, both for reporting on eating frequency and on dietary intake. People tend to make errors in reporting their intake and report less than what they actually ingested. In order to create an accurate overview of one's intake, it is important to track intake automatically. Automatic tracking will increase the accuracy and simplicity of tracking intake and helps to create more insight into one's patterns.

Technology is not yet at a point where caloric intake can me measured automatically; at least not using non-invasive methods. However, several research papers exist in which the automatic recognition of the act of eating is researched and tested through various sensors. This chapter will show and shortly discuss the different options that were found during research to automatically recognize eating.

For medical reasons, in cooperation with a doctor, invasive methods could be suitable and effective. Options such as measuring blood glucose or a dental strain gauge sensor implant (Amft, 2010) can be used to track eating. However, for a consumer product, an invasive product is not preferred. For the comfort of the users, the choice was made to search for a non-invasive option.

The choice for an on-body solution was made in 5.2 for the reason that it enables tracking eating continuously during day. For this reason, options such as (at home) video recognition to track eating will not be considered.

Indirect sensing

A short look was also taken at sensors that measure reactions in the human body that occur after eating. For instance, after eating, the body's temperature will rise due to the thermic effect caused by metabolizing the food. However, these are indirect responses and give inaccurate results. The windows of eating are hard to determine using these indirect techniques. Additionally, aside from the time of ingestion being inaccurate, even in case the ingestion is measured correctly it is sensed only a certain amount of time after the start of ingestion. This is not ideal for analyzing triggers. For these reasons, research on these sensors was discontinued.

Non-invasive, on-body, automatic intake recognition methods

Actuation

- **Accelerometers (arm gestures)**

  Amft, Junker & Troster (2005) use inertial sensors on the wrist and upper arms in their research to recognize eating. An accuracy of up to 87% was reached in continuous movement data of predefined movements using cutlery. Eating with a spoon only resulted in a 52% accuracy. Adding a proximity sensor between the arm and the collar could significantly improve the accuracy. This study is limited in multiple aspects, such as the test group consisting of only two people. A lot of further research needs to be done in order to improve the recognition, especially in a real-world setting.

Gesture recognition using accelerometers could be a method of tracking food intake in the future. However, up to this point, the research is not far enough to be sure it is feasible, especially within the scope of this project. On top of this, it requires 4 sensors spread over the arms. With the current state of technology this is not very practical for daily use.

Acoustical methods

In chewing recognition through acoustical methods, algorithms analyze characteristic sound frequency spectra of chewing to recognize intake.

- **In-/on-ear microphone (for air transmitted sounds)**

  Using in- or on-ear microphones, air conducted vibrations of food chewing can be sensed. In a study by Amft (2010), a small omnidirectional electret microphone (most widely used form of microphone) was used. Close proximity of a microphone to the ear canal allows for a proper recording of chewing sounds. Note that these air transmitted sounds are prone to environmental noise. Amft (2010), Liu et al. (2012), Amft et al. (2005), Nishimura & Kuroda (2008) and Päßler, Wolff & Fischer (2012), all show proper functionality of chewing recognition using in-ear microphones. Liu et al. (2012) performs the detection tests with significant environmental noise, resulting in an 82.5% detection rate for eating and 28.6% for drinking. The low detection rate for drinking is caused by its low sound volume, which is suppressed by the loud background noise. Recognition rates for chewing range from around 83% (Liu et al., 2008; Päßler, Wolff & Fischer, 2012) to 99% (Amft et al., 2005; Nishimura & Kuroda, 2008) for chewing depending on the environmental noise on the test setting and presumably also the algorithm used for the detection. In-ear is an unobtrusive location for a sensor that is socially acceptable due to the common use of in-ear headsets. A point of attention is the comfort and possible irritation due to daily wearing in-ear headphones for approximately 16 hours a day. Additionally, wearing it constantly may still be problematic in social settings since others might think the user is not interested in what is being said

- **Bone conduction microphone (for sounds transmitted through solids)**

  Chewing recognition through bone conduction, or contact microphones, works similar to that of generic microphones. The difference is that sound is transferred through solid objects instead of through the air. Sazonov et al. (2008) and Shuzo et al. (2010) both show intake detection through bone conduction microphones is effective. Zheng et al. (2003) tests an in-ear bone conduction microphone for separating the user's speech from background noise. It shows that a bone conduction microphone is insensitive to ambient noise and captures the lower frequencies of speech signals (see Figure 15).

- **Throat microphone**

  A throat microphone picks up vibrations directly from the throat. It is also a contact microphone and is commonly used for communication in situations with a high level of environmental noise, such as on a motorcycle or in military applications. The application of this sensor should be similar to that of the previously mentioned (in-ear) bone conduction microphones, though the picked up signals will differ. A throat microphone would be more effective for recognizing food intake through swallowing compared to chewing.

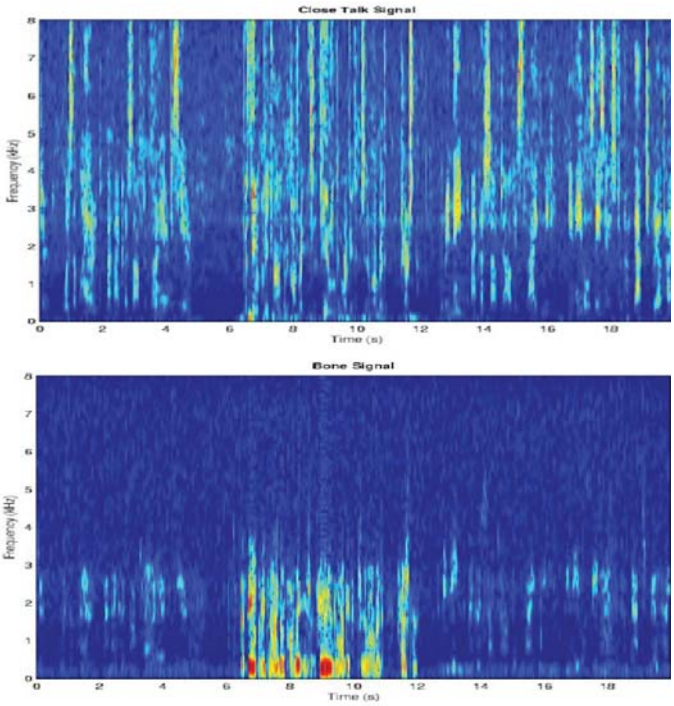

Figure 15 *Spectral view (0-8kHz) of a regular microphone (top) versus a bone conduction microphone (bottom) (Zheng et al., 2003)). Whereas the regular microphone measures the complete spectrum of speech plus the environmental noise, the bone microphone captures the lower frequencies of the signals and filters out the environmental noise almost completely.*

Acoustical methods all provided promising results and seem to be a feasible method to use within this project. In addition to detecting mastication and swallowing, multiple of the mentioned papers have started with food texture class recognition through spectral bandwidth analysis (Amft, 2010; Amft et al., 2005; Shuzo et al., 2010). Although this research is only at a point of separating some basic foods, the results seem promising. For instance, in research by Amft (2010), an accuracy of 86.6% was reached for categorizing apples, chocolate, chips and carrots through spectral bandwidth analysis. This can provide valuable additional input for the user in the future. For instance, perhaps a certain trigger makes one crave for food with a crispy texture. Signal energy is found to be a critical element in clustering foods.

Other methods:

- **Strain-gauge sensor, piezoelectric**

  In research by Sazonov & Fontana (2012), a strain-gauge sensor is placed on a person's jaw in order to recognize periods of food intake by monitoring characteristic jaw motions (see Figure 16). Attachment of this sensor can be problematic for daily use. Sazonov & Fontana state the sensor can be diminished in size and made into a wireless 'band-aid' sensor in the future. It does not seem optimal however to need adhesives, that need replacing, for attaching the sensor for daily, long-term use

- **Photo-reflector**

  Kitazono et al. (2011) use a photo reflector consisting of an infrared LED and a photo detector to recognize chewing (see Figure 17 and Figure 18). Changes in distance measured between the sensor (attached to the ear and pointed to the jaw) and the jaw are used for the chewing recognition. The regularity of the movement of the jaw dictates the difference between talking and chewing. According to Kitazono et al., this provides a solid, accurate recognition for chewing. This does not seem like a design to be used in daily life however. At best it might be given the appearance of a headset (the type with a microphone sticking out on the side of the user's face). Due to its bulkiness, the necessary hovering placement above the jaw it will remain bulky and obtrusive.

- **Surface EMG**

  An EMG (electromyogram) measures electrical activity in the muscles. This technique could be effective for recognizing the ingestion of food by analyzing mastication (chewing) muscles of the jaw and potentially also of the throat (swallowing). Contrary to an intramuscular EMG, a surface EMG is non-intrusive. Electrodes used for surface EMGs measure muscular activity through the skin. The electrodes require precise placement, directly above the muscle on the skin. Fat can affect EMG recordings, resulting in lower signal strength and less accuracy. As stated by Sazonov & Fontana (2012) and Shuzo et al. (2010), in daily life this technique seems unpractical due to its obtrusiveness, facial placement and method of attachment (through adhesives normally).

These three sensors, as explained in the bullet points, do not seem ideal for chewing recognition. Especially considering the alternative of the acoustic options, these options have lower potential. The following table shows an overview of the discussed methods along with their ups and downs.

For a quick view, Table 2 provides an overview of the technologies described in this chapter.

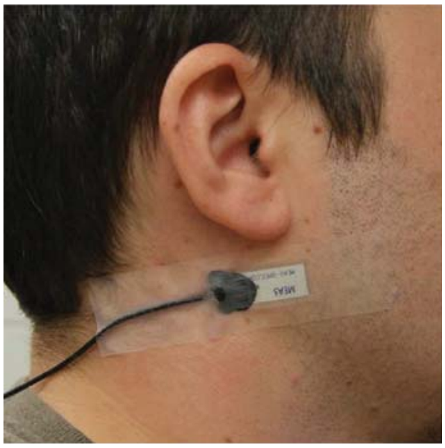

Figure 16 *Strain-gauge sensor adhered to someone's jawline in order to monitor characteristic jaw movements for intake recognition (Sazonov & Fontana, 2010).*

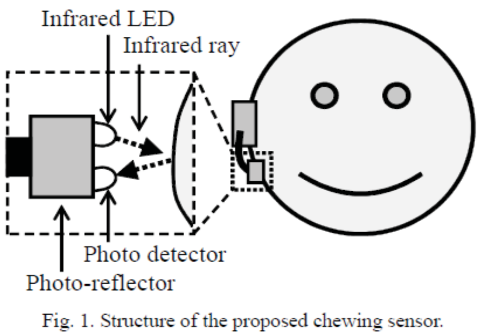

Figure 17 *Shows the functioning of the photo-reflector sensor used for chewing recognition in the research by Kitazono et al. (2011).*

Figure 18 *The photo-reflector sensor as used in the research by Kitazono et al. (2011).*

Chosen sensor category

Based on the collected data, the acoustical sensors appear to be have the highest potential for intake recognition within this project. More research and testing on these sensors can be found in chapter 7.

Acoustical sensors appear to be best suitable option for intake recognition within this project. Solutions can be accurate, small, non-prominent, and acceptably priced. Multiple studies have showed the feasibility of chewing recognition using acoustical sensors. Additionally, possibilities exist for texture category recognition in the future.

Table 2 *An overview of the technologies for chewing recognition described in Chapter [4], along with an impression of their pros and cons. Note that this concerns the current state of the technologies.*

Sensing technology	Bites	Chews	Swallows	Sensitive to environmental noise	(potential) Comfort/ obtrusiveness	Design possibilities	Implementation difficulty within project	Impression of accuracy	Odds of social discomfort
Accelerometers (arm gestures	V	x	x	n/a	+/-	-	--	-	+/-
in-ear mic (for air transmitted sounds)	x	V	V	-	+/-	+/-	+	+	+
Bone conduction microphone	x	V	V	++	+/-	++	+	++	+
Throat microphone	x	x	V	++	-	+	+	+	-
Strain-gauge sensor	x	V	x	n/a	+/-	-	+	+	-
Photo-reflector	V	V	x	n/a	--	--	+	+	--
Surface EMG	x	V	x	n/a	--	--	-	++	--

Conceptualization

This section will concisely show the global idea and concept development process, up to the choice of concept.

5. Ideation

In conclusion of the analysis phase, a List of Requirements (LoR) and a Design Vision (DV) were made. Various brainstorms have been performed during the ideation phase. Depending on the type of brainstorm, the Design Vision and LoR were either kept in mind during the brainstorm, used as guidelines, or used to filter and combine ideas after the brainstorm.

5.1 *Design Vision*

The Design Vision provides a personal image of the way the to be designed product should function in its context, based on the performed analysis.

Identity

My vision on designing for those who are overweight is to change how people view themselves and approach their weight loss, with a focus on energy intake. They should believe they are able to change themselves, contrary to what previous attempts might have made them start to believe. In order to accomplish this, the feeling of failure, which causes many to be severely demotivated or even quit, should be eliminated.

Scientific approach

If people were to look at themselves from a distance and see themselves as the subject of a scientific study, this feeling of failure would be greatly diminished. A bad day, instead of failure, would be seen as good data. If something would turn out not to be effective, they would attempt a different approach. Everything, the good and the bad, is useful input for self-analysis.

Personal Habits

Creating a pattern of healthy habits is the key to long-term behavior change. Eventually these habits will lead to a healthy body and weight. Everybody is different and there is no one-fits-all solution for weight loss. The design should facilitate behavior changes people desire to make in a manner that fits their lives, which also means a low requirement of willpower.

Simplicity

The design should focus on simplicity. Any form of tracking should be easy or automatic. Steps taken to change should be small. The smaller the steps taken, the more likely they are to stick. Aside from the low mental resources necessary to take these small steps, they will create success momentum which can increase one's confidence and help dealing with more difficult aspects.

Health

Weight-loss should be about health, not weight alone. Though a negative caloric balance is what makes one lose weight, calorie counting alone can make one focus on the wrong things. Instead of health and nutrition, the focus with calorie counting lies purely with energy intake. While this can make one lose weight, it is usually hard to sustain. The human body is better at regulating itself while eating nutritious foods. Hormonal balance is said to (at least partially) be restored in time when eating a proper diet combined with a recommended amount of daily activity, which makes it easier to sustain results. Additionally, when the body receives a nutritious diet, one will feel better and more energetic in general. Portion control is also very important. Instead of calories, pictures of a normal day´s worth of food for instance can be very clarifying.

Positive

Although negative reinforcement can be an effective tool, especially combined with positive reinforcement, positive reinforcement in itself is the preferred approach. Used in the right way, it can be very powerful. Encouragement should not only be provided when people are improving; maintenance should also be rewarded. For many, weight maintenance is the most difficult aspect of losing weight; largely because they miss the boost they got from seeing progress. Adding a form of biofeedback when the goal weight is reached is also very effective.

5.2 *List of Requirements*

This List of Requirements (LoR) includes important aspects of the performed research that should be implemented in the design. The Requirements show important aspects that should be implemented in the design and which are testable within the scope of this project.

The aspects listed below Wishes are important as well and should be implemented in the design if possible. The reason these are not listed under Wishes instead of Requirements is that they are hard to be quantified, or that that there won't be enough time within the scope of this project to test them. For instance, the wish 'Helps people in improving their eating habits', although a crucial aspect, is placed in the Wishes category since it is not possible to test this aspect properly in the scope of this project.

Table 3 *LoR. The Wishes and Requirements are both important. However, contrary to the Wishes, the Requirements are (easily) verifyable.*

Requirements	Origin
Usable in combination with a smartphone and/or tablet	[1.2] *Assignment*
Increases awareness of eating patterns	[2.4] *Environmental and psychosocial causes.* To counter the influences of the food industry
Increases awareness of triggers and rewards	[3.4.2] *Changing Habits*
Easy or automatic tracking of intake activity	[3.2.1] *Simplicity & Simplicity versus Motivation*
Non-invasive	This project aims to design a consumer product. Though for medical purposes interesting options are available, the barrier for people to use an invasive product is high
Wishes	
Helps people in improving their eating habits	[1.1] *Problem Definition*
Comfortable and easy to use	[3.2.1] *Simplicity & Simplicity versus Motivation*
Non time-intensive	[3.2.1] *Simplicity & Simplicity versus Motivation*
"Scientist approach"	[5.1] *Design Vision. Neutral, analyzing attitude towards themselves*
Personal approach of the application (helps to find the right approach for you)	[5.1] *Design Vision* . The definition of an efficient approach varies greatly per person
Fun/entertaining to use	[3.3] *Fun Theory*
Positive approach	[5.1] *Design Vision*
Provide means for people to, step by step, change their environment	[3.2] *Understanding Human Behavior*
Socially acceptable	[3.2.1] *Simplicity & Simplicity versus Motivation*

5.3 *Ideation*

As mentioned in 1.3, a heuristic approach to design was taken during this project. Idea generation and research were performed parallel to each other during the course of this project. Ideas that took shape while researching in the analysis phase of the project were written aside while continuing the research on the topic. Inspiration was gained for instance by exploring current Bluetooth application and smartphone add-ons on the market, and drawing quick storyboards of a person's day. After the main research had been performed, the focus was shifted to idea generation.

Ideas varied widely, from reducing one's appetite by reducing sense of smell to movement sensors which can reduce the intensity of the light or the speed of the internet when too little activity is sensed. The following are a couple of examples of ideas that popped up during the analysis:

- A Bluetooth lock which can be placed on the inside or outside of the fridge, or on a cupboard where one puts their unhealthy food. Beforehand, using an app, one can set the times the lock will be open, and thereby when one is able to access the food inside. This can help people in adhering to their plans, while still providing them with the autonomy to make their own plan. This is basically environmental control. Some people decide to not buy unhealthy foods and thereby reduce temptation for themselves. This is simply an alternative, with a little less/a different kind of restriction. It will reduce the willpower necessary to reduce intake of (certain) food(s) in the house. Additionally, it can reduce the number of times one fails to adhere to one's diet plans and thereby help achieving/fostering the feeling one can change. In case of emergency, a self-appointed friend can be asked to open the food source.
- Weighing shelves, to be placed on normal fridge or cupboard shelves. These shelves can communicate weight difference to a nearby tablet or phone, easing calorie counting. When using one on a shelf purely for snacks, it is easy to track when and how much a person is snacking. When sorting food, it can be a quick and dirty method for seeing how much of different kinds of food one eats relatively to the other, which can put things in perspective. When seeing one is eating 100g of vegetables and 200g of snacks on an average day for instance, this can be a good reality check.

At one point, idea generation was split into three interesting and relevant contexts:

1. On-body

Part of the population eats too much throughout the day. They may snack during office hours, in the evenings and in the weekends. Their portions can be too large. For part of the population, much of this happens semi-consciously or is quickly forgotten. On-body sensors could for instance provide the user with insightful information about their patterns and help them realize how much they actually eat.

2. In-house

For many people, the problem with food intake lies mainly in snacking at home. In this context for instance something that changes the home environment or stimulates the user to change it for increased simplicity of adhering to the desired behavior, or a product that helps to separate coupled bad behaviors (e.g. eating chips while watching tv) could help the user with his or her goals.

3. Parent-children interaction

To take another point of view, it is interesting to look at the interaction between parents and children. Children can be reached through their parents and vice versa. Children are subject to their parents habits. Low activity levels combined with bad teachings on food and drink intake induced by the parents often lead to unhealthy, overweight children. Parents want what is best for their children. Within this context, parents and children can learn a healthy lifestyle together in a fun, interactive way. When the parents realize the negative impact their own lifestyle can have on the health of their children, this can be a powerful motivator to improve their own behavior.

Basic context choice

After some brainstorming, the choice was made to continue with on-body sensors. Using on-body sensors, patterns can be tracked through the whole day, which is important for a proper analysis. With in-house solutions, only problems at home can be addressed. Although the parent-children interaction is interesting, coming up with a solution for this problem might be more of an interaction solution and will be quick to land outside the scope of this assignment. Therefore, the choice was made to continue with on-body solutions.

Individual brainstorms

Aside from normal brainstorms and mindmaps, a number of lateral thinking techniques was used in order to gain inspiration and a variety of ideas:

- Provocation

Works by thinking of something relative to the situation that is taken for granted and making a wrong or unreasonable statement about it, e.g. 'people know exactly how many calories they ingest without ever having consulted caloric values'. This statement, called provocative operation (Po), provides you with a new angle to look at the problem and thereby stimulates creative thinking. An example of this can be found in Appendix 2.

- Random input

Opens new lines of thinking by using random input in brainstorms. This input can be words, pictures, or even sounds for instance.

- Rolestorming

Brainstorming where one takes another identity, e.g. a superhero or a drunk person. Aside from taking away the shame some people experience in outing their ideas, this technique enables viewing problems and potential solutions from another standpoint.

Group brainstorm

A group brainstorm was done with a group of five colleagues from DoBots. It took place over the course of an afternoon. At the start, the most important theories were explained briefly together with the goal of the brainstorm session and the project itself. This information was also written on a whiteboard for reference. The basic brainstorm rules were: no criticism during the brainstorm, wild ideas are welcome, and aim for quantity; later, elements of different ideas can be mixed and matched to reach quality. As a warm-up exercise, a brainstorm was done on 'Food and drink intake triggers', to get as many associations as possible until the A2 paper was filled.

Next, all participants were supplied with felt-pens and a stack of sticky notes. Five A2 papers with 'how to' statements were divided among the team:

- How to use games to create a fun environment to improve intake habits
- How to give someone a rewarding feeling
- How to make someone more aware of their triggers
- How to make someone more aware of their eating habits
- How to track someone's food intake (both manually and automatic)

Every 4 minutes, the papers were passed along the team clockwise. At the end of the brainstorm, the ideas were clustered over a line ranging from 'easy' to 'complicated' to 'crazy'. Clustering had two purposes:

1. To talk through the ideas and get new input on them.
2. To receive an idea of the feasibility of the concepts. Technical people were present with knowledge on technical feasibility.

More on the results of the brainstorms can be found in Appendix 2. After the brainstorm, an overview was made of most notes on the 'how to' questions, supplemented with more of my own ideas. This table can also be found in the Appendix.

After these brainstorms, the forming of concepts was started.

6. Conceptualization

After generating a variety of ideas, concepts were formed by taking aspects of the best ideas and combining them.

6.1 *Concept Generation*

The guidelines of the assignment combined with the outcomes of the ideation caused the decision to create an add-on with an accompanying app. Due to the importance of making permanent changes, the focus of the app will be to change eating habits.

The following three concepts were chosen to be best and most interesting based on the Design Vision and the List of Requirements.

1. Camwatch

The base of this concept is to, with little effort, take photos of everything the user ingests. This will provide the user with a direct impression of his or her intake. Images of ´normal´ meals or daily intakes will be shown next to the user´s own intake for comparison to easily create more awareness. The idea of the comparison is simply to educate so that users can gain insight on how to improve their diet without the intrusiveness of having to log all they eat and drink. A photo overview of the food (and liquids) ingested through the day also leaves a quick impression on the overall health of the intake. The action of taking photos itself will additionally create a momentary awareness of that, and what, the user is eating or going to eat.

Macronutrients, (graphical) caloric values and color coding for a health indication on different kinds of foods can be displayed occasionally, in a daily tip for instance, to gradually increase the user's knowledge and thereby ultimately help them make better choices. Minigames can also be added that teach the user about what they are eating.

A camera integrated in a (smart)watch would be a practical, socially acceptable manner to apply this concept. It might however be difficult to need two arms in order to make a picture of what you are eating, especially when eating snacks. Instead of pushing a button, a different triggering mechanism such as speech or a specific arm or wrist movement could be used to take photos. Other options for placements of the unit are an attachment for glasses, a necklace, or on a clip free to place on a preferred location on the body.

When finished with eating, another picture can be taken to gain data on the duration of the meal in addition to the extent of finishing it. These photos will be bundled by the app. The difference in taking one or two pictures can be set by either short-pressing the trigger button for a snack, or longer pressing for a meal where two photos will be expected by the app. When opening the app at a later time convenient for the user, the photos can be categorized by swyping them to the suitable folders which can be renamed by the user. Users can choose to add photos of other things or activities they want to keep track of as well, such as exercise.

An additional value of this concept is that the photos of one´s food can also ease identifying the triggers of one´s eating. Photos trigger the memory. Additionally, in the photos, (parts of) the trigger can often be identified, such as a certain location or previous action. Games such as 'find the similarities' between different photos categorized in a folder of choice (e.g. 'unplanned snacking') can aid the user in finding their triggers.

2. Automatic camwatch combined with intake recognition

Although taking a photo of what one ingests is much easier and less intrusive compared to keeping a caloric intake diary, it is still prone to some of the same disadvantages of logging intake. Users might forget to capture something they eat or withhold from capturing part of their intake due to feelings of shame for instance.

This second concept is the same as the previous one, except that the photos will be taken automatically based on sensors that measure that one is eating or drinking. Due to the automatic nature of the tracking, the collected data will be more objective and complete. Aside from the usefulness to the user, it can also provide valuable, objective information for dietists. Unless users will exert effort in cheating the system by preventing the camera from taking (proper) photos, an objective, complete overview will be automatically be created. Although it will always be possible to cheat the system with this kind of product, the data will be much more reliable compared to self-reporting. In terms of nudging: with automatic tracking, the default is that all intake will be tracked; it takes effort to prevent foods from being tracked. Also, because the photos are taken automatically, the user's mind will usually be occupied with other things. With manual tracking, the user consciously has to make the choice to take a photo of the intake. The default of manual tracking is to not track the intake.

In this concept it might be difficult to properly aim the camera on the food while keeping the add-on small, unobtrusive and comfortable to wear. Also, properly timing taking the photos and distinguishing a meal from several snacks eaten in a row might prove difficult.

3. Automatic intake recognition

This concept is the same as the previous concept, with the exception of there being no camera function. The main reason for leaving out the camera is the potential social discomfort to have a device automatically taking pictures attached to you. The camera can make others, as well as the user his- or herself, feel uncomfortable, self-aware and worried about their privacy.

This concept is aimed at finding and analyzing intake patterns and to thereby help finding the user's triggers. Additionally, for dietists this can provide very valuable data on the users.

6.2 *Choice of Concept*

In order to increase insight and to help choose the best concept, the Narrative test was done. This test consisted of me manually taking photos of everything I ingested for a week using a small clip-on camera called Narrative.

Automatic tracking

First, to discuss the necessity of automatic tracking: during the first couple of days, taking photos of all I ate seemed to be fine: no big deal and not too much effort. In these days, I had a normal, healthy pattern of three meals a day with perhaps an apple in between. However, in the weekend I had a birthday among other things, and had already planned to snack more due to not having eaten enough in the weekdays. However, even when not considering the social aspect, it became quite annoying to have to take photos of every snack and handful of chips I was eating at the birthday. This feeling was amplified by the non-ideal

Figure 19 *The Narrative clip attached to a vest. This camera takes a photo automatically every 30 seconds. Additionally, photos can be made by double tapping the device.*

interface of the Narrative. In the end I consciously skipped several bites of food at the birthday due to its tediousness. The last days I simply forgot to take photos a couple of times, or remembered only after finishing the meal or snack.

This test made me realize that having to take photos of everything one eats is still too much effort and prone to error in the long term. Especially when the user's diet involves snacking through the day, which is the case for many overweight people.

This insight combined with the evidence found in Chapter 4 showing that self-reporting has been proven inaccurate, made for the realization that ***automatic tracking is necessary for this concept to be effective***. With the use of automatic tracking, an unbiased overview of the intake will be created in addition to lowering the impact on the user's life.

This decision leaves concept 2 and 3.

Photos

When wearing the Narrative, many people asked questions about what it was and why I was wearing it. When explaining it was a camera that automatically takes a photo every thirty seconds, some people noticeably became a bit uncomfortable. Even I myself, especially during the first days, often felt aware of the presence of the camera. Partly I felt aware of what the camera would capture of me and what I was doing, but also the worry about other people's privacy and how they would feel about the presence of a camera.

For most people, including for me, it is undesirable and it gets tiring to constantly have to explain your actions or what you are wearing. The effect will be even larger when the wearer of the camera would actually be wearing it in order to lose weight. Some people like to talk about their weight loss. However, many want to keep it to themselves aside from selected people perhaps, for various reasons (e.g. to avoid people giving them 'advice' while they do not have proper knowledge on the situation, or simply because they feel embarrassed about the subject). In this situation, the less noticeable the product, the better.

Due to concerns for other people's privacy and the negative social impact that wearing a camera can have on the user's life, ***the decision was made to turn away from the idea of automatically tracking the user's intake using photos***.

Intake tracking should be automatic in order to lower the impact on people's lives and to create an unbiased overview of the user's intake.

Automatically taking pictures of the user's intake will have a negative impact on the user's social life and will create privacy concerns for surrounding people. For these reasons concept 3, the automatic chewing recognition, has been selected to be the best concept for this project.

Embodiment

This section will elaborate on the different aspects of the concept: the functionality, technology, shape and accompanying app. Starting with studying the feasibility of automatic intake recognition, a type of sensor will be chosen and an algorithm written. The focus on this research lies with attaining functional eating recognition. The possibility of drinking recognition was considered as well, though not worked out. This thesis works towards a proof of concept of the chewing recognition.

Due to the many different aspects and possibilities within this concept, choices had to be made as to which aspects should be worked out in more detail. Section 8.2 will provide more information on the choices made.

7. Sensor Prototyping

In order to research the feasibility of the concept and to be able to continue designing, it was important to first find out whether automatic intake recognition would be feasible, and what type of sensor should be used in the design for the intake recognition.

In chapter 4, a variety of possibilities for intake recognition are discussed. An acoustic solution is concluded to be the best option for this project. In order to test what type of microphone is most suitable for this purpose, different types of microphones were tested.

7.1 *Testing Microphones*

After performing basic research on microphones, a couple of small sensors were bought for initial testing: electret condenser microphones small enough to fit inside an in-ear phone, and piezoelectric transducers. In-ear bone conduction microphones and throat microphones were also looked for, though not found commercially available or too expensive. The decision was made to first find out whether the other sensors worked. To test the sensors, they were connected to the microphone input of a laptop using a common audio plug. The audio was recorded with WavePad software, an audio editing and analysis program.

In-ear phone speakers

In-ear phones were utilized as housing for the electret condenser microphones. Apparently the speakers of the earphones functioned quite well as microphones themselves, though the received signal was not very clean. Therefore these were also tested as sensors.

Electret condenser microphones

Electret condenser microphones, a type of electrostatic capacitor-based microphones, are widely used in various recording settings. The majority of microphones made today are electret microphones.

After testing the in-ear phone's speakers, these speakers were replaced by electret condenser microphones (TOM-1242L-NF-R) as can be seen in Figure 20. The output of these microphones was too low to be able to record sound. In order to

Figure 20 *Electret condenser microphones embedded into in-ear phones. The signal output of these microphones, without amplifier, was too low to process.*

create an audible (and usable) sound level using these microphones, an amplifier was necessary to increase the output signal. An amplifier design was made using Ltspice 4. However, before having built and tested the amplifier, the choice was already made to use another type of microphone for the design. This will be explained in 7.1.2.

Contact microphones

A contact microphone, or piezoelectric transducer (piezo), senses vibrations through solid objects. Contact microphones are insensitive to air-borne vibrations. They work by transforming vibrations (deformation) into an electric signal; the piezoelectric effect. When using a contact microphone on a person's (skin on top of the) bone, it is also called a bone conduction microphone.

For bone conduction (with either microphone or speaker function), the following spots on the head are known to be used: in-ear, on the

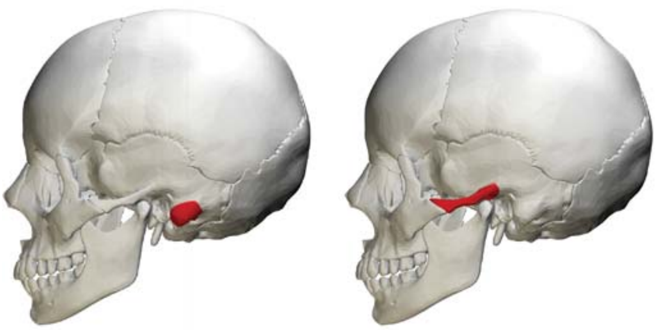

Figure 21 *Possible practical locations for the bone conduction microphone. The red selection on the left image shows the mastoid process; the image on the right shows the zygomatic process (Database Center for Life Science, 2014a; 2014b).*

mastoid process, and on the zygomatic process. The location of the last two mentioned bones are illustrated in Figure 21. These three locations are practical for the following reasons: stable bone placement, absence of hair, subtle placement, relatively small presence of fat, and possibilities for attachment. Aside from these locations, placement of the contact microphone on the throat and chest will also be tested.

To start with, a basic piezo buzzer was tested as a contact microphone, as shown in Figure 22. This piezo gave a lot of noise and did not provide a very clear distinction of chewing sounds due to the high level of noise when pressed against the zygomatic process. The noise almost overruled all audible sounds. Adding a resistor did not improve the sound quality. The noise differed considerably depending on the piezos' applied location on the head.

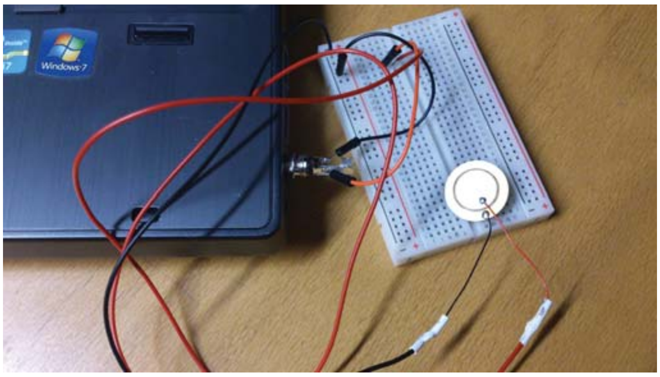

Figure 22 *A piezo sensor connected to the microphone input of a laptop. Using Wavepad, the input was recorded and analyzed. The signal to noise ratio in these recordings was very low.*

Studies show however that it is possible to receive a decent signal from bone conduction microphones, and that signal processing is feasible concerning chewing recognition (see Chapter 4). The next step was to figure out how to receive a cleaner signal.

7.2 Mogees Reverse Engineering

The Mogees (2014) is a contact microphone meant for making music. It picks up vibrations of the (solid) surface it touches, which are then converted into sounds by a phone application.

DoBots happened to receive the bèta Mogees fresh from the Kickstarter when the sensor research was being performed. The Mogees was also used as audio input for the laptop. This sensor provided clear, low-noise recordings with next to no environmental sound. When placed against the zygomatic process, chewing was clearly distinguishable.

To find out how the Mogees differs from the bare piezo and therefore causes the large difference in sound quality, the Mogees was reverse engineered.

Analyzing

Figure 23, Figure 24 and Figure 25 show the components and electronic scheme of the Mogees.

Analyzing the Mogees showed it consists of very basic components: a piezo disc stuck (probably glued) to a plastic housing, a PCB (Printed Circuit Board), two 12 kOhm resistors, a switch, and a sort of gel. The switch can change the resistance between 12k and 6k Ohm. Its purpose is yet unknown, though suspected to serve a purpose related to phone input. The final component is a sort of gel, of which the purpose is likely to cut off some of the higher frequencies.

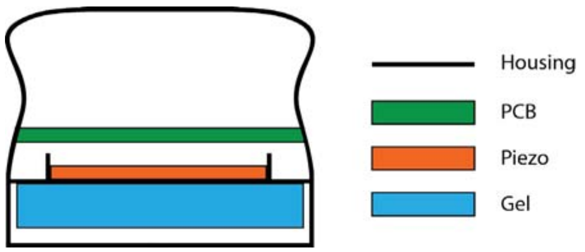

Figure 24 *Schematic section view of the Mogees, showing the location of the important components for the analysis.*

Figure 23 *The Mogees taken apart. The hardware consists of basic components: a piezo, two 12 kOhm resistors, a switch, a PCB, the housing and a sort of gel.*

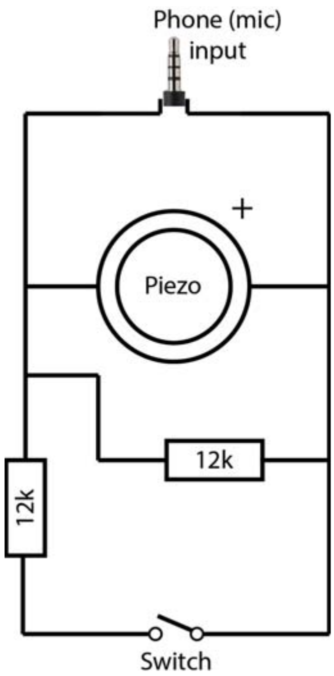

Figure 25 *Electronic scheme of the Mogees.*

The following hypotheses were made to explain the large difference between the bare piezo and the Mogees (the last two points were not expected to be responsible for the large difference, though kept open as option):

- Resistors
- Attachment of the piezo to a solid object
- (The shape of the housing
- The gel)

Testing the hypotheses

Resistors:

No audible difference was found between using and not using a resistor in the circuit, meaning the resistors are not the cause of the difference in signal quality.

Attachment of the piezo to a solid object:

Next, when gluing a piezo to a flat piece of plastic using a glue gun, the sound quality of the piezo improved drastically. It only had a slightly higher noise level compared to the Mogees. This means the attachment to a solid object is what improves the sound quality. By simply gluing the piezo to a piece of plastic using hot glue, the sound quality became sufficient for chewing recognition.

Testing different on-body locations

To explore possibilities, the piezo was tested on different parts of the body.

- When placed on the lower chest or stomach, chewing and swallowing were inaudible on the recordings, which ruled out the option or placing the sensor invisibly under the user's shirt.
- When placing the piezo on the throat, swallowing was audible and talking was recorded clearly. Chewing however was inaudible on the recordings.
- When placing the piezo on one of the facial bones, chewing was clearly distinguishable. Talking is audible as well, though on a lower sound level compared to chewing. Normal swallowing seemed inaudible.

Chewing is a better indicator of eating compared to swallowing. Chewing recognition has the potential to provide more information, such as the speed and count of chewing, and information on the texture of the foods eaten. Additionally, the signal strength of swallowing is lower and therefore the detection less robust compared to chewing, as can also be seen in research by Liu et al. (2012). Therefore, placement of the piezo on the facial bones is preferred over placement on the throat.

The possibility of recognizing swallowing from the facial bone is not yet certain. Though normal swallowing seemed inaudible on the recordings, research by Shuzo et al. (2010) shows that swallowing recognition is possible when using an in-ear bone conduction microphone and research by Sazonov et al. (2008) that this is also possible using a mastoid bone conduction microphone. This does however not provide guarantees for the piezo sensor placed on the zygomatic or mastoid process: though they both are bone conduction microphones, the sensor used in the research performed by Shuzo et al. (2010) and Sazonov et al. (2008) are different from the one tested.

Sensor type choice

The two types of microphones are both suitable for chewing recognition. However, contact microphones are preferred due to their low ambient noise levels and design possibilities. The low environmental noise levels of bone conduction microphones allow very robust chewing recognition. Electret condenser microphones are prone to environmental noises which will hinder the recognition. Additionally, contact microphones have more on-body placement possibilities. Where electret microphones can only provide functional chewing recognition inside the human ear for chewing recognition, contact microphones have additional placement options allowing for more design possibilities.

Bone conduction microphones appear to be best option for chewing recognition in the light of the current project for the following reasons:

- No/very low ambient noise levels
- Low cost
- Design possibilities (ergonomics, comfort and aesthetics)
- Accuracy
- Unobtrusive

Attaching a piezo to a solid object provides a contact microphone with a sufficient quality for chewing recognition.

7.3 *Sensor Selection*

In order to select a sensor for the proof of concept prototype, the first thing to find out was which on-body location should be used for the placement of the sensor; an in-ear sensor requires a different form-factor compared to a sensor that can be used on the mastoid or zygomatic process.

A quick survey amongst 10 people was held about preference between an in-ear solution and a solution on the mastoid or zygomatic process. 10 out of 10 participants pointed out they would prefer a solution on the mastoid or zygomatic process for a prolonged period of time.

Based on this survey, the choice was made to create a solution for placement on the mastoid or zygomatic process.

The most suitable type of piezo for this purpose is an external drive type piezoelectric diaphragm (see Figure 26); the same type as the piezo used inside the Mogees. In order to find the best suitable piezo for the chewing recognition setup, the following aspects were important:

Figure 26 *External drive type piezoelectric diaphragm: the chosen sensor type.*

- **Resonant frequency**
  Should be as close to the average chewing frequency as possible. The better the match, the stronger the chewing frequencies will be amplified compared to other sounds, easing the chewing recognition.
- **Size of the disc**
  Should be an appropriate size to process in a design; not too large. The piezo disc of the Mogees has a diameter of 20mm, which is quite standard for a piezo. For a usable design, the disc should not be much larger than this.

Figure 27 shows average frequencies of chewing crisp foods, and provides references to other useful resources which can aid in chewing recognition (Kilcast, 2004).

According to this information, the average frequency of chewing of crisp foods falls between 0,5 and 3,3 kHz. Crisp foods contain more higher frequencies compared to non-crispy sounds. Scanning suppliers for piezos made it clear that a larger disc generally means a lower resonant frequency. At a supplier more often used by DoBots (Mouser), a piezo with the lowest resonant frequency with a diameter no larger than 20mm in diameter that was in stock, was selected: 7BB-20-6L0 (muRata, n.d.). It has a diameter of 20mm and a resonant frequency of 6.3 kHz.

The location of the sensor was chosen to be on either the mastoid or the zygomatic process. The sensor that will be used to for the chewing recognition is an external drive type piezoelectric diaphragm: 7BB-20-6L0.

7.4 *Audio Analysis*

A quick audio analysis was done to search for distinguishable characteristics of chewing, which could potentially be utilized in the chewing recognition algorithm. The analysis was done using WavePad.

A benefit of WavePad is that it has a built-in Fast Fourier Transform (FFT) function. An FFT converts a signal from a time domain to a frequency domain, as shown in Figure 28. This provides an easy view of the frequency spectrum, making a signal analysis easier and faster.

Author	Parameter	
Drake (1965)	Mean frequency Bite time Sound level at 1.2 kHz	
Mohamed *et al.* (1982)	Equivalent continuous sound level (L_{eq})	
Edmister and Vickers (1985); Vickers (1987)	Mean height of the peaks (mhp) Duration of sound Number of peaks (NP)	
Seymour and Hamann (1988)	Mean sound pressure (N/m^2)	Averaged over frequency ranges of: 0.5–3.3 kHz
	Mean sound pressure level (dB)	Averaged over frequency ranges of: 0.5–3.3 kHz
	Acoustic intensity (watts/m^2)	Sum over frequency ranges of: 0.5–3.3 kHz
Lee *et al.* (1998)	Sound level (dB) for each chew	
Lee *et al.* (1990)	Total sound level (dB)	
Dacremont (1995)	Frequencies	
Duizer *et al.* (1998)	Fractal analysis	

Figure 27 *Average frequencies of chewing crisp foods (Kilcast, 2004). The average frequency falls between 0,5 and 3,3 kHz.*

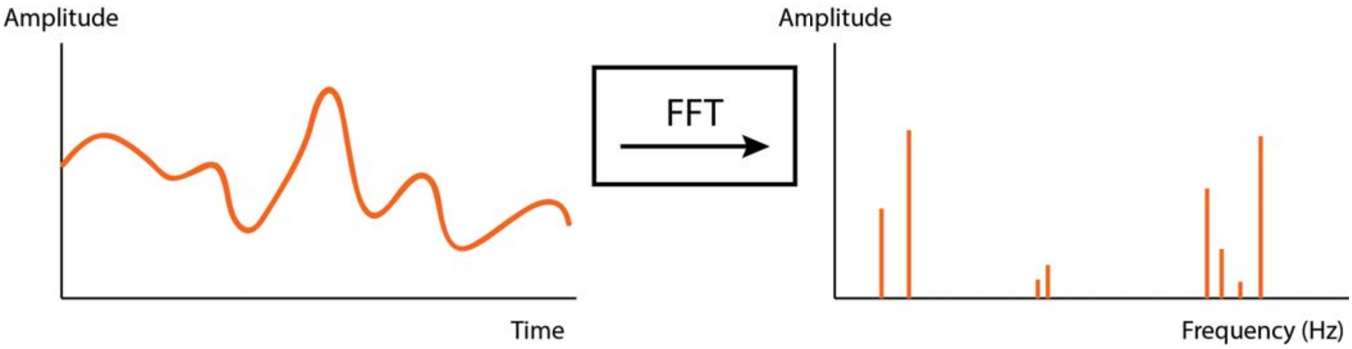

Figure 28 *An illustration of an FFT conversion. The converted signal shows the frequency spectrum of the signal on a given time frame.*

To get a basic idea of the frequency spectrum of chewing and how it compares to the sounds it has to be distinguished from (speech and background noise), sound samples were recorded on a laptop using the Mogees and consecutively analyzed using WavePad. FFTs were applied to the recorded samples in order to view the frequency spectra. In order to be able to receive more meaningful data, a noise reduction feature was applied. Captures of the frequency spectra of speech and the chewing of a crunchy and a soft food are shown in Figure 29.

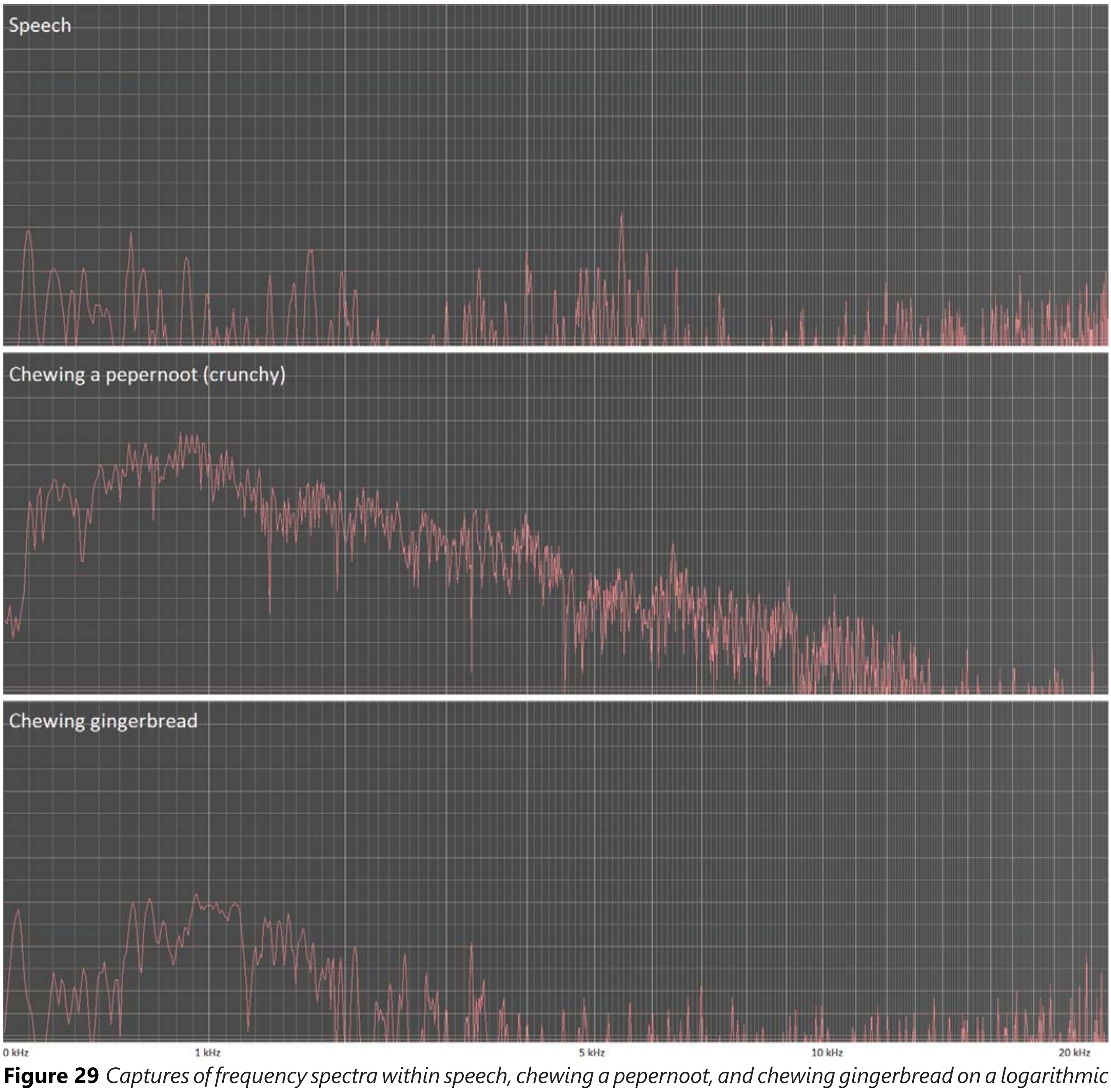

Figure 29 *Captures of frequency spectra within speech, chewing a pepernoot, and chewing gingerbread on a logarithmic scale ranging from 0 to 22 kHz.*

The first thing that caught attention was the high energy density of chewing a crunchy food; it is much higher compared to that of speech. Another noticed characteristic difference was that the frequencies of chewing mainly occur in the lower frequencies. Conform to the research by Kilcast (2004), the average chewing frequency of the measured chewing falls between 0,5 and 3,3 kHz. The speech spectrum is much more uniformly divided over the complete displayed frequency ranging from 0 to 22 kHz. It has a higher average chewing frequency.

7.5 *Sensor Connection*

The add-on will be connected to a smartphone using Bluetooth in the final design. In testing however, a wired connection was applied. Connecting the sensor to a smartphone using Bluetooth was not simple with the materials at hand. Additionally, adding a wireless connectivity to the prototype would not have added much value to the (proof of concept) prototype and would have taken a disproportional amount of time to establish. For testing, the microphone/headphones input was used as input stream.

In order to be able to stream the microphone data of the piezo to the phone, a TRRS (Tip Ring Ring Sleeve) connector was used. AHJ/CTIA and OMTP are the commonly used smartphone configurations for audio plugs (see Figure 30). Most Android and iPhones are wired using AHJ configuration. However, in this case it does not matter whether AHJ or OMTP configuration is used due to the in- and outputs being interchangeable.

At first, the connection to the phone did not work. The phone did not accept the input of the contact microphone. Adding a parallel resistor to the system, as applied in the Mogees, fixed this problem. Figure 31 displays the connection of the piezo to the smartphone.

Adding a resistor increases the impedance of the microphone and diminishes its signal strength. Smartphones, depending on the type, require a specific microphone impedance for the microphone to be recognized and thus to function. This resistance is usually above 1 kOhm, due to certain lower resistances being utilized for other purposes.

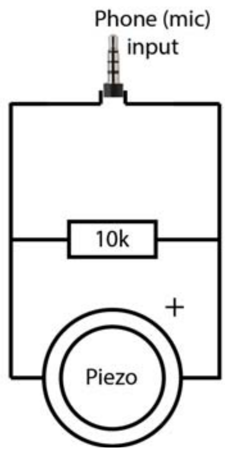

Figure 31 *Functional connection between the piezo and a smartphone.*

Different resistors were tested. Based on the Mogees, 12 kOhm was used initially. However, the 10 kOhm and 2kOhm worked as well while showing no difference in signal strength on the recordings. The reason for the switch between two separate resistances on the Mogees is probably for compatibility with a variety of phones. The compatibility with different phones will not be tested within this project. The tests were done on a Sony Xperia S smartphone.

The connection of the piezo to a smartphone was established using a TRRS connector with the microphone input of the phone, wired for an AHJ standard. An added parallel resistor enabled compatibility with the smartphone.

OMTP 'AV' Connector Interface		AHJ 'AV' Connector Interface	
PIN	**Description**	**PIN**	**Description**
1	Ground	1	Microphone
2	Microphone	2	Ground
3	Right Side Earpiece	3	Right Side Earpiece
4	Left Side Earpiece	4	Left Side Earpiece

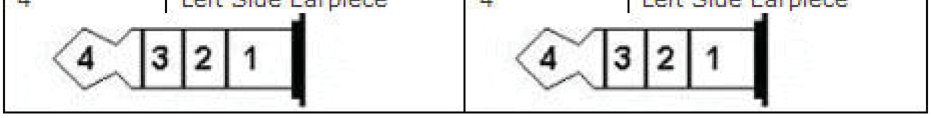

Figure 30 *Common smartphone audio (TTRS) connector types: AHJ and OMTP (Windows Central, 2013).*

7.6 *Chewing recognition*

Due to time restrictions and my lack of expertise on the field, employees of DoBots have helped me by writing the algorithm and android application for the chewing recognition, based on the research found on auditory chewing recognition in Chapter 4.

First, the basic algorithm was written in Matlab. When applying the algorithm to a recorded audio file, a text file is created containing the starting and ending times of the detected chews, supplemented with labels named 'Chew'. These text files can be imported and visualized by Audacity, as can be seen in Figure x.

Consecutively, an Android app was created in Eclipse using Java. The Mogees was used as sensor for creating and testing the chewing recognition. The following piece will briefly explain the basic functioning of the algorithm.

The chewing recognition algorithm relies on the extraction and comparison of features present in the audio recorded by the piezo. While most algorithms rely on multiple different types of these features, the chew recognizer uses a single type, called the Mel-frequency cepstral (MFC) feature.

Feature extraction of similar sounds leads to similar features. An algorithm can be used to compare a set of features of an unknown sound to a set of features extracted from a pre-recorded chew. When the features resemble each other closely enough, they are considered a match. This resemblance is measured by taking the mean squared error between all features. This value is then compared to a threshold value to determine whether or not the features represent an actual chew.

This setup requires a clear example of a confirmed ‘chew’ to continuously compare to. Within the app, multiple chews are used with each different thresholds to be able to recognize a larger variety of chewed foods. There is a delicate balance between too little and too much comparison material though. In case many chews are embedded, (more) false positives could be generated.

Results

The chewing recognition works quite well. Speech and environmental noises do not provide false positives. Friction sounds of rubbing on the sensor however do get recognized as chewing. This should not be a big problem though since the sensor should be placed stable enough on the head to avoid false positive from this source; a time window will only be categorized as eating in case a minimum of fifteen chews are recognized within a minute.

A second point of improvement is that the chew count was not completely accurate yet. While it recognized all chews, it regularly counted one chew as if it were two or three. Through setting a minimum of time between chews, this problem can be solved. Research by by Po et al. (2011) shows that chewing occurs mainly between a frequency of 0,94 Hz (chews per second) (P5) and 2,17 Hz (P95), with an average of 1,57 Hz and median of 1,58 Hz. When placing a minimum time frame of 0,4 seconds between chews, this should greatly improve the accuracy of the chew count.

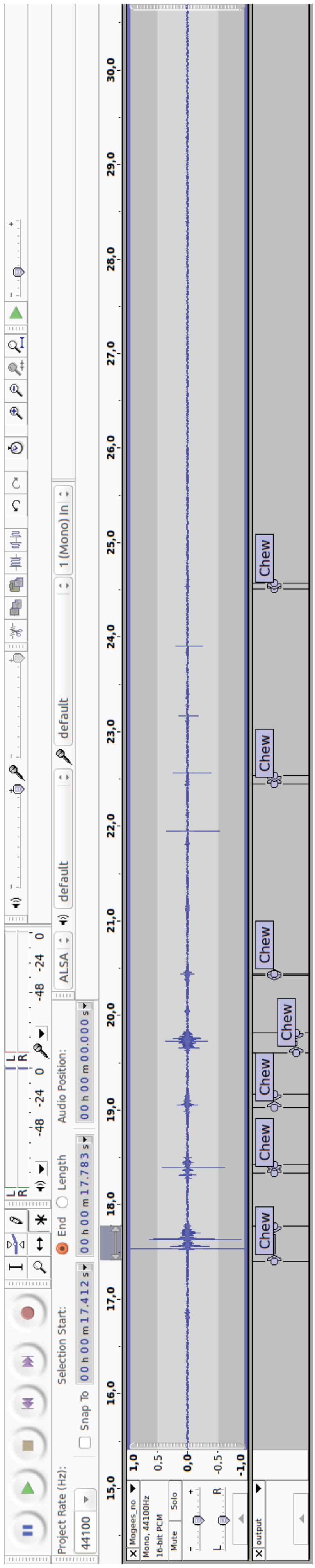

Figure 32 *A visualization in Audacity of a text file generated by the algorithm in Matlab.*

At times, swallowing is also recognized by the current algorithm as chewing. This indicates that swallowing is audible and thus that it should be possible to add distinct swallowing/drinking recognition to the algorithm in the future.

The connection of the piezo to a smartphone was established using a TRRS connector with the microphone input of the phone, wired for an AHJ standard. An added parallel resistor enabled compatibility with the smartphone.

8. Final Design

This chapter will present an overview of the basic design and functionality of the final design: the BitsLab. It will start by explaining what aspects of the design will be presented in more detail, and what aspects will be left for further research. Consecutively, these different aspects will be presented.

8.1 *The Bitslab*

The function of the BitsLab is to improve the users' eating habits. Instead of focusing on calories, it focuses on creating a sensible eating pattern. It helps the users understand why they eat at times they should not or would not want to eat and gives them the tools to change this. By changing and creating habits, the product focuses on long term changes. Figure 33 shows the the basic functionality of the BitsLab.

Through attaining a new habitual pattern, the willpower necessary to sustain the desired behavior will steadily reduce. Eventually the new pattern will become (nearly) automatic; the user's default behavior. Take note that it will take a long time for the user to get to the point that the new behavior is his or her default behavior. For difficult changes, it might take several years, although it does become a lot easier to sustain in the process. This depends on the person, the difficulty and intrusiveness of the change(s), and the duration of having performed the old habit. Additionally, changing habits takes significantly more time compared to forming new habits.

Users

The BitsLab is aimed at those who would profit from changing their eating patterns; those who snack more than they would want to or for the wrong reasons, and those who have an (undesired) irregular eating pattern. For people whose problem is to eat too large portion sizes, while eating three meals a day for instance, the BitsLab (add-on) will not provide much value. The app itself on the other hand with its tips, habit forming, and habit changing, could be helpful for them to reduce portion sizes. However, the add-on itself will not help them solve their problems.

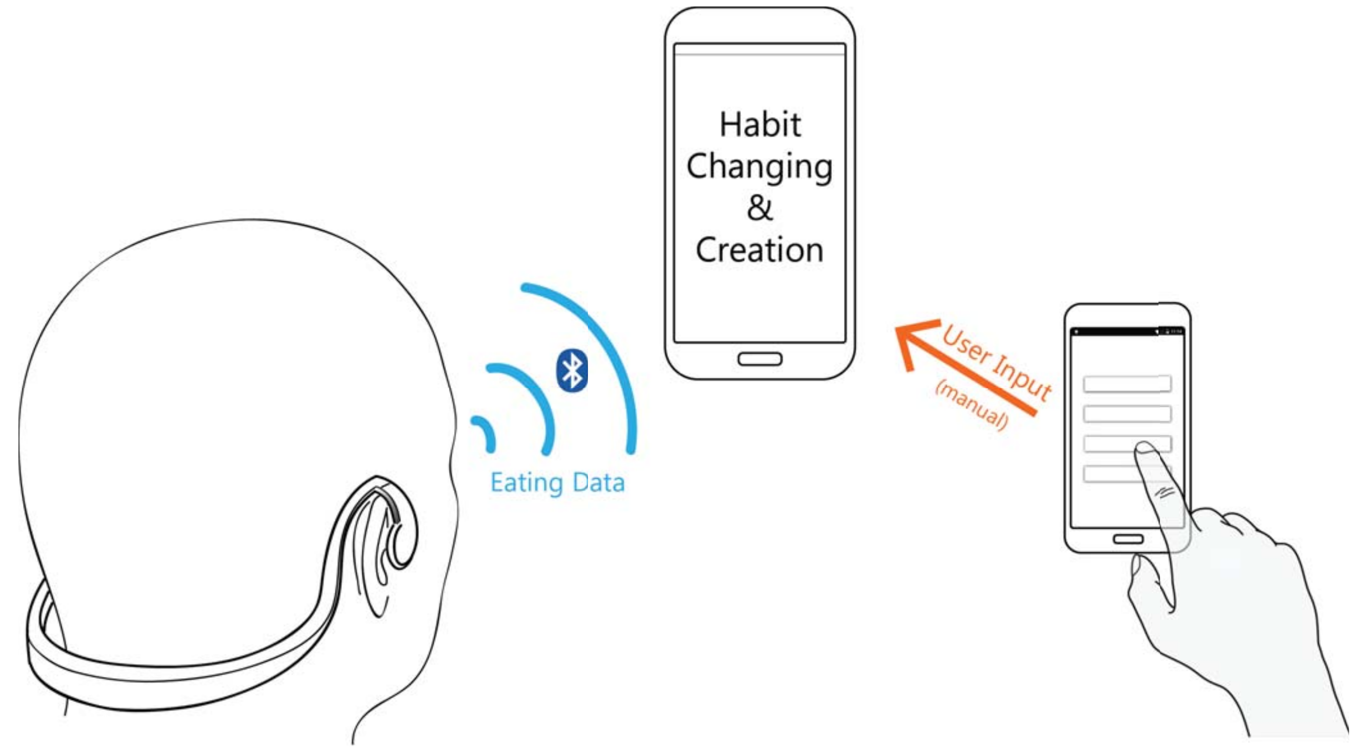

Figure 33 *Illustration of the basic functionality of the BitsLab. The app collects data from the user's input and the sensor, analyzes this data and utilizes it to help the user create an improved habitual pattern.*

For those whose problem is that they eat out often at places they invariably eat unhealthily or too much, the Bitslab can also be useful. Through the user's smartphone's GPS, the location of eating can be tracked. Consecutively, it can help the users analyze what triggers their habit to eat out, what the reward is that they are actually craving, and teach them how to change this routine.

8.2 *Choices on Focus*

Due to the many different aspects and possibilities within this concept, choices had to be made as to which aspects should be worked out in more detail. This section provides more information on the choices made. These choices were made keeping my own and DoBots' expertise in mind; for instance, DoBots has expertise in software, whereas I have little knowledge on this field. Therefore, it was more meaningful to focus on other aspects of the design.

Hardware

Within this project, the hardware will be kept basic. The essentials for the chewing sensor and the wireless connectivity will be mentioned. There are however valuable possibilities for elaborating on and supplementing this hardware. For instance, the possibility of bone conducted notifications can be introduced. More on this subject will be discussed in the Recommendations 10.2.

Proof of concept prototype

This project worked towards a proof of concept prototype. This proof of concept prototype features basic chewing recognition, as presented in 7.6. 9.3 will present a next step in the prototyping; implementing the piezo sensor into a 3D printed model.

Swallowing recognition, wireless connectivity, and improved accuracy on the chewing recognition resulting in accurate chew counts will be for future research.

App

The app will contain five different menus with each their own function:

- Create Habits
- Change Habits
- Games (in a future app or product update)
- Social Environment
- Lab

Within the scope of this project, this app will not be elaborated much. The purpose of the different menus of the app will be explained. Additionally, the basic functioning of the habit changing will be explained due to it being the most important aspect; changing habits it the goal of the BitsLab. Additionally, it is the main part of the app that interacts with the sensor.

Ergonomics, shape & aesthetics

It is important for this product to fit people's heads properly and comfortably; users should wear it the whole day, only taking it off at night. On top of that, it has to look good and not attract too much attention. The process of developing the shape will be shown in 8.5. An improved model, based on an ergonomic study, will be presented in 9.1.

User testing

The habit changing cannot be tested within the scope of this project due to its (long-term) nature. Theoretically, based on findings of the analysis, this product should help users in accomplishing their long-term weight-loss goals. However, tests to verify the effectiveness should be performed in the future.

Comfort and aesthetics will be tested within this project.

8.3 *Hardware*

The hardware of the BitsLab consists of the following components:

- *Piezo sensor*

  One piezo is enough to measure the chewing. An additional piezo (with additional hardware) could be added to enable bone conducted notifications.
- *Housing*

  The housing of the sensor is designed to fit around the back of the head, while pressing the sensor gently against the zygomatic process. The development of the housing is presented in 8.5 and 9.1.
- *Bluetooth low energy (BLE) module with flash memory sufficient to save at least one day of data*

  The memory is important in case the user's phone is not connected to the BitsLab for a period of time. The user should not lose attained data after not connecting the device for less than a day. Figure 34 illustrates how the flash memory is used to temporarily save data. The 1 minute wait between every check is to reduce battery power usage.

- *(Rechargeable) Battery*

A wirelessly rechargeable battery would be optimal, though not necessary. This would also be convenient for water resistance purposes. However, whether wireless charging in this size and shape is feasible at this point in time is unsure. The battery should last for at least a week.

- *Charging connector (micro USB) or wireless charging dock*
- *Resistor*

The purpose of this resistor is to enable a connection to a smartphone. The prototype features a 10 kOhm resistor. The quantity of this resistor should be optimized for the strongest signal. Whether this configuration works on all BLE enabled smartphones is yet unknown. A switch to change between resistances, as included in the Mogees, might be required to enable functionality with all/a wide variety of smartphones.

- *Connector cables*

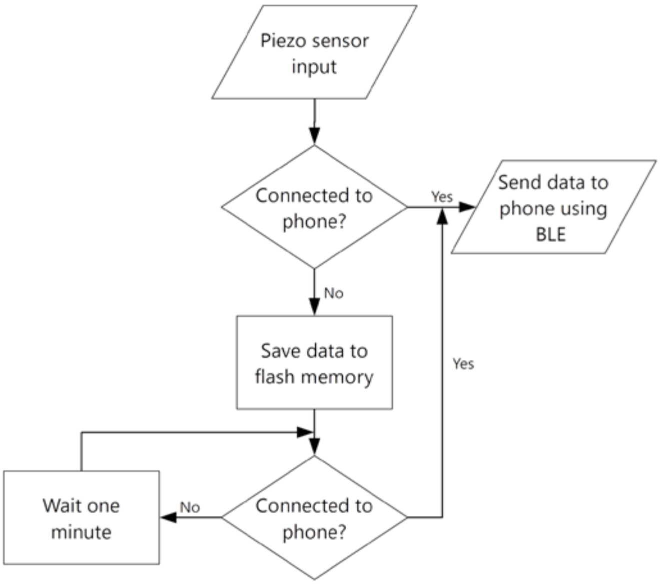

Figure 34 *Scheme of the incoming data stream.*

8.4 App

As mentioned before, there are five (initially four, since games will likely not be introduced until a later time) different menus of the app. Of these menus, 'Changing Habits' will be explained more in depth.

- Create Habits
- Change Habits
- Games
- Environment
- Lab

After providing more general information about the app, brief further information will be provided on the menus of the app that were not focused on. Consecutively, the basic functioning the Change Habits menu will be explained.

8.4.1 General Functioning

Throughout the app, defaults and practical pre-selected options are given in selection fields in order to simplify the process of analysis and speed up the interaction; habit changing is a difficult process in which many users can use all the help they can get. These defaults will reduce decision paralysis and give the users more confidence that what they are doing is effective.

The app is self-learning. It learns from the users' actions and use this data to optimize their workflow. For instance, often selected options are placed on top of the list. Also, options that users have written themselves are supplemented to the list of options.

To keep things simple, most settings will be preset. The option to personalize does exist however. Users can adjust the app to suit their needs in the Settings and the Advanced Settings. The distinguishment between Settings and Advanced Settings is meant to not confuse users who want to change a basic setting, such as turning off the trigger notifications.

Tip of the Day

Daily, when the user opens the app, a tip or message is given about habit change, food, or gives another constructive message. These tips should be brief. If users want to, they can receive additional information by clicking on the tip. Tips can also be shown while the app is loading.

Tips can for instance be an image of a certain food along with a color coded health indicator, a percentage of daily caloric needs and macronutrients. They can also be tips or remarks. Some examples:

- Don't focus on results; focus on change
- Eat from a smaller plate to eat less without feeling deprived
- Everybody is different; find out what works for you
- Breakfast is optional

Normally, tips are given at random, with the purpose to educate. However, if a certain recognizable problem is detected, tips will be aimed at helping to solve this problem. Daily tips can be turned off in the settings.

Positive reinforcement

Aside from a daily tip, the app provides occasional positive reinforcement. These messages are given at random points in time for the best effect. At times users may think they are failing, they are also given positive reinforcement on the things they are doing well. This might even be more important at this point, to avoid a negative spiral. For instance, when they have been eating a lot outside of their pattern in the last day or couple of days, however did fill in the prompts (see 8.4.3), the app can comment on how well they have been analyzing their habits. They can be reminded that they have gained valuable data on themselves by doing this, which will prove useful in the future (turn a bad day into good data). This might improve their state of mind or even change their way of thinking about their process, and thereby reduce the odds of a negative spiral.

8.4.2 *Menus*

This section will briefly explain the function of the menus besides the Change Habits menu.

Create Habits

The menu of creating habits will be based on Fogg's Tiny Habits (3.4.1). Aside from creating habits, starting out by using this method is a good way to *build the confidence in one's ability to change*; a crucial element in achieving behavior change. Users are advised to start small, and to only tackle habits they truly care about.

After users have learned a new habit, they are reminded of what they have already accomplished. A list of learned habits is visible within the 'Create Habits' section of the Lab (see 8.4.3). Additionally, at certain points in time (for instance, two months later), the app message reminds them. This is important since, depending on the habit, it can be easy for users to forget about all the changes they have already accomplished. This can easily happen when a new behavior has turned into a habit and thus occurs (nearly) automatically. Being reminded of how much users have already changed will boost the confidence they possess in their ability to change.

Games

The purpose of the games is to playfully educate the users on habit changing, a healthy lifestyle, and a proportional and healthy diet. An online RPG (Role Playing Game) offers a rich variety of possibilities for this purpose. Online mechanics can be made so that actions performed within the game have similar, though faster effects compared to the real world. Thereby, the long-term effect of positive changes can be visualized intuitively to the users.

In addition, such a game can be designed so that users can meet others with similar goals or lifestyles within the game environment. Connecting with others is a great way to increase motivation (SDT, 3.3.1, relatedness), and makes the process much more fun. In addition, users can support and learn from each other.

How well users are doing with their plan, habit analyzing, changing, or forming, can influence their character in-game. When not doing well, this feeling should not be amplified by decreasing abilities. These should stay the same, to show there is simply no progress for a while, but that it is easy to pick it back up the next day. When performing according to plan or analyzing well, the user could increase abilities for instance. Maintenance should also be rewarded.

Environment

This menu consists of a forum and a friend list. Within the Environment, users can ask questions to other users, share their experiences, and ask for support to help solve their problems. Through the forum or the Games, they can find friends which whom they can stay in contact.

Lab

The Lab is the location within the app where all measured and entered data can be observed and analyzed by the users. The Lab displays the times eaten, placed over the defined eating windows. More data on periods of eating can be attained by touching the eating window: chew count, exact duration, and even chew (frequency) intensity over the duration of the window. Additionally, the Lab has a 'Trigger Finder' and 'Cravings Finder' section, in which attained data can be analyzed (more information on these sections can be found in 8.4.3.

In case users take photos of what they eat when prompted (see 8.4.3), an overview of these photos can be found in the Lab as well. This overview provides a quick insight in the types of foods users eat when eating outside of their plan.

When linked with other applications, the Lab will show linked data. For instance, when using

MyFitnessPal for calorie counting, the chewing instances will be shown next to caloric intake. Or when using a FitBit smart scale, which sends weighing data of the user to their phones through WiFi, the weight will be shown side by side with the eating data. This might unveil useful relations.

Manual input can also be added in the Lab. Whether this be weight, measurements (e.g. of the waist), or something completely different such as energy levels, or the money users save by adhering to their eating plan.

First use

Figure 35 demonstrates what occurs the first time the app is used. When they open the app, users are given a concise explanation on how habits work through the habit loop, and how they can be changed. They are explained the important point that *the first weeks are meant for analysis*; they should not try to make real changes yet, only to experiment and observe. Consecutively, they are prompted to answer several questions on their eating habits and problems.

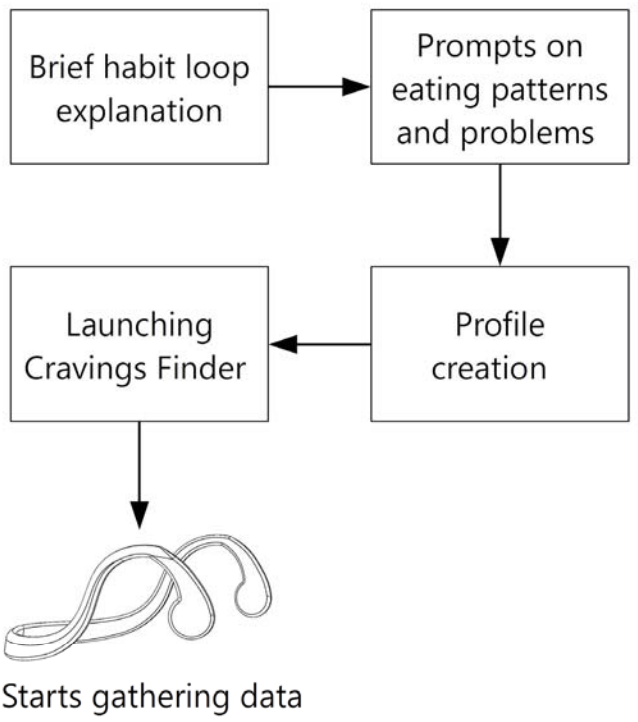

Figure 35 *Scheme of the app flow of the first time users open the app.*

Next, users are asked to fill in a user profile. This profile is used in the Environment and Games. It shows a user name and a characteristic line about themselves, along with an (optional) image or avatar. This characteristic line has the following format: "I am someone who…" which should contain something constructive/positive, preferably concerning their health or attitude. As default, to show an example, "takes care of her health" is filled in.

After filling in the profile, the Cravings Finder is launched. The BitsLab will start gathering data from this point onwards. Data will be saved to the Lab.

Explanations on different aspects of the app will be given at the time these are activated, in order to reduce the amount of information the users have to process at a time.

8.4.3 *Change Habits Menu*

The Change Habits menu is based on Duhigg's Habit Loop (3.4.2). It helps users analyze and break down their eating behavior, and provides them with the tools to change it. The app has a Trigger and a Cravings Finder, which will be explained within this section.

Different users

Depending on the person, usage of the app will differ. Some will not use the habit analyzer at all, and will simply collect eating data. This might occur for instance with those who use it as supplementary information for a dietist. Others might use it to support their calorie counting. This chapter however, revolves around the group that uses the BitsLab for the habit changing function.

Those who wish not to use the habit functions can skip the questions about their eating patterns. After filling in their user profile they can skip right to the Lab.

Cravings Finder

This part of the app consists of an interface where users can find their cravings through the method described in 3.4.2; substituting an undesired behavior with an alternative one. If users have a specific eating routine they want to change, that would be ideal; the more specific the habit, the easier it is to analyze and change it. Although other habits can be changed as well using the app, the basic routine to be changed within this app is unwanted eating.

Figure 36 shows how the users will test and rate their alternative habits using the app. First, users are asked to choose a routine they want to change, and to be as specific as possible. The default is "Snacking in the evening". Next, they are asked to fill in alternative activities they want to attempt to substitute the habit with, in order to find their craving. To get them started, examples of alternative routines are provided. When selecting an empty slot for an alternative behavior, they can either select one of the suggestions provided, or type in something themselves.

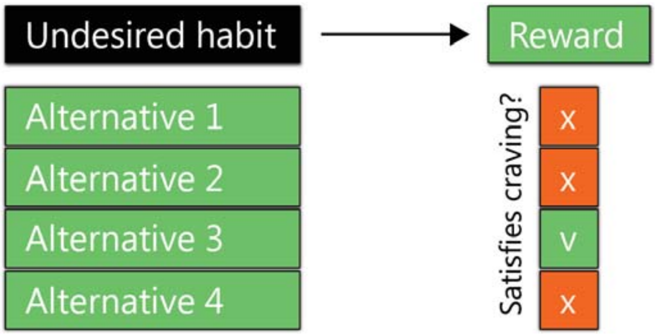

Figure 36 *Cravings Finder. Substitute an unwanted behavior with alternative ones to find out what users are craving.*

After the setup, users should start experimenting by replacing the unwanted behavior one by one with the alternative rewards. Fifteen minutes after having performed the substitute behavior, users should mark whether the craving is satisfied. When unsure, a question mark can be filled in and the substitute behavior can be attempted again at a later occasion.

If after these fifteen minutes the craving is gone, the activity likely contains the reward the user's body is craving. When they have found what they are craving, users can start using the Trigger Finder. An overview of what performed substitute behaviors seem to satisfy the cravings and which do not, can be found in the Lab under 'Cravings Finder'.

Trigger Finder

After having found the user's craving, the Trigger Finder is launched. A brief explanation follows on how the Trigger Finder works. Next, users should set up their desired eating pattern. These settings can be changed at all times. Based on previously provided information, combined with data the BitsLab has acquired up to this point, recommended default options will be pre-selected. The users are recommended, though not obliged, to create a consistent pattern through the week (including the weekend), since changing habits is greatly simplified when consistency is applied. The eating windows determined during this pattern setup serve as input for the Trigger Finder.

After having composed a desired eating pattern, the app shows the following message:
"The trigger finder is now active. It can be turned off in the Settings. Maximum number of daily notifications: 3"

The maximum number of trigger notifications can be changed in the settings as well. The reason for providing this maximum is that if people have a bad day and eat often outside their set eating windows, receiving too many notifications could be very annoying. It might make them take off the BitsLab, or turn the notifications off. Three notifications on such a day would still provide very useful insights. A minimum of 30 minutes should pass between notifications. This duration can be changed in the settings as well.

When the trigger finding is turned on, the process within the app is as shown in Figure 37.

Eating windows will be handled flexibly by the app. For instance, if users do not eat breakfast in their eating window between seven and eight o'clock, but do eat something at eleven, which is outside the set eating windows, it will see this as breakfast and withhold from notifying the user.

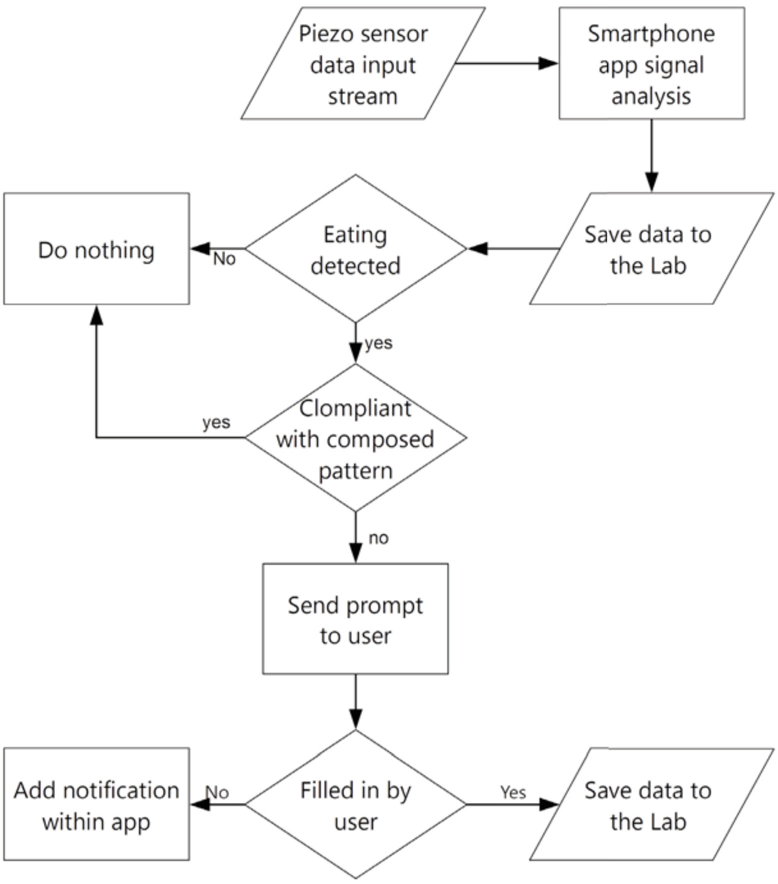

Figure 37 *Scheme of the trigger finder with notifications turned on.*

These are default settings. In the advanced settings, users have the option to change in what cases and how often the Trigger Finder should notify them.

The prompt will be sent to the users in the same manner as they receive text messages on their phones. The phone can signal the user either through sound or vibration of the phone (this can be set by the user). When opened, the user can fill in the Prompt screen.

Prompt

The prompt sent to the users when they go outside of their plan has the purpose of finding information on the users' triggers. Using Duhigg's trigger categorization, the following five points of data should be collected:

- Time
- Location
- Emotional state
- People around
- Previous action

This is where the self-learning aspect of the app comes in especially handy. When clicking on one of the questions, a screen will pop-up with a list of options to choose from, plus an option to fill in one's own input. The most used answers will be shown on top. Most recently used answers will be pre-selected.

Figure 38 gives a possible layout of the prompt within the app. Clicking on one of the questions will open a drop down menu. An emotion can be chosen either through emoticon or text. The time is captured by the phone. If turned on, GPS data will pre-select the location. If the user wants to be more specific, for instance 'in the living room', this data can be added to the GPS data. The app can be taught what different addresses represent, such as 'home'.

On top of answering the questions, users are encouraged to take a photo of what they are eating. This can quickly be done with the camera button on the bottom right of the screen; a simple, low threshold handling when they are already filling in data in their phone. In terms of Fogg's behavior model, this trigger would be called a 'facilitator' (3.2.1).

On the bottom left, users can fill in whether they are feeling hungry. This is set to 'no' as default. If the users really are hungry, they can click on the button to change the 'no' to 'yes'.

Figure 38 *A possible layout for the prompt screen.*

Discovering triggers

After filling in or dismissing the prompt, users are sent to the Lab. Here they can see the recorded data and analysis. After having filled in the prompts for a couple of weeks, depending on the habit, chances are large that there is a consistency to be found within the recorded data. The app can find basic similarities, such as a certain time frame, location, or (category of) emotion that seems to trigger the behavior. However, users should analyze the results for themselves as well. They might see a connection the app does not see.

Previously input trigger data can be found in the 'Trigger Finder' section within the Lab. A 'trigger count' is displayed here as well. This is a list displaying the previously input data instances categorized by frequency of entry, with the most often entered instance on top. This provides a quick overview of how many times certain circumstances coincide with the unwanted behavior.

Creating a plan

After a time span ranging from days to weeks, users will likely have discovered their trigger(s). Now that they have found what triggers their cravings, they can crate a plan. Every time the trigger occurs, or right before the trigger will occur in case time is a trigger, users should perform the substitute behavior which has been found to satisfy the craving (see Figure 39). When having pre-decided how to act on triggers, it is much easier to deal with the situation when it occurs.

It will take time for the users to adjust to this change, and for it to become automatic. Users should be reminded that it is completely normal to have setbacks in case their plan does not always work. In time however, it will slowly become easier and more automatic, until true habit change has been accomplished.

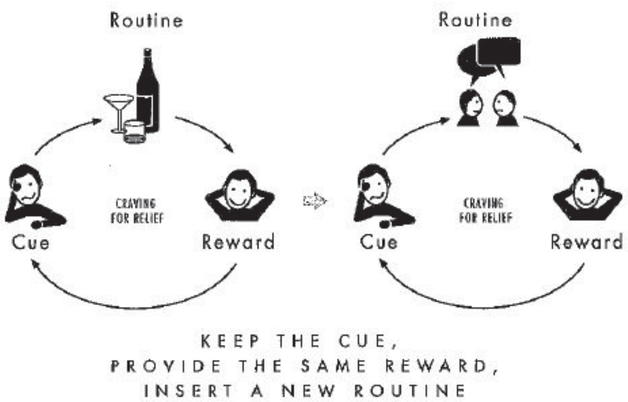

Figure 39 *An example of replacing a routine with a substitute behavior (Duhigg, 2012).*

App opening screen

When opening the app by oneself, the starting screen that will be shown will depend on circumstances. The Lab will be the default starting screen. The exceptions situations are described below.

First use	Introduction, as explained in 8.4.2
When actively (more than once a day) using the Cravings Finder	Cravings Finder screen, so that users can rapidly fill in whether a tested substitute behavior was effective in satisfying the craving.
When exited the app previously in the middle of something	Continue where left
When having eaten outside of plan	Prompt

Shape & Aesthetics

The function of a product is usually the reason why people buy it, especially when concerning tech products. However, the shape of the product is a decisive factor in itself. Even if a product has a desired functionality, people may decide not to buy it when the shape or aesthetics are undesirable.

8.4.4 *Important Aspects for a Desirable Shape*

There are multiple aspects of shape and aesthetics important for this product to adhere to: comfort, social acceptance and the functionality/usability of the shape.

- Comfortable fit
  - Size and shape for a proper fit
  - Appropriate pressure of the design on the user's head to avoid discomfort, while applying sufficient pressure to keep the sensor in contact with the (skin on top of the) zygomatic process
- Socially acceptable
  - Aesthetics that do not draw much attention. People often prefer not to explain themselves or talk about their weight loss outside of with select people
  - Fits inside current fashion sense
- Functional/usable
  - Sufficient pressure for a proper piezo input and stable placement
  - Correct placement of the piezo
  - Easy to use
  - Resistant to everyday use (handling, rain, falling)

8.4.5 *Shape Exploration*

Inspiration

In order to find a practical and socially acceptable shape, it can be useful to look at existing products used on the same area of the body. In this case, headphones and headsets were a good source of inspiration, especially considering the high market saturation of these products. Existing bone conduction headphones, also called bonephones, which are not widely used yet, are also useful to see how current products using a similar technology are applied. Bone phones are headphones that work using similar sensor technology compared to contact microphones, though they play sound instead of recording it. Figure 40, with images collected from various online sources, shows existing bonephones and some other headgear for playing sound/music. These images were used for exploration and inspiration.

Creating a similar design to commonly used objects has two advantages. First: practical, comfortable and aesthetic shape options have been explored by many. Second: similar designs are natural for people to see and will therefore attract little attention.

Placement

For the placement of the bone conduction microphone (the piezoelectric sensor), the following two locations on the human body are used for optimal placement, as shown in 7.1.1:

- mastoid process
- zygomatic process

Exploration

Inspired by the shape exploration and keeping the sensor placement in mind, sketches were generated. At first, one-ear solutions were also considered (think of Bluetooth headsets). However, after some exploration, it became clear this was not the best solution. The main reason being that, especially when not using an in-ear piece, it is difficult to keep proper placement and pressure of the sensor on the zygomatic process; especially considering the various shapes and sizes of people's ears. A headset wrapping both size of the head would fit more securely, provide better pressure levels, and be able to provide a more comfortable fit. Asymmetrical options wrapping around the head were also considered, however not deemed practical or aesthetic due to imbalances. Some sketches of the shape exploration can be found in Appendix 3. Solutions with the sensor located on the zygomatic process were found most appealing and appropriate.

The sketch shown in Figure 42 and Figure 41

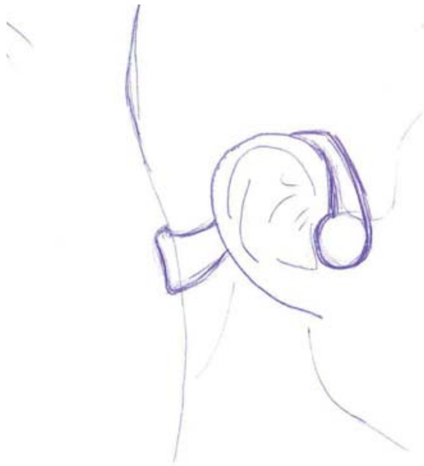

Figure 41 *The design chosen to develop*

Figure 40 *Compilation of bonephones and other headgear for playing sound/music; used for exploration and inspiration (images collected from various online sources).*

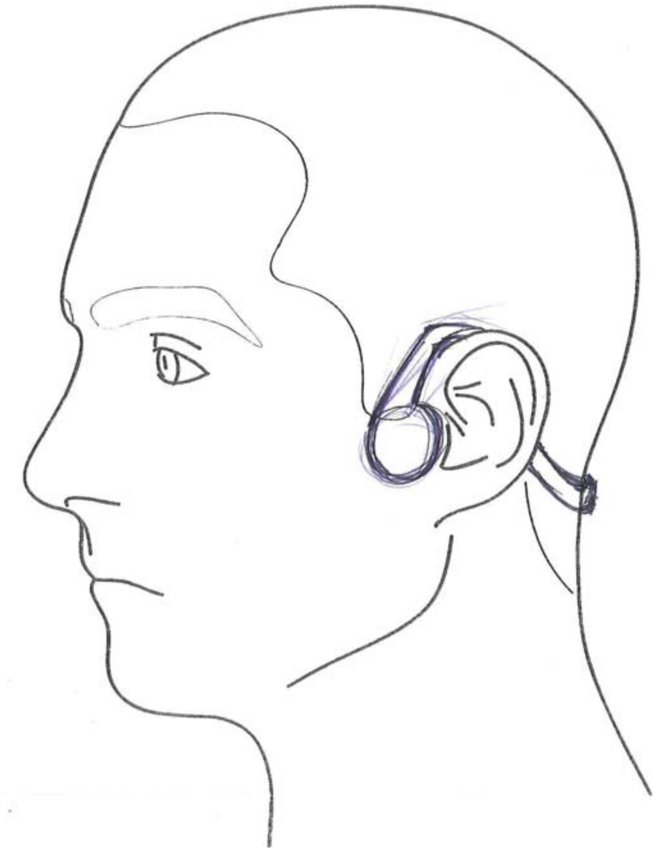

Figure 42 *The sketch chosen to develop.*

8.4.6 *Designing the Shape*

In order to further develop the shape, a design was created in SolidWorks (SW). A 3D surface model of a proportional human head was downloaded and used as a base to model the design around.

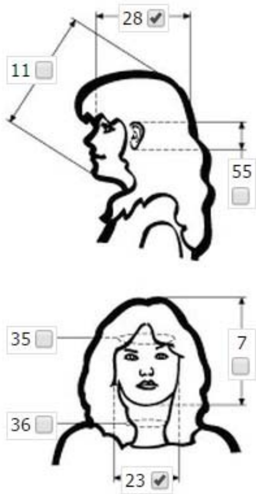

Figure 43 *Relevant measurements for designing the shape, taken from the database (DINED, 2004)*

Dimensions

For designing a fitting 3D shape, proper measurements of the human head were required. Measurements from the anthropometric database DINED (2004) representing the average Dutch adult in 2004, also called P50, were taken as reference:

- Head breadth (23) mean: 148 mm
- Head depth (28) mean: 194 mm

Figure 43 illustrates the provided measurements. In order to apply these measurements, a 3D representation of the human head created by XAMR (2013) has been used as base for modeling the shape around. The measurements of the head were already close to average. A small scaling function has been applied to create a near-average sized 3D head, keeping the head breadth a bit smaller in order to ensure the presence of a little clenching force on the average person's head.

Designing

Based on the previously chosen sketch, the shape was modeled around this 3D head in SW. The image to the right shows the basic design after small initial changes performed to enable the 3D printing process (improved thickness). The larger section area of the model at the point of the back of the neck is meant for holding the necessary electronic components. This space will be designed according to need.

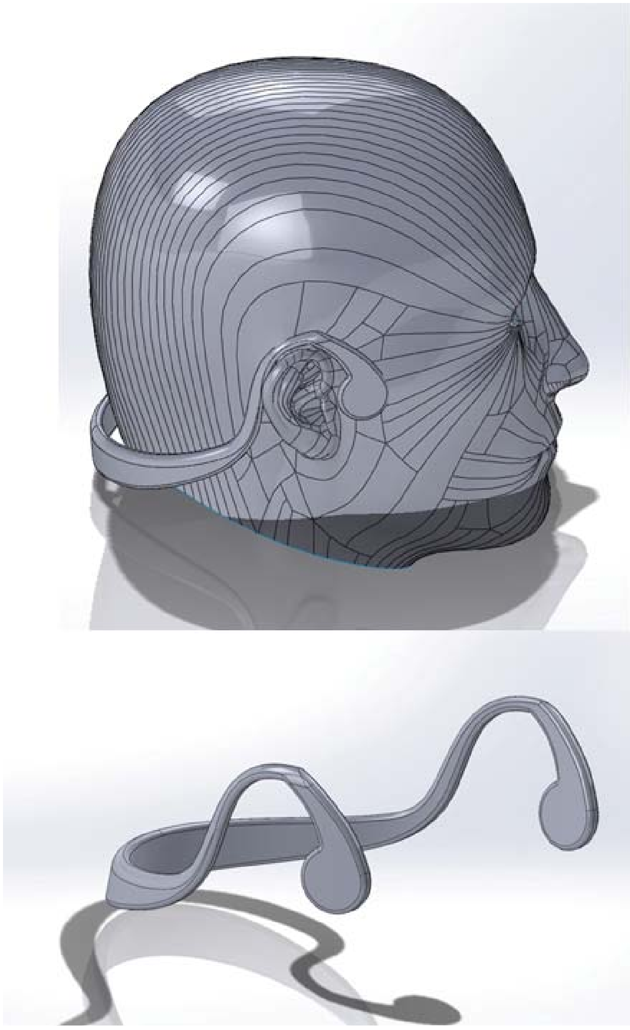

Figure 44 *A near-average sized human head by XAMR (2013), enwrapped by the created design.*

FDM (Fused Deposit Modeling) printers, a type of 3D printers that prints by extruding material layer upon layer, were available to use at DoBots and the university. After making some changes to the shape to enable proper FDM printing, the model was printed. Due to printer problems resulting in bad layer attachment at random places combined with general FDM print material properties, the model was quite brittle and broke easily.

First tests

Before breaking, the model was shortly tested on two persons for a first impression on fit and quality of the model. For the first person, with a small head, the fit was good. For the second person, with a head slightly smaller than average, the model did fit though not that comfortably: at certain areas the model could do with some more wiggle space. Figure 45 shows the second person testing the model, along with the sensor location. A third person was unable to get the model on his head. His neck was too wide for the model to fit around.

Aesthetics & social aspect

The design looks quite subtle and does not stand out when having a face to face conversation with someone, especially when applying a less apparent color. When worn by people with (loose) middle to long hair, it can be practically invisible to those around. However, even for those people, the design will be visible at times. Although it has similarities to sports headphones, it will likely induce questions. Even if, people would assume they were some sort of headphones, they would wonder why someone is wearing it at social occasions for instance. Due to the ears still being open however, the design does not shut the user off from the outside world. He or she will still look open for conversation even if the people around do not know the function of the design.

Important to note is that, although it was not found a big problem by the tester, the design is not ideal for use with glasses. The glasses could be worn around or above the model. This is not yet an optimal solution with its current shape and thickness. However, due to time restraints, in the course of this project the design will not be optimized for use with glasses.

Next steps

It was clearly visible that this design was not suitable for larger heads (and necks). A quick moment of seeing the model next to the head of a heavy person with a large head made it clear that there needed to be either a larger model, an adjustable design or different sizes. A one-size-fits all is possible. However, this might be uncomfortable and obtrusive for people with small and normal-sized heads since the design would stick out too far from the head. This is not acceptable for a device that is to be worn through the whole day.

Additionally, a solution had to be found to create proper 3D prints ready for ergonomic testing. In 9.1 the next iterations of the design process of the shape will be presented.

Figure 45 *Testing of the first successfully 3D printed model. The image on the right shows how it came out of the printer; within support material.*

9. Detailing & Production

9.1 *Ergonomic Study*

Previously (in 8.5.3), it was concluded that one size is likely insufficient to provide a comfortable fit for a wide range of people. This leaves two options: either an adjustable design, or different sizes. Another point of notice was the width of the model around the neck; this was too tight or too small for some of them to even fit. A little more 'wiggle room' was said to be appreciated.

This section will describe the next iterations of the process in creating a better fitting, more comfortable design; one ready to test when 3D printed. An overview of this process is shown in Figure 46.

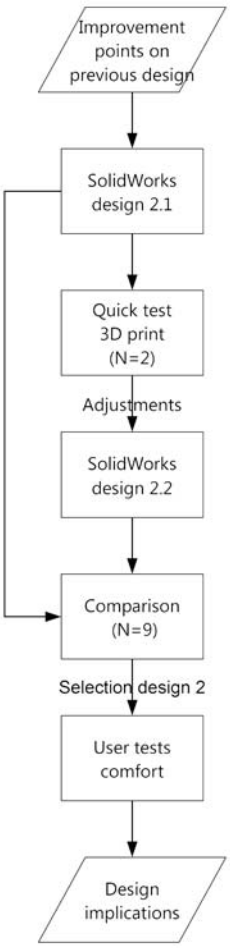

Figure 46 *Scheme of the process of developing test models for 3D printing within this chapter.*

Figure 47 shows anthropometric data from the database DINED (2004) on the width and depth of a range of percentiles of Dutch adults' heads (aged 20 to 30). The shape will be designed for the P5 to P95 (5th percentile to the 95th percentile), while not disregarding the P2 and P98. The most important measurement is the breadth, due to the need for an acceptable pressure level for the whole range of potential users and the necessary contact with the zygomatic process.

A quick exploration was done on adjustable designs through a morphological chart. It can be found in Appendix 3 . A variety of ideas was generated for the subproblems of tension, size differences, and head shape. For a startup with no expertise in product design and production, these solutions might be difficult. First, the possibility of the different sizes, and how many would be required, was explored.

The more different sizes, the higher the investment costs. For this reason, the possibility of two sizes was explored first. The two sizes would be aimed at the P33, while including the at least the P5 to 67, and the P67, while including at least the P33 to P95. This overlap should allow a comfortable fit for the whole range of P5 to P95, including the average sized head.

Pressure indication

In order to gain insight into the pressure levels and to see the effects of the bending on an applied material, a mechanical analysis was performed in SolidWorks (SW). For the purpose of analysis, an adjusted model was made. This design was made so that the sensor would be in good contact with the zygomatic process of the users within the range of P5 to P67. Figure 48 shows width measurements within this model.

In order to get an indication on pressure levels, the force necessary to open (relatively tight) headphones was measured. It required approximately 0,5 kg, or 5N (Newton), to pull the ear pieces far enough away from each other for an average sized head to fit in between.

The following material, available within SW, was applied to the model:

Figure 47 *Head width and depth of a range of percentiles of 20-30 year-old Dutch adults (DINED, 2004).*

populations	DINED 2004 (20-30 years), mixed						
measures	P2	P5	P33	P50	P67	P95	P98
23. head breadth (mm)	132	135	144	148	152	161	164
28. head depth (mm)	171	176	189	194	199	212	217

PA type 6 (nylon)
Young's modulus: 2,62 GPa
Yield strength: 103,6 MPa

Figure 49 and Figure 50 show results of the analysis. The green arrows represents a fixture. the purple arrows represents an applied force. This applied force was set to 3 N. This applied force resulted in a maximum displacement of 31 mm; more than enough to cover the range of the P5 to P67. The applied force induced a von Mises stress of up to 6,74 MPa. This is far below the yield strength (the stress at what point a material starts to yield, or permanently deform) of the applied material (103,6 Mpa), meaning that it can easily withstand the applied forces. A quick hand

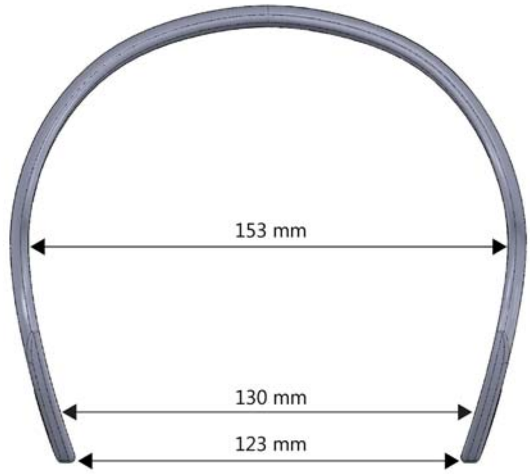

Figure 48 *Width measurements of the SW model prepared for mechanical analysis.*

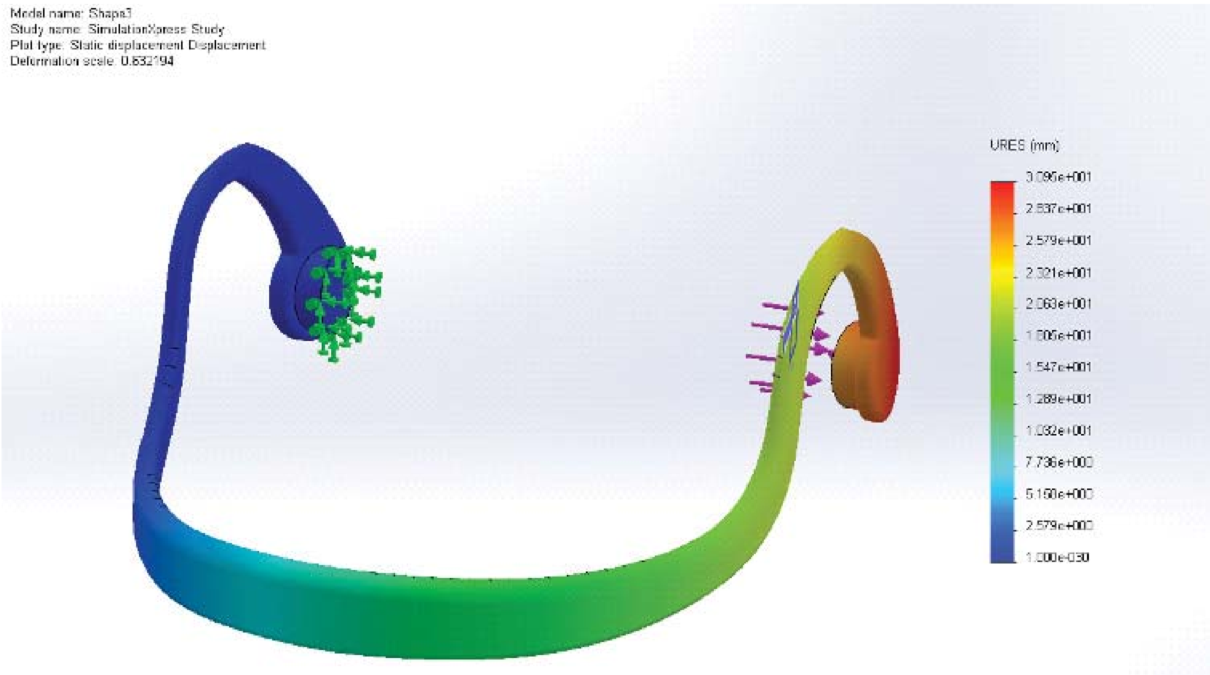

Figure 50 *Displacement SW analysis. Under a load of 3 N, the maximum displacement is 31 mm.*

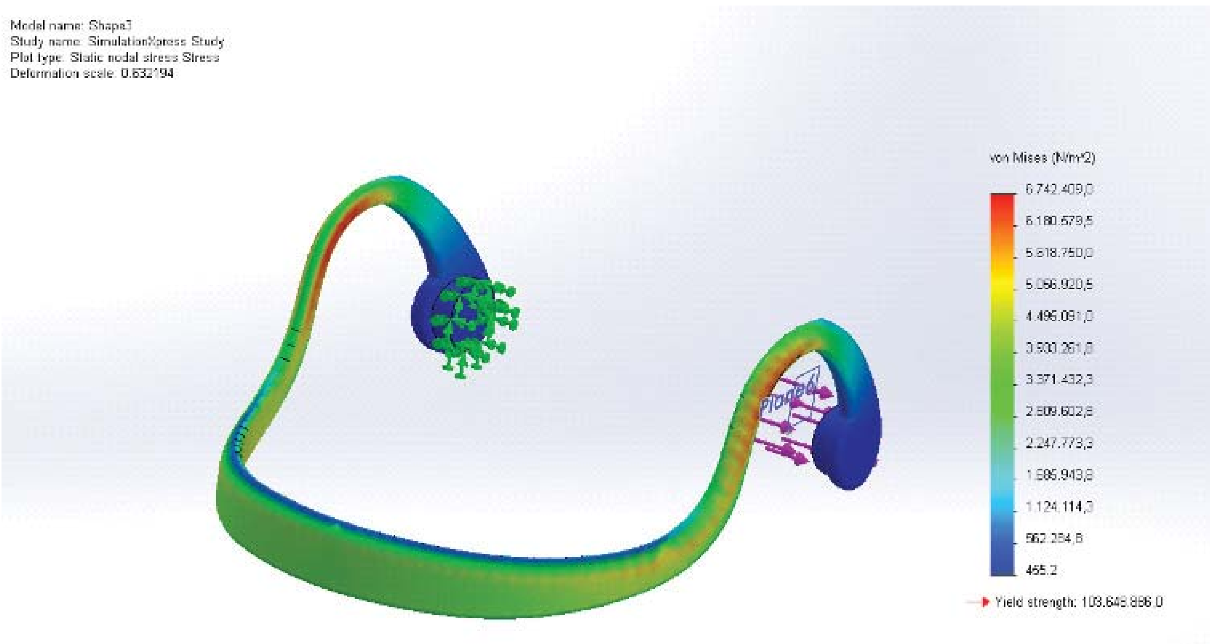

Figure 49 *Von Mises stress SW analysis. The material does not yield under the applied forces.*

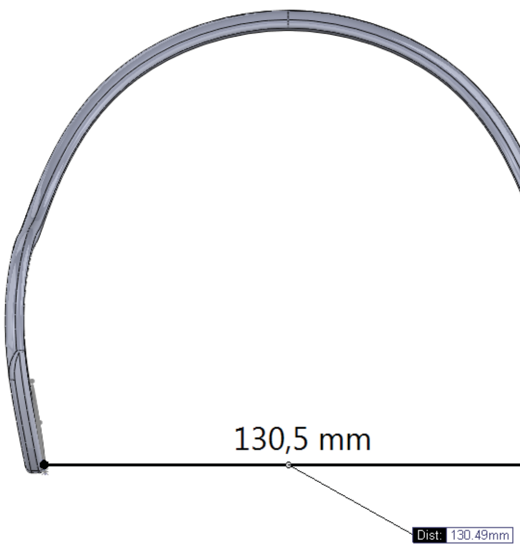

Figure 51 *Top view of design 2.1.*

calculation in order to verify, resulted in a similar order of value. Seeing these results, the design should easily be able to withstand the forces exerted on the model when someone puts it on his or her head.

Note that this model is solid. In production this model will be hollow inside. The estimated material thickness will be approximately 1 mm. This will cause the shape to be less stiff, and therefore apply less pressure to the head.

In conclusion to this analysis: mechanically, applying two different sizes for the P5 to P95 is feasible. The pressure levels provided by the SW analysis seem promising for proper comfort, however should be tested.

Adjusted design: design 2.1

The next step was to create a model that can be tested on comfort. This shape was aimed at the lower to middle spectrum of the (head sizes of the) population. Now that the printer problems were solved, properly testable models could be printed.

Compared to the previously printed model,

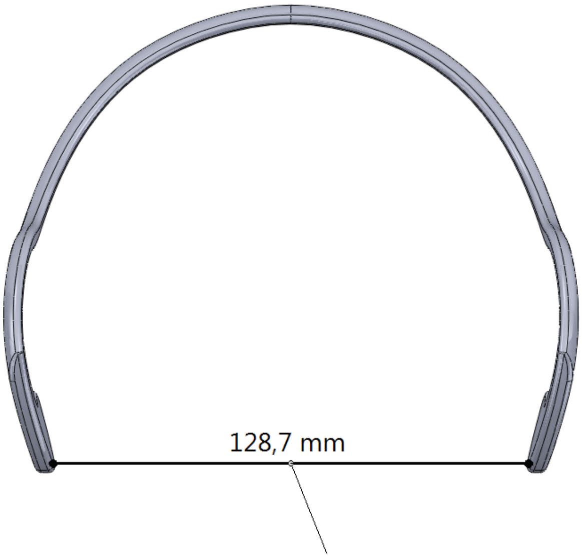

Figure 52 *Top view of design 2.2.*

this model has more space around the neck. Additionally, in order to enable a more realistic representation of the resistant force in a possible future product when flexing the model, the back side was made thinner in order to reduce the stiffness. A top view (orthogonal) of this model can be seen in Figure 51.

Quick test (N=2)

A quick test was done amongst the same two test persons that tested the previous model. For the participant with a small head, the model fit great. For the participant with a close to normal sized head though, although OK, the pressure division was not ideal. The shape did make contact with the zygomatic process. However, most of the pressure was applied right above the ears. Based on the insights gained, a new model was made to compare with.

Design 2.2

This design places the pressure more onto the zygomatic process. It is wider around the ears and the neck, and should therefore fit a larger variety of people. For people with smaller heads this size will probably be a bit too loose. However, for the purpose of comfort testing, it is better to have a

Figure 53 *Back view of design 2.2.*

Figure 54 *Side view of design 2.2.*

model fit for the more average person.

In addition, the 'earpieces', the parts where the sensor goes, is slightly pointed inwards in this model to allow for contact with the zygomatic process for a larger variety of people; both smaller and larger heads.

The top, back, and side views of this model can be seen in Figure 52, Figure 53 and Figure 54.

Comparison test (N=9)

In order to see which of these two models was considered better, a test has been done amongst nine people. The test subjects were asked to, one by one, try the models. Consecutively, they were asked to give their opinion on the most comfortable design. Eight out nine preferred the new version over the older one (the one preferring design 2.1 being the one with the small head). Figure 55 shows a set of images of people trying the newest design. The difference in head sizes is quite visible; for one of them, the model sticks out quite a lot, while for another it fits exactly around the head.

Due to the results of this test, the choice was made to perform the comfort test with design 2.2.

Figure 55 *Participants testing design 2.2 in the comparison.*

9.2 *Final User Test Comfort (N=8)*

A user test was set up in which eight users wore the 3D printed shape (design 2.2) for a minimum of two hours. At the start, when receiving the model, they were asked to fill in their opinions on the design and comfort. After a minimum of two hours, they were asked to fill in the other side of the page. The questions can be seen in Figure 57 and Figure 58. Questions were asked so that the right side of the spectrum was always positive. Table 4 shows the results of these tests. The filled in forms can be found in Appendix 4.

Head measurements were taken with the caliper shown in Figure 56. For the width, the measurement was done on with the caliper on the zygomatic process. Images of the testers with the model can be seen in Figure 59.

The question whether the users have space to move the model around on their heads is related to blood flow and comfort in general. When there is space to move the model around, it can be shifted a bit in case it starts to feel uncomfortable. After participants took off the model, for some participants the location that was in contact with the zygomatic process had turned slightly red. It was not very noticeable. However, it is good to keep this in mind for future research.

The question comparing the comfort of the model to headphones had an indicative purpose. depends a lot on what headphones participants have worn previously. However, this

User tests Comfort

First try

Aesthetics – How would you rate its looks?

Very Poor *Very Good*

Comfort – How would you rate the comfort?

Very Low *Very High*

Pressure – How does the pressure on your head feel?

Very High *Very low*

Fit – How well does it fit the shape of your head?

Very bad *Very good*

Do you have space to move it around a bit?

Yes / No

Head Measurements

Width:

Depth:

Figure 57 *Page one of the comfort test.*

After some hours of wearing it

How many hours did you wear it?

.... hours

Comfort – How would you rate the comfort?

Very Low *Very High*

Pressure – How does the pressure on your head feel?

Very High *Very low*

Would/do you feel comfortable wearing it in public?

Very Uncomfortable *Very Comfortable*

Obtrusiveness – How much do you feel it attracts attention to itself?

Very Much *Very Little*

If this product would help you attain your weight-loss goals, would you be prepared to wear it daily, same as a fitness bracelet (only taking it off at night)?

Oh hell no *Definitely*

In your eyes, how does it compare in comfort compared to a headphone?

Much worse *Much Better*

Did you wear it in public?

Yes / no

Figure 58 *Page 2 of the comfort test.*

Figure 56 *Caliper used for head measurements*

does at least a level of reference.

9.2.1 *Results*

Overall, the test results were very positive. The average score for all (quantified) questions combined was 75,2 on a scale from 0 to 100. The comfort and pressure levels are rated higher after having worn the model for a couple of hours. It appears users get used to wearing the model. Three participants also mentioned that the model started to feel more comfortable through time (vocally) when filling in the form. One of the users, who wears glasses, mentioned (after having worn the model for nine hours) that wearing the model felt the same as wearing glasses concerning pressure and comfort around the ears.

Pressure

Another promising result is that none of the participants found the pressure to be too high. In addition, the model kept in contact with the zygomatic process of all the users. For reference: in this model, the force applied to displace an end of the model 20 mm away from the other end was measured to be approximately 160g, or 1,6N.

This model was found more comfortable compared to headphones in general.

Fit

There was one person who found the model quite uncomfortable; the model did not fit well. If he looked to the side, it would close an ear off. Compared to the rest of the participants, his head is on the large side; however, not enough to explain the difference completely. He said it might have to do with his hair. Another possibility is that his ears are located more forward, or that his neck is thicker or 'more backwards', compared to the other participants. This sort of anthropometric data however was not found, nor extensively searched for.

Overall, the fit is found to be the point of improvement. Though not problematic for most, and still comfortable, the fit can be improved. The depth of the model, concerning the neck, was the largest problem. Some found it too large; some would need or prefer a deeper model. For those with smaller heads, the fit was too loose in general, with the model sticking out on the back. This was expected due to the measurement choices of the test model. The contact with the zygomatic process was still sufficient. However, one person would have preferred a higher pressure for a more secure fit.

A good thing about the fit is that, although not always comfortable, it did fit on any head it encountered. One person with quite a large head and neck (The middle image in Figure 59) tried it on for a minute. Though clearly tight, it did fit. This points out the likeliness of two sizes being sufficient for covering a wide variety of people.

Note that the average width of the participants' heads was quite a bit lower (9mm) compared to the P50 data of DINED. This might be caused by taking the measurements on the zygomatic process instead of on top of the head; probably the

Table 4 *Results of the comfort test. The test had positive results, with an average score of 75,2 out of 100.*

Page 1	1	2	3	4	5	6	7	8	Average
Aesthetics	75	70	85	85	80	85	85	80	80,63
Comfort	85	85	77,5	70	70	65	70	45	70,94
Pressure	90	90	95	80	75	100	70	45	80,63
Fit	65	75	85	60	55	35	80	45	62,50
Wiggle space	yes	yes	yes	yes	yes	yes	yes	yes	
Width (cm)	13,6	13,2	14	13,7	14,7	13,3	14,2	14,5	13,90
Depth (cm)	19,2	19	19,2		18,5	18,5	20,8	20,5	19,39
Page 2	After ≥ 2 hours of wearing it								
Hours worn	3	3	9	3	2	9	2	2	
Comfort	85	80	85	70	85	85	80	30	75,00
Pressure	85	90	85	100	70	100	70	80	85,00
Comfortable in public	90	90	85	70	70	85	90	45	78,13
Obtrusiveness	75	90	80	55	85	85	55	80	75,63
Daily wearing	85	85	70	75	100	85	55	45	75,00
Headphone comparison	n/a	80	55	85	80	80	65	35	68,57
Worn in public	at work	yes	yes	yes	yes	yes	no	no	
									75,20

Figure 59 *The model being tested during the comfort test.*

measurement on the zygomatic process is lower on average. The head depth in contrary only differed 0,1mm from the P50 data.

Aesthetics

The aesthetics were found pleasing. Depending on the wearer's haircut, it can be practically hidden. Aside from the person for whom the model was too small, none of the participants would find it a problem to wear it in public.

Daily wearing was found acceptable, if it would help them with their weight-loss goals, for 7 out of 8 people. This point scored a 75 on average. This is higher than expected. This might have to do with the group of participants. When taking a random sample of people on the street, this might be different.

It was noticeable that multiple participants were initially confused on how to orient the BitsLab on their head. They first looked at it, with a difficult look in their eyes, and consecutively flipped it the wrong way upside down.

9.2.2 Design Implications & Recommendations:

The suggested approach of continuation is to first improve the fit. Based on the findings, it seems feasible to create two sizes from the tested model to cover the P5 to P95:

- A version which is a minimum 10mm deeper in the back. In addition, the width can be slightly increased.

A version that is around 5mm smaller in width. The depth of this model can be decreased by approximately 7mm.

These numbers are rough indications, though should provide improvement compared to the previous model. Consecutively, these models should be tested to see whether these provide a comfortable fit for a variety of people.

In conclusion, an adjustable model does not seem to be required. Two different sizes should suffice in providing a large range of people with a decent fit. However, this should be verified by testing new 3D printed models in the future, before making next steps in the design. Testing should also be done on a larger test group, with a wider variety of people; for comfort, aesthetics, and also the social aspect. Within this test, most people were similar-minded.

9.3 Proof of Concept prototype

A wearable proof of concept prototype has been realized. A piezo was glued inside a 3D printed housing, as can be seen in Figure 60 and Figure 61. This piezo was connected to a TRRS audio plug, with a parallel (SMD) resistor of 10 kOhm soldered inside the housing of the microphone plug.

Figure 60 *Placement of the piezo within the designed shape.*

When testing, the signal of the piezo was significantly weaker than that of the Mogees. This might be caused by the difference in resistance. Partly, it might also be attributable to the piezo impedance, that of which is unknown of the Mogees. Optimizing the signal strength is a point for further research. After applying an amplification inside the app, the chewing recognition was functional again.

Figure 61 *The functional proof of concept prototype.*

The most recent version of the software of the app can be found on the attached CD.

9.4 Materials & Production

9.4.1 Material

Due to its low weight, price, ease to mass produce, and its strength to flexibility ratio, the choice was made to use plastics. Due to the exact shape design not being final, real optimization of material choice is not yet possible. The Young's modulus is critical in material selection in order to provide a comfortable pressure in the product. To still get an indication for a suitable material, CES EduPack 2014 was used for material selection. For the decision on mechanical properties, the SW previously done mechanical analysis was used to enable better educated guesses. Data inside CES was also used as reference for filtering; it provides insight into

In CES, the following filters were applied:

- Semi-crystalline thermoplastics

The design will be injection molded (see 9.4.2). These are suitable materials for this purpose.

- Elongation set to 5% strain

Plastics with elongations less than around 2% are usually considered brittle. A ductile material is preferred for this design, as brittle materials can break quite unexpectedly. The material should be flexible enough to enable somewhat rough handling.

- Young's modulus of 1 to 4 GPa
- Yield strength with a minimum of 50 GPa

A higher yield strength means that a higher stress level will be required to permanently deform the material.

- Opaque

An opaque design will look better within this context.

- Excellent resistance against fresh water
- A minimum of acceptable resistance against salt water
- A minimum of 'fair' resistance against the UV radiation (sunlight)
- Can be recycled into a material of similar quality grade

After applying the filters, the materials shown in figure x were left. By looking through the properties of these materials and its common applications, a suitable material was chosen: PTT (general purpose). It has a Young's modulus of 2,4 to 2,55 GPa, a yield strength of 58,5 to 61,5 MPa, a good chemical resistance, and a price range of 2,77 to 3,05 euro per kg.

9.4.2 *Production*

The housing of the product will be injection molded. It enables the (mass) production of the designed shape, and provides a good surface finish. A matte surface finish would be best for this product, in an inconspicuous color; preferably black.

This design will consist of six separate parts. Two for each side of the ear, and two for the back. For the different sizes, only the ones in the back have to be scaled.

Evaluation

10. Evaluation

10.1 *Evaluation*

The BitsLab seems to be a promising design. There is a need and a hole in the market for automatic intake tracking products. Additionally, it is a feasible solution in terms of execution.

The requirements of the LoR are met with this product. The Bitslab:

- is usable in combination with a smartphone and/or tablet
- increases awareness of eating patterns
- increases awareness of triggers and rewards
- automatically tracks when the user is eating
- is non invasive

The Wishes of the LoR are more problematic however. Most Wishes seem to have been fulfilled. However, this is only on a theoretical level. Although it is great that users can automatically track when they are eating, this does not mean that their eating habits actually improve long-term. The habit app should help them with this aspect. However, the app needs to be elaborated much further in order to be able to test this properly. Only the basic mechanics have been set up till this point.

The most important question is whether the simplicity of the app is sufficient. Habit changing is a difficult feat. The app attempts to simplify this by breaking it down and guiding the user in their process. To create an app with this level of intuitivity might prove difficult.

If the app would prove unsuccessful, the BitsLab could still be a valuable addition to a dietist's practice. In case dietists receive this automatically generated eating data, they could be of much more help to their patients. Dietists knowingly ask their patients to track what they eat. However, even if the patients would attempt to track their food (which many do not), research has shown this to be very inaccurate in general. While chewing recognition does not show what type of food one is eating, the pattern itself provides a lot of information. The BitsLab could be used by dietists as to tool to help patients analyze their behavior, and give better, more specifically aimed advice.

Testing has only been performed on physical and social comfort up to this point. The results of this comfort test were positive, though the user group was small. More elaborate research with a wider variety of test subjects is necessary to verify whether people really are willing to wear the design through the whole day for instance. An analysis of these tests can be found in 9.2.

10.2 *Recommendations*

First of all, it is important to create robust chewing recognition. This is the essential part of the product. Next, it is advised to seek contact with dietists and diet psychologists. Cooperation with those experts can greatly improve the effectiveness of the app.

A suggestion is to, after some further work on the robustness and the app, launch a Kickstarter project. In case this does not provide good results, working together with (medical) dietists can be considered. The reason for not starting in the medical world first is that if the product would be categorized by people as a medical device, it might reduce the odds of a successful launch in the consumer market due to its 'medical label'.

Hardware

Several possibilities exist for the extension of the BitsLab through hardware. This section will simply show some ideas on possibiliies. For instance, another piezo could be added to the design as 'bonephone', which is used to stream audio to the user without bystanders being able to notice anything.

Another useful addition would be a capacitive touch sensor or something similar to measure whether the user is wearing the device. This function would be especially useful in medical applications so that the analyzing person can see whether the user has been wearing the device during the entire day or not.

An accelerometer could be added to provide movement data next to the intake data. This way, the product will be more allround. It might also discover a link between for instance a period of being stationary, and consecutive eating.

A combination in the future,with 'Kroonsteentje' (of DoBots) could also add useful data. For instance, it could detect when a user is eating and watching TV simultaneously.

One or two buttons or a touch sensitive slider for instance could improve input simplicity in the future.

It can be combined with a smartwatch. Quick notifications can be displayed, and easy and quick responds are possible for input on triggers when eating. In addition, when using information fusion, arm movements can be counted when eating in order to be able to detect how many times the user chews per bite.

Further research

Though these additions sound interesting, for now the design should be as basic as possible and focus on creating a robust product. Further research should be done on optimizing the signal strength of the sensor, and to test whether the input works on different smartphones.

A basic app with a Cravings and Trigger Finder should be created to start testing the effectiveness of the app.

In case the product is launched, the development of drinking recognition should be added. This is also the point where game development can be started. Although games can be a valuable addition to the app, it is likely unrealistic to implement this into the first product version. Developing these games would be material for an app or product update.

Concerning the design, the current model should be adjusted according to the results found in the comfort test. Additionally, use in combination with glasses should be looked into.

Concluded: all in all, there is much left to do in the development of this design, and there are many possibilities for expansion. In the first phase however, it should solely focus on creating robust recognition and to start testing the effectiveness of the product with a basic habit app.

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