somnox mini

master thesis

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summary

Millennials, a generation of individuals born between 1981 and 1996 that are shaping the current working class. One trait that makes millennials stand out from other generations is that their generation is the most stressed out. It is estimated that 20% of employed millennials in the Netherlands are suffering from symptoms due to stress. These symptoms include less life satisfaction, tiredness, and, most importantly, insomnia. The fact that stress causes insomnia makes stress a relevant problem for Somnox, as its mission is to help 100 million people sleep better by 2030.

Somnox is a Dutch scale-up that focuses on developing companion-like innovations that improve human wellbeing through the power of breathing. The fast-growing company is on the look-out for new ideas to expand its product portfolio. One of these ideas is a portable breathing regulation device.

The assignment's initial brief was to turn this rough idea of a portable breathing device into an advanced concept design. I approached this by adopting an iterative approach in which I quickly ideated, built prototypes, and validated these with users. This approach has led to the final concept: the Somnox Mini.

The Somnox Mini is a portable breathing regulation device that simulates breathing motion using robotics. By following the device's breathing frequency, the device guides the user in slow breathing - which is a breathing exercise in which the breathing frequency is reduced to 6 breaths per minute. Research shows that breathing at this particular frequency induces a biological phenomenon called respiratory sinus arrhythmia (RSA), which synchronizes the heart rate variability (HRV) and breathing frequency. This stimulates the body's relaxation response. Long-term practice of slow breathing has been proven to balance overactive stress response and improve insomnia symptoms.

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Introduction

1.1 insomnia, an increasing societal problem

Sleep deprivation is a growing problem that impacts millions of people across the world. It is estimated that 10% to 20% of the world's population suffers from insomnia (Buysse, 2013). Insomnia is a chronic sleep disorder in which the patient has trouble falling or staying asleep (Mayo Clinic, 2016). Common treatments for insomnia include prescription medication, which unfortunately has strong side effects such as headaches, drowsiness, and dizziness (Glass et al., 2005). Long-term medication use can also lead to dependency (Holbrook et al., 2000; Bateson, 2002).

1.2 the client

Somnox is a scale-up located in Rotterdam. The company was founded by 4 engineering students of the technical university of Delft. The company's mission is to provide companion-like, intuitive technologies that will help 100 million people sleep better by 2030.

Somnox brings an alternative, effective solution without side effects with the world's first Sleep Robot. The Sleep Robot relies on the science of breathing exercises that have been proven to reduce the body's stress response and stimulate sleep. The Sleep Robot is a pillow-like object that simulates a natural breathing pattern. When holding the product, the user subconsciously takes over the breathing pattern of the product.

1.3 problem definition

One of the most critical risk factors for developing insomnia is stress (Mayoclinic, 2018). The Sleep Robot reduces the body's stress response right before the sleeping process to help users fall asleep. Another method for combating insomnia is to directly tackle the source of insomnia by helping people manage their stress levels throughout the day.

Breathing regulation is a powerful way to manage stress. However, the design of the Sleep Robot is not optimized to be used throughout the day. The Sleep Robot is specifically designed to be used while sleeping and is therefore optimized for a single context which is the bed. Unlike the night, which primarily takes place in the bedroom, the day-schedule of an individual is much more diverse and includes many more contexts (work, commuting, university, etc.). This limitation of the Sleep Robot brought Somnox to a new idea: creating a portable breathing regulation device, which they refer to as the Somnox Mini.

Currently, the Sleep Robot is their only product. The strategy is to start developing other products in 2024 to add to their product portfolio; one of these products is the Somnox Mini.

Figure 1 -The Somnox Sleep Robot

1.4 the assignment

At present, the Somnox Mini is still a rough idea. The assignment is to help Somnox define a potential market for the product, and turn this idea into a feasible concept that can fulfill this market's needs. The product concept will specify the following:

1. The interaction between user and product. (How will the product be used? What is the product behavior?)
2. The features that the product should have depending on the market needs. (do we limit ourselves to only a breathing guide, or should we also include other features such as light, sounds, a companion app etc.? And will the product be a wearable or a separate object?)
3. The key technologies that can facilitate the features and interactions

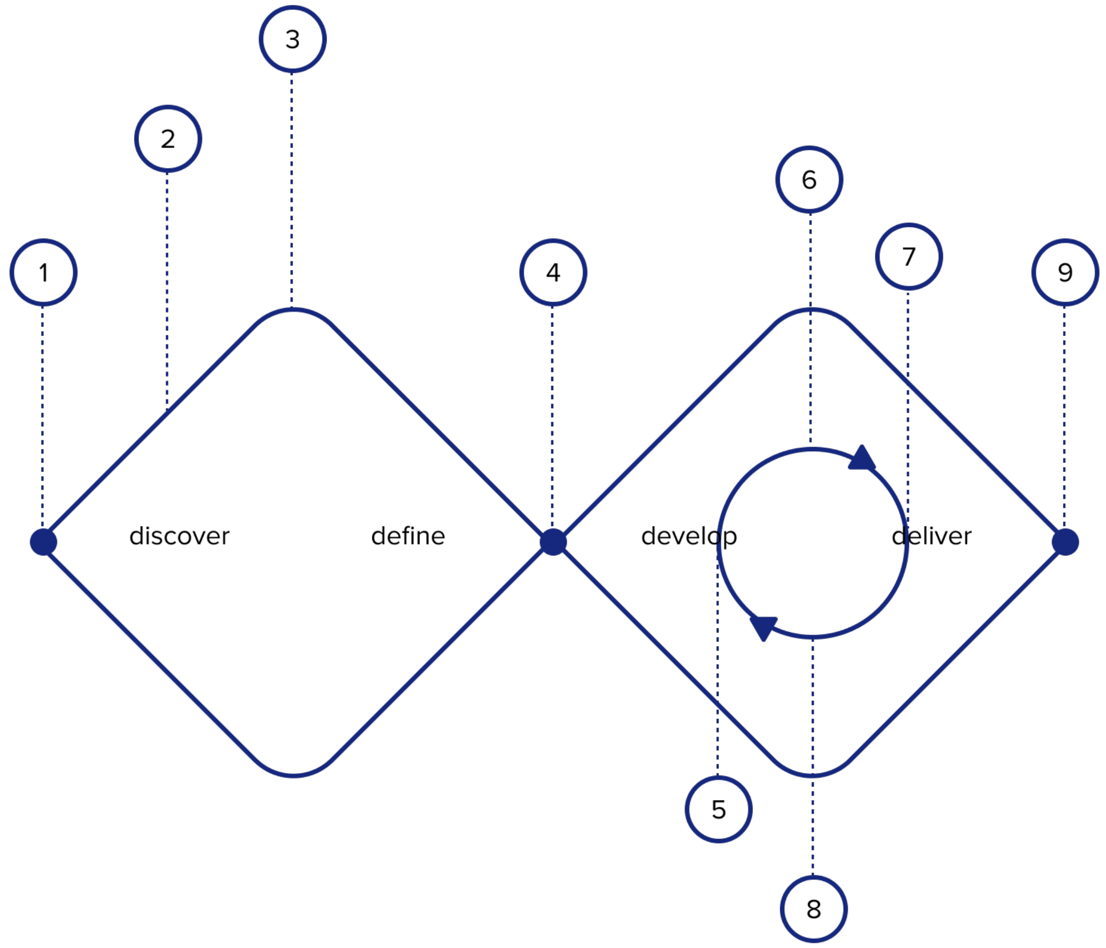
As the graduation project only takes 100 working days, it should be clear that the project's result is a conceptual design and not a manufacturable product. We merely indicate what functionalities and technologies the product should have, but they have yet to be optimized for production.

1.5 design process

To systematically approach the design problem, I used the double diamond framework (British design council, 2015) for its divergent and convergent approach. The Somnox Mini is a rough idea and still has a lot of room for exploration. The double diamond allows us to explore and create an overview of the possibilities and select the optimal solution within our requirements.

Our process starts with a thorough research process, in which I explore the topic, identify, and specify a potential market and a value proposition. The research phase is then followed by a design phase. This phase consists of smaller iterative design cycles taking approximately 2 to 3 weeks each. In each iteration, we explore ideas, specify one idea, build the idea, and test it with end-users. I choose this approach for two reasons. First, working iteratively allows me to identify critical user requirements early in the process. Second, working iteratively will enable me to evolve the product while gathering user and client feedback. This iterative way of working ensures that the result is a product that is desirable for both client and user.

Figure 2 - The double diamond design process



1. Establish the project brief together with the client.
2. Learn about the topic of breathing and stress through literature research.
3. Discover opportunities for Somnox through literature research and interviews.
4. Formulate a value proposition.
5. Ideate on potential solutions.
6. Build prototypes to validate solutions.
7. Testing the prototypes with users to gather insights for future iterations.
8. Evaluating user test results and establish a list of requirements.
9. Concept delivery

02

research phase

2.1 background research

To effectively design a product that can manage stress using breathing exercises, I first needed to understand what stress is and why it is a problem. Secondly, I needed to understand the impact of breathing exercises on stress to understand how breathing exercises should be implemented in our product.

2.1.1 what is stress?

To understand what stress is, we first need to understand how the autonomic nervous system functions. The autonomic nervous system is a component of the peripheral nervous system that regulates involuntary physiological processes. These include heart rate, blood pressure, respiration, digestion, and sexual arousal (Waxenbaum, 2020).

The autonomic nervous system consists of two systems that counteract each other: the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). The SNS is also referred to as the fight and flight response. It is responsible for optimizing the body for external threats. When the SNS is activated, processes that occur are:

- Mobilization of energy from storage nutrients.
- Increasing heart rate to optimize oxygen.
- Glucose delivery to muscle tissue.

The PNS, on the other hand, is responsible for the restorative processes of the human body. These processes include digestion and growth.

From a biological perspective, stress is defined as a fundamental response that adapts the body to threatening environmental stimuli. In homeostasis, the SNS and PNS are in balance. Homeostasis can be described as the resistance to change, to maintain the optimal stability for the functioning of the human body (Elizabeth, 2008). This equilibrium is usually reached through feedback mechanisms that can judge and accordingly counteract previous changes. However, when stress is perceived, the SNS becomes dominant, while the PNS is suppressed (van Reeth, 2000; McCorry, 2007). In other words, when stress is perceived, the body switches to its flight or fight response.

Although the word stress is often associated with something negative, this is not necessarily the case (Sanders, 2013). Stress has helped our ancestors survive predators and fight off enemies, and is likely why you and I are thriving today. In a modern context, occasional stress helps us to work more efficiently or meet our deadlines. More specifically, research found that stress can increase the attention towards a task which respectively increases the performance on that task (Hunter & Thatcher, 2007)

However, the problem arises when the source of the stress is prolonged or uncontrollable. In this scenario, the feedback mechanisms fail in restoring the body to equilibrium; the stress response becomes inadequate and may result in the dysfunction of physiological systems resulting in stress-related symptoms such as headaches, exhaustion, concentration problems, sleep disturbances, and in more severe cases result in diseases such as hypertension, mood disorders, and (e.g. anxiety, depression) burnout (Cleveland clinic, 2015; van Reeth, 2000).

2.1.2 the power of breathing

Breathing exercises are exercises in which the practitioner controls their breathing to restore and enhance one's health. These exercises have been practiced for thousands of years as part of spiritual and religious practices in eastern cultures, such as yoga, meditation, qi-gong, and tai-chi (Russo et al., 2007; Smith, 2012).

Although breathing exercises originated from these religious and spiritual practices, science shows that it has many proven health benefits. This resulted in the increasing popularity of these exercises in western culture. However, in contrast to eastern cultures, the western cultures have adopted these breathing techniques independently of their religious and spiritual context and are mainly used for therapeutic aims.

The west has developed many breathing exercises. Examples are Buteyko, the 4-7-8 method, box breathing, or the Wim Hof method. Despite the diversity, there is one particular form of breathing exercise with great scientific interest; slow breathing (sometimes also referred to as deep or paced breathing). As the name states, the technique is based on slowing down the breathing frequency by taking slow and deep diaphragmatic breaths. (Zaccaro et al., 2018).

Multiple studies have found an interesting phenomenon that occurs when the breathing frequency is reduced to 6 breaths per minute. At this rate, we see that the heart rate variability (HRV) synchronizes with the practitioner's respiratory rate. HRV is a measure of the variation in time between each heartbeat and is controlled by the ANS (Campos, 2017). During this synchronization, the heart rate increases during inhalation and decreases during exhalation (see figure 3). The medical term of this phenomenon is respiratory sinus arrhythmia (RSA) (Laborde et al., 2016); sometimes this is also referred to as resonance (Steffen et al., 2017).

This synchronization results in improved gas exchange and oxygen saturation and increases vagus nerve activity (vagal tone). The vagus nerve is one of the main components of the parasympathetic nervous system, an increase in its activity is a sign of an increased relaxation response (Breit et al., 2018).

The regular practice of breathing at 6 breaths per minute has helped PTSD patients reduce their stress response (Fonkoue et al., 2020). Furthermore, regular breathing practice at this frequency improved insomnia complaints (Jerath et al., 2019; Russo et al., 2017). Notably, both studies state that these exercises should be practiced daily for 10 to 20 minutes to be effective.

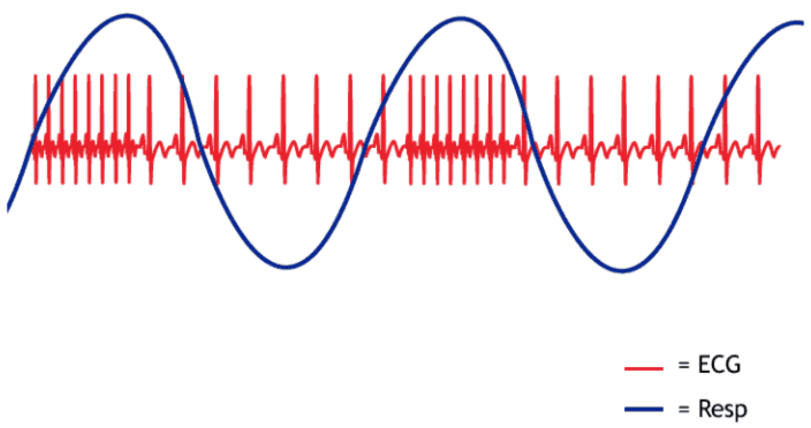


Figure 3 - a visual representation of RSA. The red line represents the heartbeats that are collected through an ECG. The blue line represents the breathing (source: https://support.mindwaretech.com/)

2.1.3 conclusion

The background research insights suggest that a breathing regulation device that facilitates slow breathing exercises can help manage stress and treat stress symptoms when used daily.

The next question is; how do we embody these breathing exercises in a product that will be valuable for our users? To answer this question, I first need to understand who our users are going to be. The challenge is that stress is a broad problem. Because it is a natural biological response, it is an experience that every human being will or has experienced; as a result, there are many target groups that we can design for. Each target group might have different requirements for how these breathing exercises should be embodied. For instance, a middle school teenager will likely need another product than a CEO with weekly business trips. Furthermore, stress also comes in different severities. Some people only stress once a while, while for others, it has become chronic, and for some, it might even have turned into a burnout. Similarly, the different types of stress also ask for a different solution. For example, a person who only stresses once in a while will likely require a preventive product, whereas a person who suffers from burnout might need a more invasive treatment product. The first step in determining the target group is identifying and specifying which severity of stress we are focusing on. Accordingly, we conducted literature research. Then, we created a simplified overview of different categories of stress to make the topic more graspable. An overview and detailed description of the four stress categories we defined, can be found in figure 4,

Several interviews were held with Somnox's commercial team employees to specify which category of stress would fit Somnox's future business strategy the best. From the interviews, we concluded that category 3 is the best option. This category is aware that stress is a problem, as it has a chronic impact on the quality of life. But the problem is not severe enough yet, that it becomes a clinical product.

Figure 4 - Stress categories

Low perceived problem

Category 1

The first category we defined contains people suffering from acute stress. Acute stress is the most common form of stress and is the stress people suffer from for a short duration (APA, 2012). This type of stress is considered normal and, in some cases, even beneficial (Mayo Clinic, 2019)

Category 2

The second category is people suffering from chronic stress. Chronic stress is the stress that arises when the stressors are of high frequency and/or prolonged. The body does not have enough time to recover from the stress. If left untreated, biological systems may be disturbed, resulting in physical symptoms such as frequent headaches, exhaustion, sleep disturbances, and more (APA, 2018; Cleveland clinic, 2015; Mayo Clinic, 2019). In this second category, people have not developed these symptoms yet.

Category 3

The third category contains people suffering from chronic stress who have developed physical symptoms, such as stated above. This group is aware that stress has a detrimental impact on their well-being. However, the symptoms are not severe enough, yet they have to make serious compromises to their lifestyles. They are still going to work, social gatherings, doing their daily chores, etc.

Category 4

The fourth category consists of people that left their chronic stress untreated. As a result, a severe condition has developed, such as depression, anxiety disorder, chronic insomnia, burnout syndrome (van Reeth, 2000; Schmidt, 2001; Basta et al.,2007). At this stage, the symptoms have a significant impact on their lives. They are taking a long break from work and cannot do some of the things they were used to doing anymore. These people require professional help to manage and/or recover from their condition.

High perceived problem

2.2 discovering opportunities

2.2.1 user interview

In the previous section, we specified the “stress category” we want to provide a solution for. The next step is to understand how stress and its related symptoms impact people within this category. The goal is to find incentives for why people would purchase the Somnox Mini to tailor the product to match those incentives. To achieve this, I started by conducting several explorative interviews with participants that fell into the specified stress category.

2.2.1.1 Method

The interviews were held with 8 participants (age 24 – 55). Before conducting the interview, I screened the participant to ensure they fell into the specified stress category using the Perceived Stress Scale (PSS; Cohen, 1983). The PSS is a 14-item questionnaire that determines the degree to which situations in one’s life are appraised as stressful. For the participants to be recruited for the interview, their stress level had to “moderate” or “high”.

Due to COVID-19, the interviews were held online through Zoom and Microsoft Teams. It was a semi-structured interview, in which we discussed the following topics:

1. The impact of stress on the quality of life of the participant
2. How the participant coped with stress
3. The reasons for their stress
4. Their experience with breathing exercises

2.2.1.2 Results

Insight 1

Stress leads to an array of physical symptoms among the participants. Symptoms such as headaches, tiredness, grogginess against the partner, lower energy, and concentration problems. Although the symptoms differed per person, stress has affected the sleep quality in 7/8 of the participants. Participants mentioned overthinking at night, disrupted sleep, and suffering from nightmares.

Insight 2

I found that the younger participants (N = 5, age 25 - 28) adopted unhealthy strategies to cope with their stress compared to older participants (N = 3, age 49 - 56). These unhealthy coping strategies included: drinking alcohol, escaping stress by sleeping, ignoring the pressure, or smoking. For the older participants, these included: saying positive affirmations, crafting, going away for the weekend, and finding love in family members.

Insight 3

All participants were aware of the cause of their stress. In all participants, the stress was all related to their full-time occupation (work or studying).

Insight 4

The majority of the participants (N = 7) have tried breathing exercises in the past to cope with their stress but eventually gave up due to various reasons:

1. Participants did not know how to breathe during the exercise.
2. Participants were uncertain whether they were breathing correctly during the exercise, which increased stress. Example: “I am constantly worrying about whether I am performing the exercise correctly or not, which makes me feel stressed.”
3. Participants mentioned that the perceived breathing exercises were too spiritual. Example: “I once downloaded a meditation app (that included breathing exercises), however how these exercises were narrated made it seem very spiritual. He mentioned things like chakra and energy flows. Since I am not a spiritual person, I felt these exercises were not right for me. “
4. Participants mentioned that they gradually quit practicing due to a lack of motivation and a lack of time.

2.2.1.3 conclusion

An interesting insight that was gathered from the interviews is that the younger participants tended to resort to unhealthy coping styles compared to the older participants. It seemed that the older participants were more aware of how to manage their stress and had established systems that allow them to do so. In contrast, the younger participants were still searching for sustainable solutions as they were fully aware that how they currently deal with stress is unhealthy.

Most participants were aware that breathing exercises have health benefits, and most of them have tried them. However, even though breathing sounds simple, people mentioned that they had difficulty practicing it independently since they did not know how to perform the exercise. Even when they knew how to perform the exercise, they were uncertain if they were doing it correctly, which ironically increased stress. This uncertainty about their performance indicated low self-efficacy during the training. Self-efficacy is defined as an individual's belief in their capacity to execute behaviors necessary to produce specific performance attainments (Bandura, 1977).

Furthermore, the majority of the participants had tried breathing exercises to cope with stress. However, these breathing exercises were often part of other practices such as meditation, yoga, and mindfulness courses. These practices have strong associations with spirituality. Consequently, participants mentioned that they perceived breathing exercises as 'ineffective', or 'too spiritual'.

Moreover, even when participants decided that breathing exercises are effective, they could still not stick to them due to a lack of motivation or a perceived lack of time.

2.2.2 expert interview

The user interviews resulted in interesting insights that can be turned into potential opportunities for the Somnox Mini. However, the study's limitation is that the interviews were conducted with a small sample (n = 8). To further support our findings, I conducted an expert interview with a clinical psychologist. A clinical psychologist encounters and has a lot of patients suffering from stress and therefore has sufficient experience with our target group to be a good source for validation. Additionally, I performed literature research on topics that the expert could not validate. The expert interview was an informal interview in which we discussed the previously mentioned findings.

Insight 1: A healthy and sustainable coping strategy is essential for managing stress levels

The majority of the patients of the expert were older than 50. Hence, she could not validate the insight that younger people would have unhealthier coping strategies compared to older people. Nevertheless, she did stress the importance of having a healthy coping strategy. Whether stress progresses into something more severe, such as a burn-out or a mental disorder (e.g., anxiety and depression), is influenced by the patient's coping strategy. Patients with unhealthy coping strategies are much more likely to develop more severe conditions.

Insight 2: Finding a coping strategy is difficult

Furthermore, she mentioned that finding a coping strategy on your own is difficult. It is often a trial and error process. During this process, counseling can be beneficial, as a psychologist can provide support and guidance. Unfortunately, the waiting times for counseling in the Netherlands have increased due to the COVID-19 pandemic. The waiting time before a patient gets treated can be as long as 11 months. This made counseling inaccessible to many people.

Insight 3: Breathing exercises are difficult to practice on your own and potentially dangerous if practiced incorrectly

Moreover, she stated that she regularly prescribes relaxation exercises to her patients to manage and treat stress and anxiety symptoms. These exercises include breathing and mindfulness exercises. She recognized the problem that breathing exercises are challenging to perform on your own and that clear guidance is essential. She gave the example of a patient who misunderstood the breathing exercise instructions, which caused the patient to hyperventilate and experience symptoms such as dizziness and light-headedness..

Insight 4: Adherence to relaxation therapy is low

Another point she addressed is that she found that the adherence to these exercises is low. She prescribes these relaxation exercises twice per day, but she finds that her patients only perform them when they feel low.

2.2.3 additional literature research

The remaining insight that has yet to be validated is whether younger people are more likely to adopt unhealthy coping strategies. Furthermore, both the user interviews and expert interviews indicated a low adherence to breathing exercises. The reasons behind this remain unclear. Participants from the user interviews believed it was due to low motivation or lack of time. However, the participant sample that stated this was too small to conclude that those are the main reasons for low adherence. To gather more clarity to the topics mentioned above, we conducted literature research which brought us to the following insights:

The millennial generation (1981 - 1996) is the most stressed-out generation

When we look into the statistical report by the Central Bureau of Statistics (CBS), we see that the most significant demographic that suffers from burnout symptoms in the Netherlands are 24 to 35 years old. The American association of psychology (APA) found a similar trend in the US. The millennial generation is the most stressful group (APA, 2012). According to them, 72% of this stress is work-related.

One of the reasons this specific generation experiences more burnout symptoms is their poor coping strategies. As mentioned previously, a coping strategy is crucial in determining whether stress progresses in severity or not. A study by APA (2012) found that the millennial generation is much more likely to engage in unhealthy behaviors to cope with stress, such as over-eating, drinking alcohol, and smoking. A report by CZ, one of the largest health insurance companies in the Netherlands, states that this young generation does not know how to properly cope with their stressors because they are relatively new to the corporate world and therefore lack experience.

A shift in mindset causes another reason why this demographic is more prone to developing burnouts, Launspach (2018) suggests. The millennial generation has higher expectations of themselves compared to other generations. Due to recent economic shifts, traditional achievements associated with adulthood have been postponed by several years. It was customary to have a permanent job in older generations, be married, and own a house in your early twenties. However, in recent years, this has been moved to the early thirties. Despite the shift, the expectation patterns remained the same. Many millennials believe they should achieve these goals before their thirties. As a result, millennials tend to work even harder at the moments they should rest and recover.

Figure 5 - An impression of the target group we're designing for

The reasons behind low adherence is difficult to explain and differs per individual

To my knowledge there are no studies that specifically examined the adherence to slow breathing exercises. However, low adherence to prescribed therapy is a widely recognized problem (WHO, 2003). The reason for this low adherence remains unclear and is difficult to define as it differs per individual as stated by Brown (2016): "the emotional make-up, culture, family, background, socioeconomic status and motivation of each person is unique".

2.2.4 conclusion: formulating a value proposition

In this section, I use the insights gathered from user interviews, the expert interview, and the additional research to formulate a value proposition.

The literature research revealed that the most prominent demographic suffering from stress-related symptoms, including insomnia, are working individuals between 24 - 35 years old. Therefore, to make the most significant societal impact, it seems logical to focus on this demographic. I have summarized this demographic into a persona named Career Carmen based on the insights that we have gathered from our research (figure 6). Giving our target group a 'face' helps us to better empathize with the user.

One of the reasons why this group is so prone to stress is their unhealthy ways of coping with it. From the user interviews, We learned that most of them are aware that they have unhealthy ways to cope with stress but lack the know-how to cope properly. A clinical psychologist further supported this insight, stating that finding a coping strategy is a trial and error process and thereby difficult to do on your own.

Somnox can help this target group by providing them an easy and effective tool to cope with stress, reduce their current stress-related symptoms, and prevent them from developing a more serious condition such as burn-out syndrome or mood disorders through the use of slow breathing, as it is scientifically proven to work.

However, for slow breathing to be effective, it needs to meet two conditions. Firstly, it needs to be done correctly and done at the right breathing frequency. We know from studies that the individual needs to breathe at 6 breaths per minute to induce RSA. However, the problem is that it is challenging to perform the exercise correctly on your own (and potentially dangerous if performed incorrectly), and even when it is performed correctly, individuals show low self-efficacy during the practice, which increases stress. So, not only do we need to guide the breathing of the user clearly, we also need to address the low self-efficacy by providing a feedback mechanism that can tell the user whether he or she is doing it correctly.

Career Carmen

28 years old, financial consultant

Characteristics

- Career is her first priority
- High expectations of herself
- She needs to have 'made it' before she is 30
- Chronically stressed, sleeps poorly
- Succesful on the outside, broken on the inside

User goal

Her symptoms are causing her to fall behind her peers. She is despiratly searching for a solution for managing her stress and symptoms.

Figure 6 - Career Carmen

The second condition is that users need to practice slow breathing regularly. Practicing it once might induce a relaxation response, but practicing it daily has proven to improve insomnia symptoms and balance an overactive stress response (Russo, 2017). However, from our research, we found that the adherence to the exercise is low. Even though we cannot clearly define the reasons behind the low adherence, we can look into ways to increase adherence through existing theoretical frameworks.

For this, we have looked into habit-forming frameworks. A habit is defined as a behavior that is automatically triggered by a context (Gardner et al., 2012). For example: performing slow breathing in the kitchen is the habit, in which slow breathing is the behavior and in the kitchen is the context. By turning slow breathing into a habit, we can ensure that the user will practice it regularly. However, it takes time for a habit to form (it is estimated that it takes on average 66 days). Many frameworks describe how to encourage habit formation. You have Lily's and Gardner's framework (2012), Duhiggs' framework (2012), the hook model by Eyal (2013), or Fogg's behavioral model (Fogg, 2019). Despite the many frameworks, they all share the following key elements:
(1) A reminder in a specified context, (2) a behavior, and (3) a reward. For instance, when we want to form the habit of "slow breathing in the kitchen," we can send a reminder to the users every time they are in the kitchen to remind them to perform the exercise. After the user has completed the exercise, we then reward the user to encourage motivation. After the habit has been formed, the need for a reminder and reward diminishes as the behavior is now automatically triggered by the context and has become effortless (Gardner et al., 2012).

In short: we can increase adherence by turning the breathing exercise into a habit by providing reminders linked to a specified context and providing a reward after performing the behavior to encourage motivation.

In conclusion, we want to help our target group, which are young working individuals suffering from stress symptoms, manage their stress, reduce their current stress symptoms, and prevent them from developing a more severe condition. We do this by providing them an effective tool that (1) guides them to perform slow breathing correctly, (2) includes a feedback mechanism to increase self-efficacy in the exercise, (3) and helps them to form a habit by providing context-linked-reminders and rewards.

Figure 7 - Hierarchy of goals that leads to our value proposition

2.3 competitor analysis

Now that I have defined the value proposition of the Somnox Mini, I conducted a competitor analysis to identify similar products that can pose a potential threat.

2.3.1 competitor list

I selected competitor products from an existing competitor list that was made for the Sleep Robot. Additional competitor products were identified through a web search. For a product to be considered a competitor, the product should help the user to tackle stress-related problems by guiding breathing exercises. We categorized the products based on their features, resulting in the categories shown in figure 8.

Considering our value proposition in the initial requirements that we received from the client, which is: to develop a portable, physical breathing guide, we speculate that the Somnox Mini will fall in the latter subcategory.

Category 1: Meditation apps

These are mobile applications that provide narrated relaxation exercises. These include mindfulness, yoga, and breathing exercises.

Category 2: Health trackers

Health trackers continuously monitor the user's stress through either HRV measurement (FitBit, Lief therapeutics) or breathing pattern measurement (Spire products).

Category 3: Breathing guides in combination with biofeedback

These are products that help users perform breathing exercises through guidance and biofeedback. We subdivided this group into two groups. The first groups contain products that rely heavily on a companion app. The app is responsible for providing guidance and biofeedback. The hardware is only the sensor accountable for gathering biometric data, such as the HRV and breathing pattern. The second group contains products in which the guidance, biofeedback, and data gathering are embedded in the hardware product.

Figure 8 - Competitor categories

Figure 9: Moonbird
Source: moonbird.com

Figure 10: EmWave2
Source: heartmath.com

Figure 11: Calmigo
Source: calmigo.com

Figure 12: RESPeRATE
Source: resperate.com

2.3.2 customer reviews

I conducted a customer-review analysis for the products in the latter category these products are shown in figure 9 - 12. The goal was to learn about each product's pros and cons that we can turn into requirements for the Somnox Mini. When performing the analysis, I found one challenge: Moonbird is still a startup and therefore lacks customer reviews from independent sources. We dealt with this problem by ordering a Moonbird to analyze ourselves, which can be found in appendix A.

For the remaining products, we collected customer reviews from Amazon.com. Amazon categorizes its reviews by critical and positive reviews. These critical and positive reviews are ranked through a peer voting system. Top voted reviews are therefore found on the very top. Using Parsehub, a web scraping tool, I collected the first three pages of each product's critical and positive reviews. These reviews were printed out and then clustered manually to identify patterns.

Not all the reviews from the analysis were valuable. There were many comments in which the user expressed how great or bad the product is without any argumentation. Furthermore, there were also a lot of comments regarding customer service and delivery times. Nevertheless, I was able to formulate several insights that are valuable for our project.

Figure 13 - Clustering customer reviews

Insight 1

Many consumers mentioned that they showed low self-efficacy during breathing exercises when performing on their own. According to the reviews, biofeedback is an effective feature to tackle this problem. Example: “This product is great! I really like the idea of meditation and the benefits, but I’m never sure if I’m doing it right. Being able to see when you’re in ‘the zone’ is invaluable.”

Insight 2

Adding gamification elements helped motivate users to use the devices daily, which we see in EmWave 2. Example: “Having tried to develop a meditation practice for years. I was never able to keep with it consistently. Until I came across this, this device appeals to the video game-loving side of me.”

Insight 3

Customer reviews from RESPeRATE emphasized the safety risks of the Somnox Mini. Wrong breathing regulation can lead to dangerous side effects such as hyperventilation, dizziness, and shortness of breath. We should ensure that these risks are minimized in our design. Example: “I synchronize my breathing to the sounds, but very soon I found myself light-headed and couldn’t catch my breath.”

Insight 4

We should carefully think about how we should communicate data if we are going to implement biofeedback. As seen in EmWave2, the false positive feedback caused people to believe that the product is a placebo. There are many reasons this false positive feedback might occur, such as a dirty sensor or not placing the finger correctly on the sensor. I believe a solution for this is to be transparent in how the system interprets the data so that users can deduce the reason behind the feedback.

2.3.3 conclusion

When we look at the products within the sub-category that the Somnox Mini is in, we see that the overall ratings and reviews of these products are favorable. This suggests that these products are effective in helping their users manage their stress-related problems.

However, most of these products (RESPeRATE, Stresseraser, Calmigo and EmWave 2) are not attractive for our target persona. These products share the same product aesthetics. They use similar colors, similar form elements, material, and resemble the aesthetics of medical devices. Our persona is a highly competitive individual that likes to be portrayed as successful to his/her peers - and carrying around a medical device would work against that goal. I, therefore, speculate that our persona might be ashamed to use the medical device in shared spaces, such as in the office. An opportunity for Somnox would be to create a product that matches our persona’s identity in terms of product aesthetics.

The Moonbird, however, is a product that has taken this problem into account. Furthermore, the Moonbird is also the only product that relies on physical breathing guidance (the product expands and contracts), whereas the others rely on visual and auditory guidance. This makes the product the highest threat for the Somnox Mini.

Nevertheless, we think that Somnox can compete well against Moonbird due to the following reasons: First, we concluded that the product Moonbird (company) currently offers is a prototype. The product quality is suboptimal. For example, the product only expands less than 5 mm, which makes breathing challenging to feel. Furthermore, the ergonomics are not optimized since a person with a small hand can not reach the breathing plate (see appendix A).

Secondly, Somnox has a competitive advantage over Moonbird in terms of credibility. The company has been covered by many national and international press outlets, has won multiple internationally recognized awards, and has done multiple studies to validate its product. Somnox is a much more established and credible brand than Moonbird, who are still working on the development of their first product.

2.4 Preliminary list of requirements

Combining the insights that we have gathered until now, we have established a 'preliminary' list of requirements. We refer to this as 'preliminary' because the list of requirements is still incomplete as much of the concept is still unknown.

This list is at a level of abstraction, allowing room for imagination yet specific enough to give us a general concept direction. For example, we know that it will be a tangible breathing guide. However, we do not know whether it is a wearable, a separate object, an attachment, etc.

The goal is to further specify this list by exploring different concepts and gathering user and client feedback. With each design iteration, our list of requirements becomes more complete and more specific.

Key functionalities

1. The product should contain a physical breathing guide (in other words, it should have a similar system as the Sleep Robot to guide the user during the breathing exercise).
2. The breathing guide should clearly indicate the breathing frequency to the user.
3. The product should contain a feedback system that tells the user whether he or she is performing the exercise correctly.

Economy

4. The product should be deployable to the market in 2026 (which is based on the fact that the development is planned to start in 2024).
5. The product should not exceed a retail price of €320,- (which is based on the most expensive product found in our product category).

Form qualities

6. The product should be portable.
7. The product should not have the appearance of a medical device.

Safety

8. The product should limit the risk of hyperventilation as a result of using it.

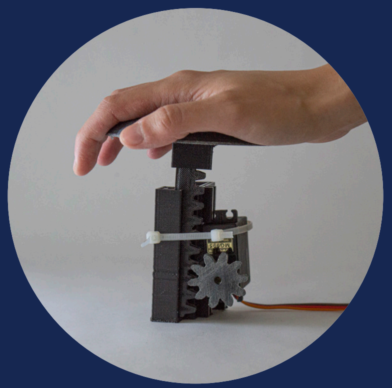
Table 1 -Preliminary list of requirements

03

design phase

In this section, we describe the design phase. In this phase, we explore potential solutions that aim to satisfy the requirements specified previously. I adopted an iterative design process consisting of three design cycles for the reasons explained in section 1.4

With each cycle, the concept increased in detail. In the first cycle, I specify a concept direction. In the second cycle, we define a concept that fits the specified direction, and in the third cycle, we refined and detailed the specified concept.



Design cycle 1

page 40

Design cycle 2

page 56

Design cycle 3

page 72

Abstract — Specific

Each cycle is based on the design thinking process (Dam & Siang, 2021) and consists of four steps: To structure the report, we subdivided the design phase section into three chapters. In each chapter, we discuss the process and insights of each design cycle. We finalize this section by presenting the final concept design.

Ideation

In this step, we specify an idea based on the list of requirements.

Prototyping

In this step, we build a prototype(s) with the intention of user testing.

Testing

In this step, we review the idea with the target user, using probes such as prototypes, sketches, or storyboards.

Evaluation

In the final step, we evaluate the idea using the insights from the user tests. Using these insights, we will update the list of requirements, which will form the basis for the next iteration.

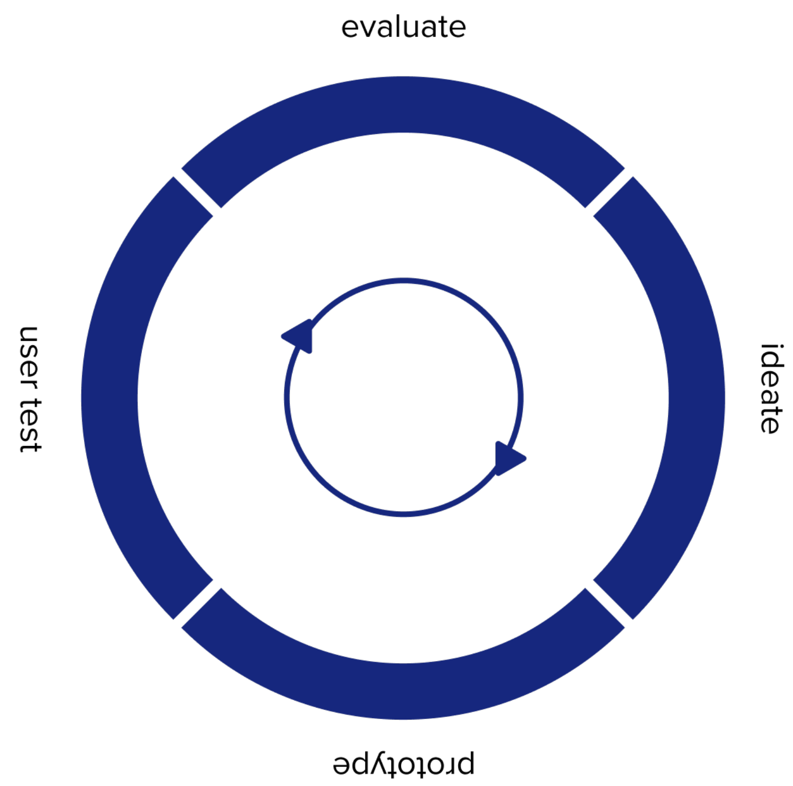
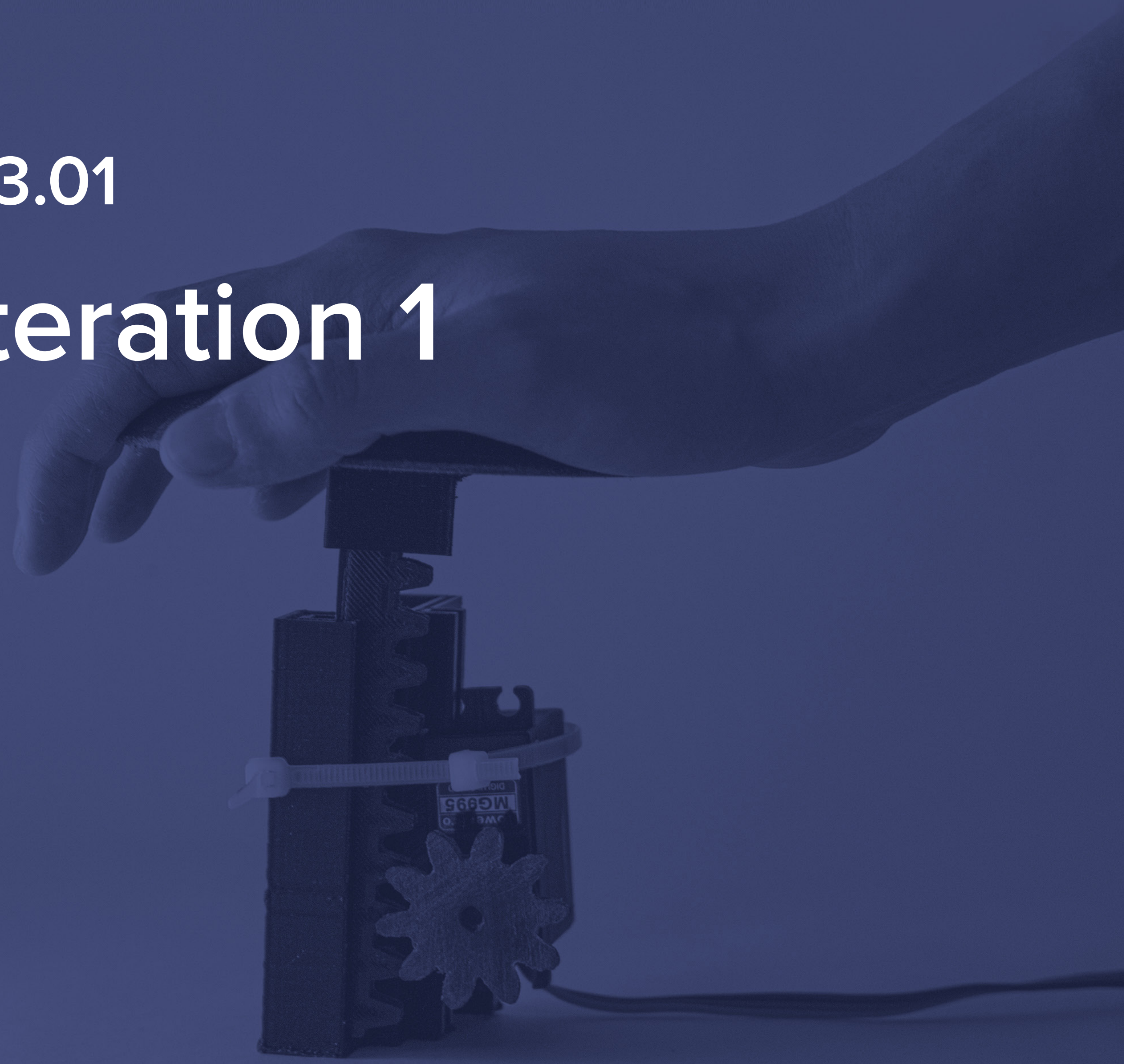


Figure 14 - The Design thinking cycle that we have used for each iteration

03.01
iteration 1



The goal of the first design cycle is to define and validate a concept direction based on our preliminary list of requirements defined in the previous chapter. To bring structure to this chapter, we subdivided this according to the steps of the design thinking process, (1) ideation, (2) prototyping, (3) testing, and (4) evaluation.

3.1.1 Ideation

Before we start discussing the ideation process, let's first refresh the 2 elements of our product which are:

1. The physical guide that guides the user in slow breathing
2. The feedback system indicates to users whether they are performing the exercise correctly

Each of the elements will be discussed in separate paragraphs. As the concept is still abstract, and the exact context in which our product will be used is still unknown at this point, we decided to neglect the context-linked reminder for this design cycle and address it later when the concept gets more defined.

3.1.1.1 the physical guide

When looking at our preliminary list of requirements, the guide already has some constraints:

1. It is already determined that the product should be a physical guide and should have a similar breathing simulation system as the Sleep Robot.
2. It should be able to simulate a breathing frequency of 6 breaths per minute.
3. The Somnox Mini should be a portable product.

What is not defined yet is how this guide is embodied - is it going to be a handheld product? A carry-able pillow? A wearable? Etc. We explored several options through sketches. As seen in figure 15.

Figure 15 - Sketches to explore potential embodiments for our design

3.1.1.2 the feedback mechanism

The feedback system's goal is to increase the self-efficacy of the user in slow breathing by indicating whether the exercise is performed correctly or not. In other words, our product needs to be able to recognize whether the user is breathing at a frequency of 6 breaths per minute. To achieve this, we need a system that the breathing frequency of the user can directly influence. For this, we identified two possible solutions:

The first option is by measuring the breathing frequency of the user. This can be realized by measuring airflow or measuring the expansion of the diaphragm, which is the muscle responsible for breathing. The second option is measuring the HRV of the user. Research shows that RSA is induced by a breathing frequency of 6 breaths per minute - during RSA the HRV, when plotted over time, forms a harmonic wave with a frequency of 0.1 Hz (6 per minute). By recognizing this wave pattern, the system can identify whether the user is performing the exercise correctly.

Option 1: measuring breathing frequency

There are a couple of limitations for both options. The problem with measuring airflow is that the product needs to be attached to either the users' mouth or nostrils. We see this, for example, in products such as Calmigo or Breathe with B (see figure 16 & 17). As a result, our product becomes quite invasive.

A similar thing can be said for measuring the expansion of the diaphragm. A standard method for measuring the diaphragm is through a band. The band is often wrapped around the belly or chest of the user. A product that applies this is RESPeRATE (see figure 18). However, when we look at reviews of the RESPeRATE, many users indicate the band was uncomfortable.

Another solution to measure the diaphragm's expansion is to use a similar system that SpireStone uses (see figure 19). SpireStone is a small device that is clipped to the user's bra or pants. When the diaphragm expands, pressure is put on the device, which uses that input to determine the breathing frequency. This option is less invasive. However, when analyzing customer reviews, we see many cases in which the device misinterpreted the data. For example in situations in which the user was moving, or when the user had a poor posture (as it exerts pressure on the device).

Figure 16 - Breathe with B. A breathing biofeedback device. Source: breathewithb.com

Figure 17 - Calmigo. source: youtube.com/watch?v=KZ_S5c1vJwU

Figure 18 -RESPeRATE uses a band to measure the breathing of the user. Source: stressnomore.co.uk

Figure 19 - SpireStone: a non invasive breathing tracker. Source: breatheffect.com

Option 2: Measuring heart rate variability

The second option that we can apply to recognize whether the user is performing the exercise correctly is by measuring the user's HRV. There are two conventional methods to measure HRV. The first one is using Photoplethysmogram (PPG): a technology adopted in many health trackers such as FitBit (figure 20). PPG consists of a light source and a photodetector. The light source emits light to a tissue, and the photodetector measures the reflected light from the tissues, which is proportional to the blood volume variations. PPG's limitation is that it needs to be attached to the skin and can only be measured at specific locations where the skin is thin. These include: the torso, fingertips, ankles, forehead, wrist, and earlobe (Castenade et a., 2018)

The second method for measuring HRV is through an electrocardiogram (ECG), which records the heart's electrical activity. Conventional methods for measuring ECG are pretty invasive and difficult to implement without professional supervision. The process includes placing 3 to 7 electrodes at specific torso locations (Cadogan, 2021). We see new ways being developed that are less invasive and more suitable to fit in consumer products. (Mindmap is a product that already implements this figure 21) This includes a 2-electrode system that can measure the ECG from the user's thumbs.

Despite the limitations of using HRV as an input parameter, I believe that HRV is the superior option. Unlike the breathing frequency, the HRV is a direct reflection of the autonomic nervous system. When RSA occurs, it indicates that the user is performing the exercise correctly and demonstrates that the body is reacting to it, thereby giving insight into the exercise's impact. I believe this is important for the user since it proves the effectiveness of breathing exercises.

Figure 20 - FitBit. A health tracker device.
Source: inqld.au

Figure 21 -Mindnap. Biofeedback meditation guide
Source: mrgadget.com.au

3.1.1.3 conclusion: concept 01

We summarized the insights from our exploration into the following concept: The concept describes a portable object that guides the user in slow breathing by expanding and contracting at a frequency of 0.1 HZ (6 per minute). The shape of this object, however, is still purposely left undecided. The reason for this is because we lack an understanding of user needs in terms of the embodiment. I intend to present several options from our exploration to our end-user to prompt a conversation and gather insights about how the product should be embodied. This will be further elaborated on in section 3.1.3.

When touching the object, the object can gather the HRV of the user. The HRV is then plotted into a visualizer on the companion app. With the visualizer, the user can see whether he or she is performing the exercise correctly.

From our competitor analysis, we conclude that it is best to keep the data as transparent as possible. In case the system misinterprets the data, the user can then deduce why it is misinterpreted. This is important because if the data interpretation is a black-box, users tend to make wrong speculations, which results in them thinking that the product is “bogus,” “placebo,,” etc. as we have seen in customer reviews from our competitors (see section 2.3.2).

To avoid the problem mentioned above, we decided to keep the data as raw as possible and allow users to interpret themselves whether they are doing it correctly or not.

Furthermore, using the device, the user can take regular measurements of their HRV. The companion app plots the values over time and thereby visualizes the progress of the user. (see figure 22 for a concept visualization)

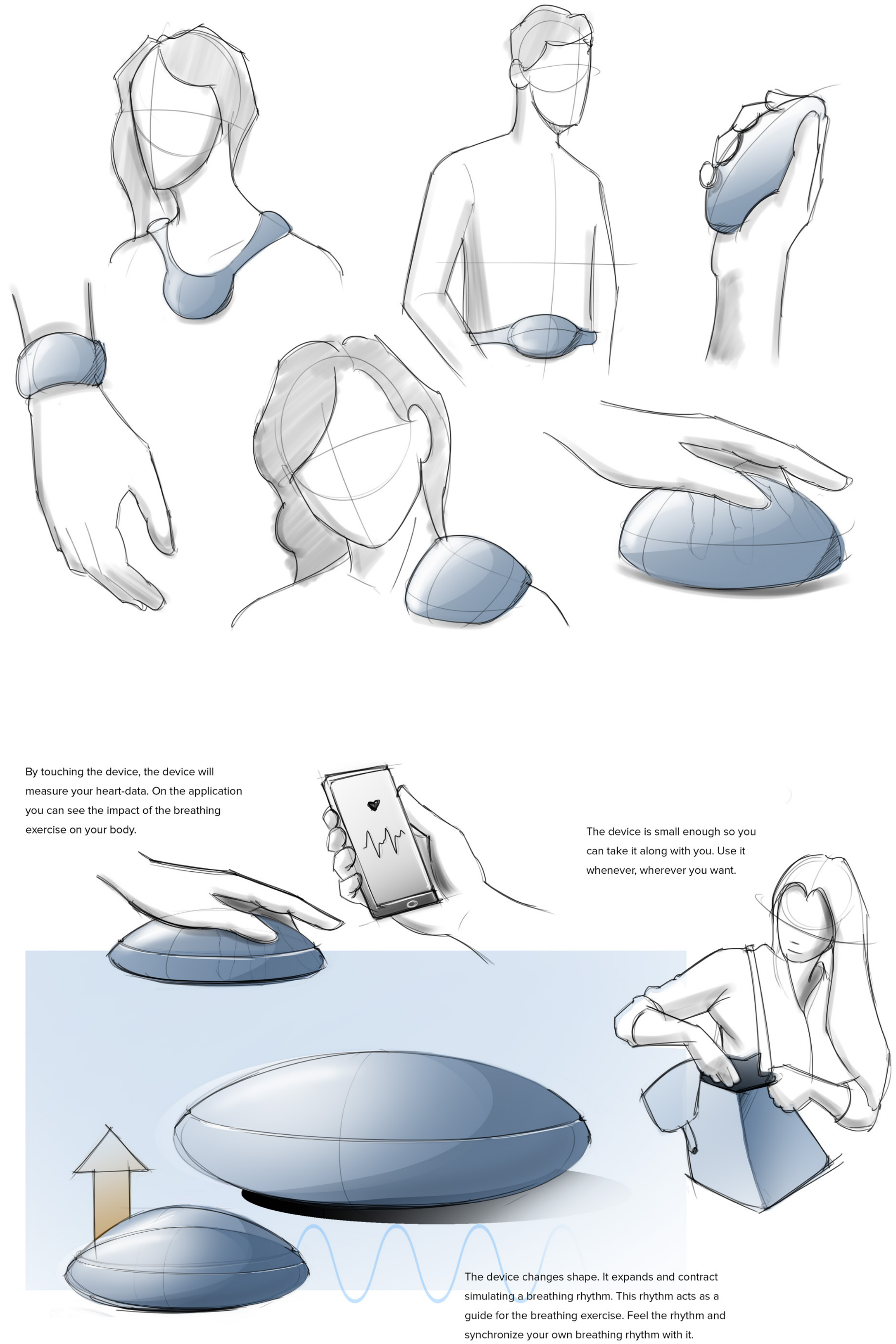


Figure 22 - Visualization of concept 1

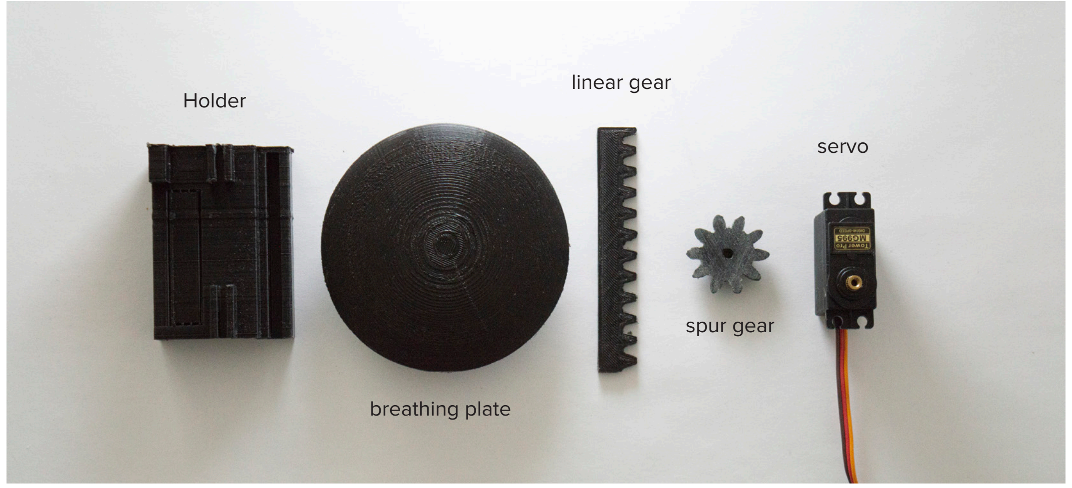
3.1.2 prototyping

In this step, I build a prototype of our concept to test with our end-user. The user test's goal is to evaluate the concept with them and gauge whether the direction is perceived as valuable for them. Furthermore, I plan on gathering user feedback that helps to specify our concept for the following iterations. The user test will be elaborated on in the next section.

The interaction with the product is likely a novel interaction for many of our test users. Therefore, we hypothesize that users might find difficulties envisioning themselves to use our product without any probes. Thus, to properly communicate the envisioned interaction, we build a semi-working prototype.

This prototype included a 3D-printed object that can move up and down through a servo system (see figure 24). The movement was programmed at the frequency of 6 per minute using an Arduino Uno. We purposely ensured that the prototype is perceived as a rough idea to leave room for user suggestions. Therefore, we did not pay much attention to the finishing of the prototype.

Next to the moving object, we also attached a PPG sensor to an Arduino. Using this sensor, we would be able to gather heart pulse data from our test participants. Using a processing program written by Gitman et al. (2018) derived from GitHub, we were able to compute the HRV using the collected heart pulse data. The program also contained a visualizer, which plotted the HRV against time and shows the breathing exercise's real-time impact on the test participants see figure 26.



Figur 23 - Parts used for concept 1

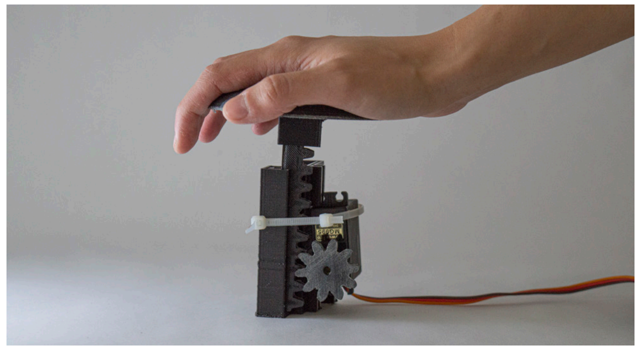


Figure 24 - Prototype 1 assembled. The servo drives the breathing plate up and down with a frequency of 0.1 Hz.

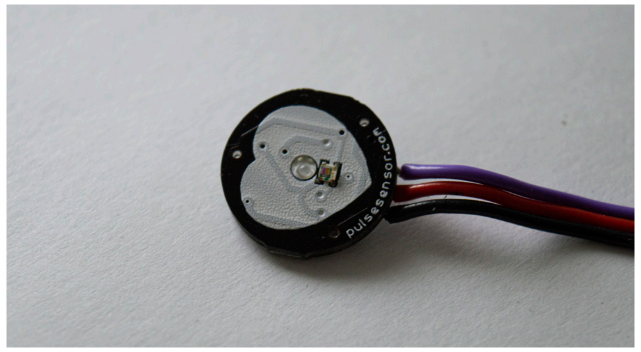


Figure 25 - the PPG sensor that we used to gather HRV data

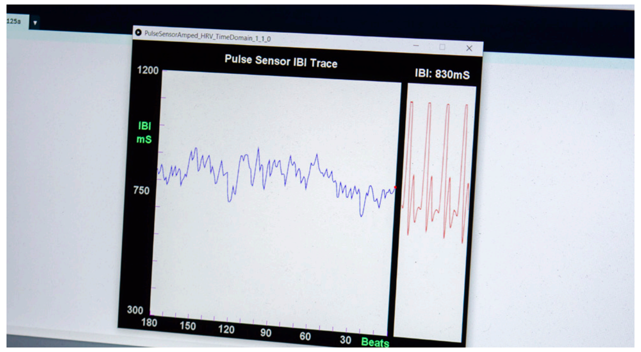


Figure 26 - The PPG sensor is connected to the HRV visualizer which computes the pulse data into HRV.

3.1.3 user testing

3.1.3.1 introduction

To evaluate the idea, we used the co-constructing stories method by Ozcelik & Terken (2012) - "It is a participatory design technique for early formative concept evaluation to elicit in-depth user feedback and suggestions, revealing attitudes and motivations of users."

The goal of the test was to gauge how people perceived the concept direction and validate whether our direction is valuable for our end-users or not. Furthermore, we also want to discover how participants envisioned themselves using this product, how participants perceived the interaction, and identify hidden needs that we might have missed during our research phase.

3.1.3.2 method

The user test was performed with 3 participants. All the participants were young (25 – 28) working professionals that stated they had trouble with stress and experienced stress symptoms (mood swings, anxiety, overthinking, and poor sleep).

The co-constructing stories consisted of two phases. The first was the sensitization phase. In this phase, I told a fictional story to introduce the problem's context and set the stage for dialogue. We then asked whether the participant recognized the situation and asked them to enrich the context with personal experiences. In our case, this fictional story was the story of the persona, Carmen:

"Carmen is a starter in a consultancy firm. She is a person who highly prioritizes her career - she wants to make it and be successful before turning 30. As Carmen is already 28, she constantly feels that she is behind. She works even harder at moments she needs to rest. As a result, she experiences stress symptoms such as poor sleep, anxiety, aches, tiredness, and less satisfaction in life in general. She knows that she needs to do something about it and is actively searching for solutions, but none have clicked yet."

The second phase was the elaboration phase. Here we introduced the product using the prototypes and concept sketches that we made(figure 27). We asked the participants to perform a 5-minute exercise utilizing the prototype. Afterward, we showed and explained the different embodiments and evaluated that with our participants as well.

Timeline of method

1. Sentization phase: Explaining Carmen's story
2. An open conversation on whether the participant recognized parts of the story
3. Elaboration phase: Introducing the concept through the product sketches
4. Participants were asked to perform the exercise for 5 minutes
5. A semi-directed interview was conducted on the experience of the concept

Figure 27 -The product sketches that we showed to our participants

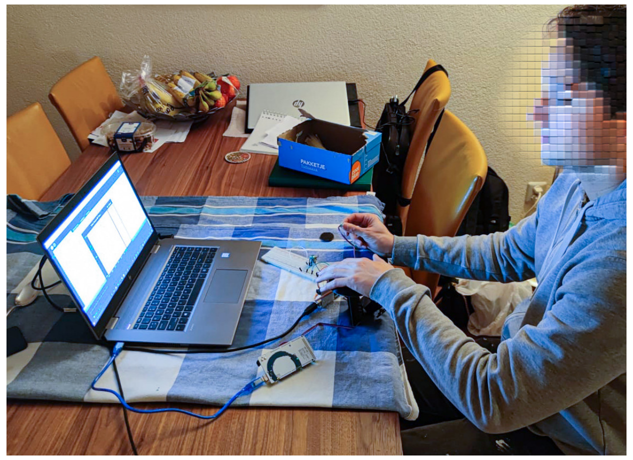


Figure 28 - Impression of the test set up. Participants were performing the exercise while looking at the HRV visualizer

3.1.3.3 result

IInsight 1: The envisioned context of use differs per individual

All participants recognized the described problem and could clearly envision themselves using the concepts to manage their stress. Participant 1 mentioned that she would likely take it to work. She envisioned it as something she could put on her lap and use as a short break during work. Participant 2 mentioned that he would likely use it before sleep, as he tends to overthink and go to bed with anxiety. He also occasionally uses sleep supplementation and noted that the concept could be a good substitute. Participant 3 said she would likely use it on the train while commuting to work. She saw it as an excellent method to prepare for and wind down from a stressful day at work.

Insight 2: The breathing guide works as RSA was present in all participants

All participants were able to perform the breathing exercises and induce RSA, which we could see on the HRV visualizer. One participant mentioned that in the beginning, the breathing rate was slightly too slow. However, after a couple of minutes, she was able to accustom to the breathing pace.

Insight 3: Real-time HRV feedback is distracting participants from the exercise

Participants mentioned that they were constantly worried about the things happening with the graph. As a result, they were not able to focus on the breathing exercise. Furthermore, participants mentioned that they would like to close their eyes during the exercise to relax completely, and the graphs were therefore not very valuable. However, they would like to know how they performed, but rather as a summary afterwards for reflection.

Insight 4: Seeing biometric data also has an educational function

All participants mentioned that they liked linking breathing exercises to biometric data, as it helped them create awareness of the health benefits. Participants were not aware of the impact of breathing exercises on the human body. There was a misconception among the participants that breathing exercises are only a “psychological thing.”

Insight 5: Stress is something our target group is “ashamed” of

The participants mentioned that stress is something that they do not want anyone else to know. Therefore, the product needs to be discrete. The design should be something subtle that they could for example, do under the table or underneath a jacket.

Insight 6: Wearables are perceived as too invasive

Participants also found that the wearable form of the device is too intrusive. They were afraid that it would feel uncomfortable and interfere with jewelry they already have, such as watches or necklaces. They preferred a separate object because they can quickly grab it and quickly put it away when they don’t use it.

Insight 6: RSA is not induced immediately

We see a different wave pattern when the user starts the breathing exercise, however, RSA is only visible after a period of time that was different for each participant. The time it took before RSA was induced ranged from a couple of seconds up to a minute.

Insight 7: The touch of the product should feel comforting

We also identified an unintentional feature of our prototype; participant 2 mentioned that she liked the texture of the 3D print. The prototype was printed using an FDM printer, resulting in filament lines. It reminded her of petting a cat which she mentioned to be a pleasant and soothing experience. She suggested that the prototype should be coated with soft and textured material – according to her, not only the breathing should feel relaxing, but the touch of the object as well.

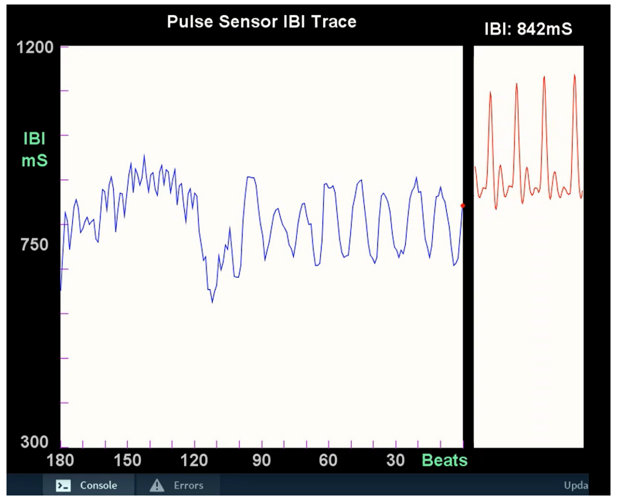


Figure 29 - A screenshot that was taken from one participant. The smooth wave indicates that RSA is present

3.1.4 evaluation

In this design cycle, I have oriented different methods to solve the identified problems. The most important addition to our concept, which resulted from the orientation, is using the heart rate variability as an input parameter for the feedback system.

We summarized all our insights from the ideation into a 'draft' concept. We refer to it as a draft, as some elements were still purposely left open, such as our device's embodiment. Likewise, we built a prototype and then tested this with end-users to encourage an in-depth evaluation of the concept.

Overall, we validated that the general direction of the concept was perceived as valuable by our end-users. All participants of the tests were able to see themselves using this product and recognized this concept as a potential solution to their stress.

The user tests also gave us insights into how we can evolve our concept further into a desirable product for our end-user. The most important thing that we learned is that we need to rethink our feedback system in our next iteration because it is currently perceived as distracting. The tests also gave us more insights into the embodiment of our product. We know that the product should not be a wearable, that it should be something discrete, and that it should be something that people can quickly grab and put away. Although the test has not resulted in a concise embodiment yet, this limits the available options for our next ideation phase.

Another insight that we have discovered is that RSA is not induced immediately. The time before RSA became visible differed for each person. For some, it took a couple of seconds, while for others, it took up to a minute. We investigated this phenomenon further through literature research. Gevirtz (2014) mentioned that there is a difference between novice and expert slow breathing practitioners. According to him, an expert can induce RSA in two or three breaths and suggests that the time to induce RSA can be shortened through regular practice. This is a phenomenon that we can in fact use to our advantage. For example, we can also use the improvement in 'time before RSA occurs' as a parameter to show progression in their skill level.

To conclude, I have validated our concept's general direction and gathered insightful feedback from our end-users that we have used to update our list of requirements (table 2) to help us evolve the concept direction into a desirable product.

Key functionalities

1. The product should contain a physical breathing guide (in other words, it should have a similar system as the Sleep Robot to guide the user during the breathing exercise).
2. The breathing guide should clearly indicate the breathing frequency to the user.
3. The product should contain a feedback system that tells the user whether he or she is performing the exercise correctly.
4. The feedback system should not distract the user from the breathing exercise
5. The feedback should be understandable even with the user's eyes closed
6. The product should contain a reward-system that motivates users to use the product regularly.
7. The product should be able to visualize the HRV progression of the user.
8. The product should contain a reminder-system to remind users to use the product regularly.
9. The product should be able to collect the user's HRV.
10. The product should be able to communicate with a companion app
11. The product should contain a Bluetooth module

Economy

12. The product should be deployable to the market in 2026 (which is based on the fact that the development is planned to start in 2024).
13. The product should not exceed a retail price of €320,- (which is based on the most expensive product found in our product category).

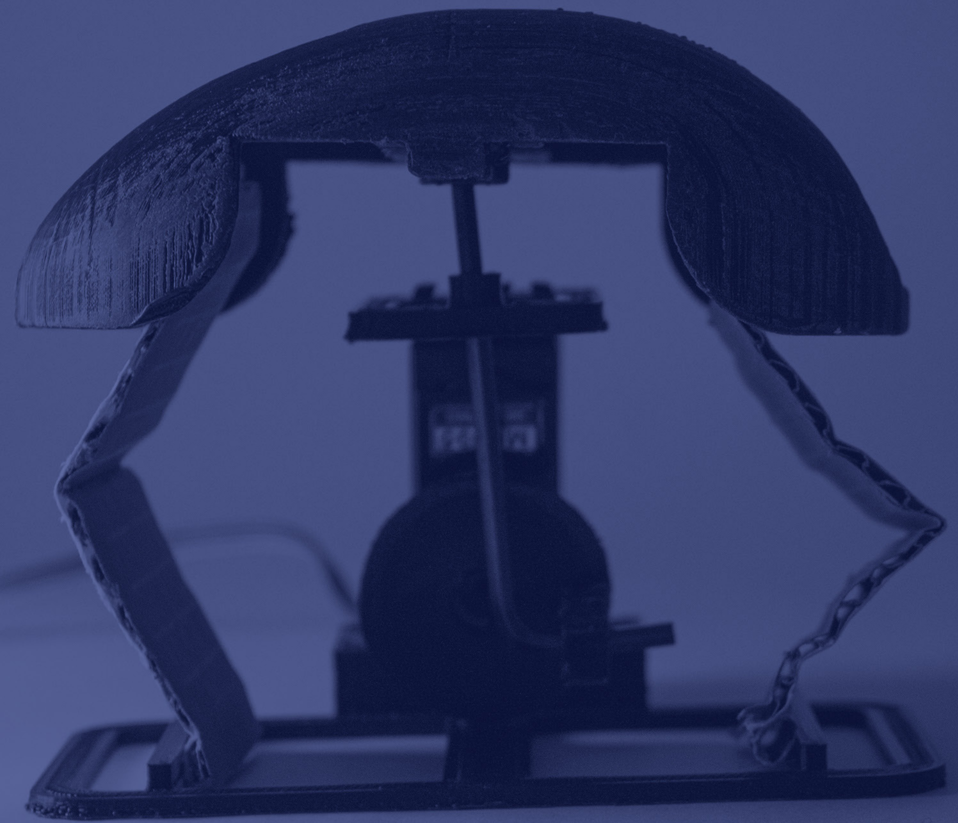
Form qualities

14. The product should be portable.
15. The product should not be wearable
16. The product should not have the appearance of a medical device.
17. The product can be set-up and removed within 10 seconds.
18. The touch of the product should feel comforting

Safety

19. The product should limit the risk of hyperventilation as a result of using it.

Table 2 -list of requirements 1



03.02

iteration 2

Now that we have defined our concept direction, this cycle aims to specify a concept within this direction based on our learnings. We take the same structure as the previous chapter, in which we divide this chapter based on the steps of the design thinking cycle.

3.2.1 Ideation

3.2.1.1 the physical guide

One of our test participants from our previous cycle mentioned that our prototype reminded her of a cat. This inspired me to use the metaphor of a pet to guide the design of the product embodiment. I believe this is a good metaphor due to the following reasons:

First, some studies show that petting a cat or a dog reduces stress and anxiety (Washington State University, 2019). This makes ‘a pet’ a fitting metaphor for our product.

Secondly, taking a pet as a metaphor also aligns with the identity of Somnox. Somnox states that they differentiate themselves from other sleep innovation companies by creating “companion-like products” - these are products that do not feel like products but instead feel like living entities that help the user improve their wellbeing. The pet metaphor acts as a guideline for us to design a companion-like product.

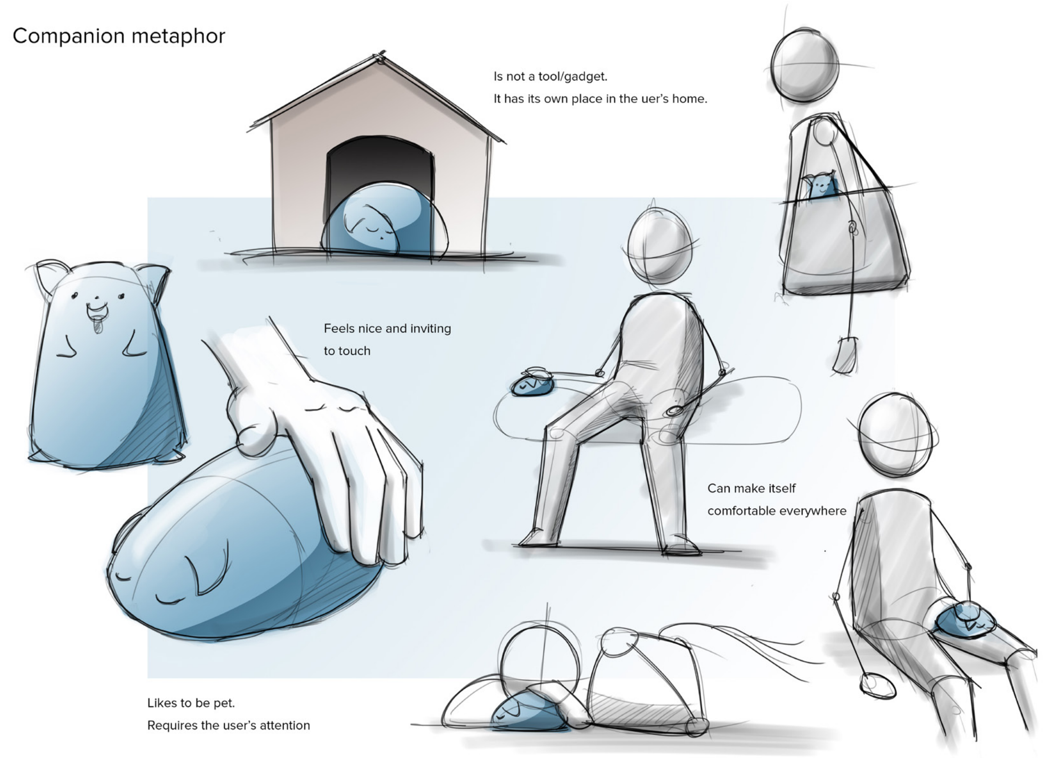


Figure 30 - A storyboard exploration to see how the Somnox Mini could behave if it were a pet

Using the metaphor, we came up with the following form characteristics. The Somnox Mini is a surface on which the user can rest their hand. The interaction of petting a pet inspires this. A piece of soft fabric covers the surface to make it feel even more like a pet.

The bottom has a soft padding. This allows the user to place the object anywhere comfortably. The idea was based on the observation of how pets place themselves. For example, if we look at a cat, a cat can find itself comfortable on your lap, on your shoulders, bed, belly, etc. Adding the soft padding also makes the product more dynamic, as it allows the user to use it comfortably in multiple positions, as seen in the figure 32.

Figure 31 - The interaction that we want to achieve with our product

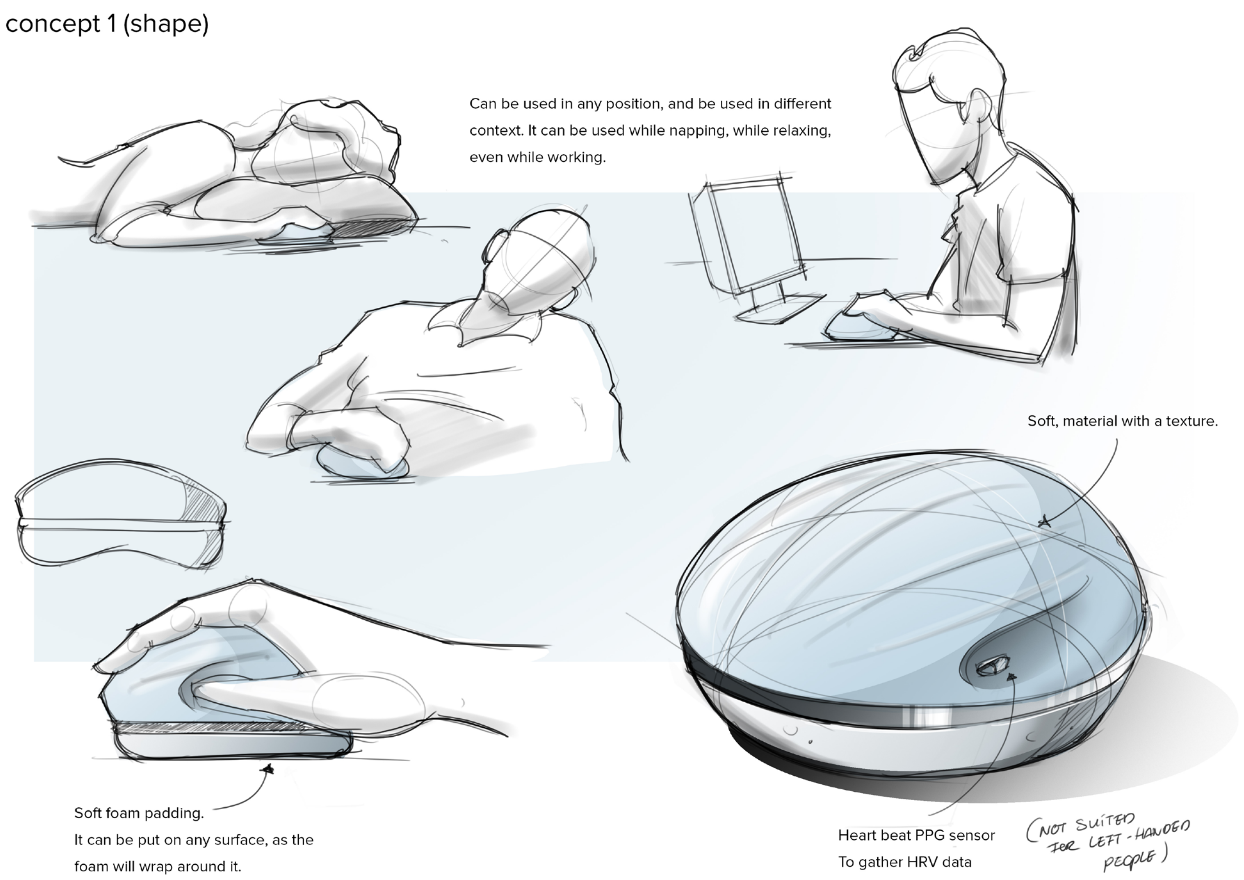


Figure 32 - A translation of the metaphor to a product

To further define our product's shape, we first need to know what type of sensor I want to use and where it should be placed. In chapter 3.1, we identified two options to measure HRV, which are (1) PPG and (2) ECG. However, ECG is invasive and requires at least two hands, as stated in the same section. This makes ECG not a suitable option for our desired position of the user's hand. I, therefore, believe PPG is the best option. HRV can only be measured from specific locations using PPG. These locations are the forehead, earlobe, torso, fingertips, and ankles. Since the product only comes into direct contact with the user's hand, the fingertips are the only available place to measure the HRV.

After I decided what sensor we had to use and where the HRV should be measured, we further defined the product's shape through a combination of clay modeling and quick form sketches. We quickly alternated between clay modeling/sketching and evaluating (figure 33 & 34).

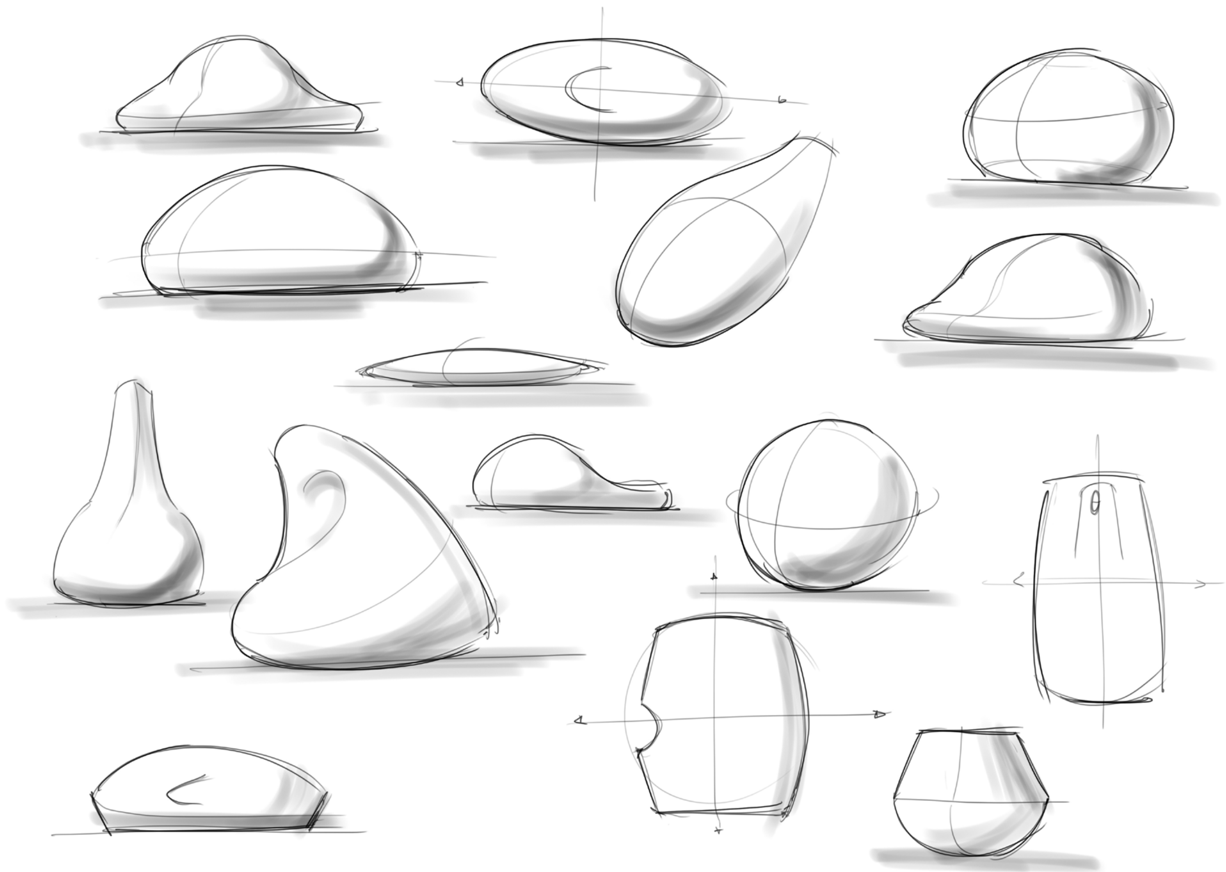


Figure 33 - Quick form sketches to explore possible shapes

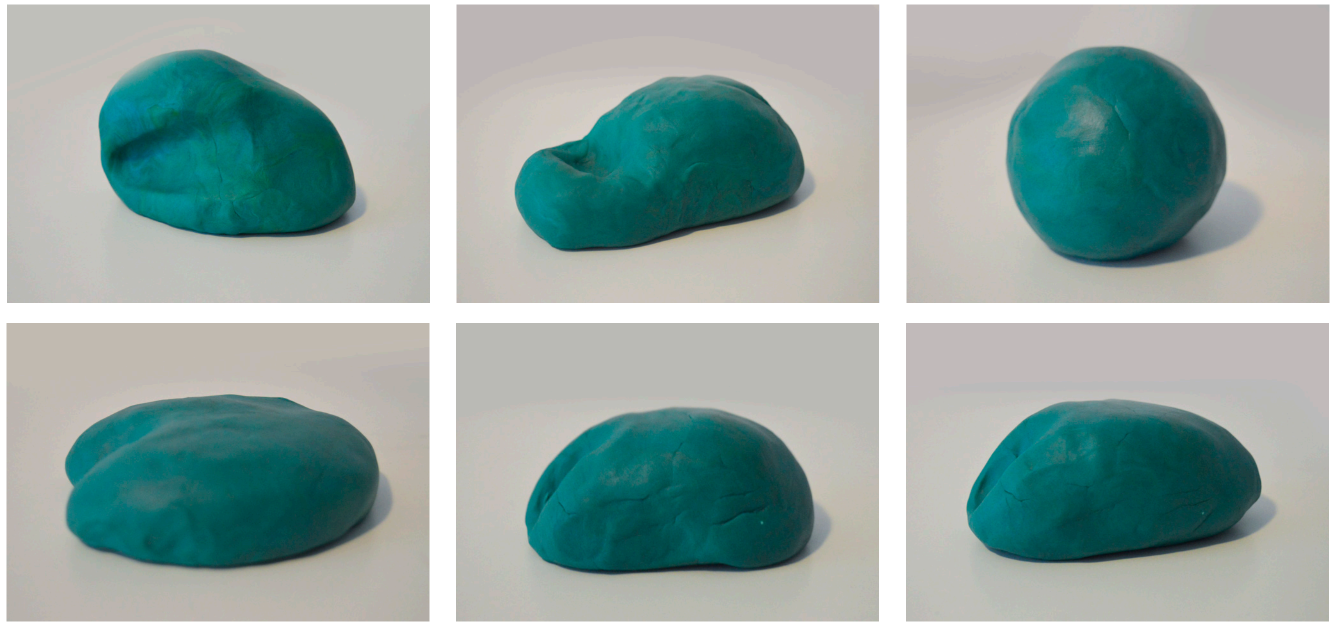


Figure 34 - Clay models that we have used to assess the comfort of our form sketches

From the exploration, I identified an obvious but overlooked requirement: both left and right-handed people should be able to use the product. I found that the very comfortable shapes for the left hand were not comfortable for the right hand and vice versa. A solution for this is to make a symmetrical product on the vertical axis, as shown below.

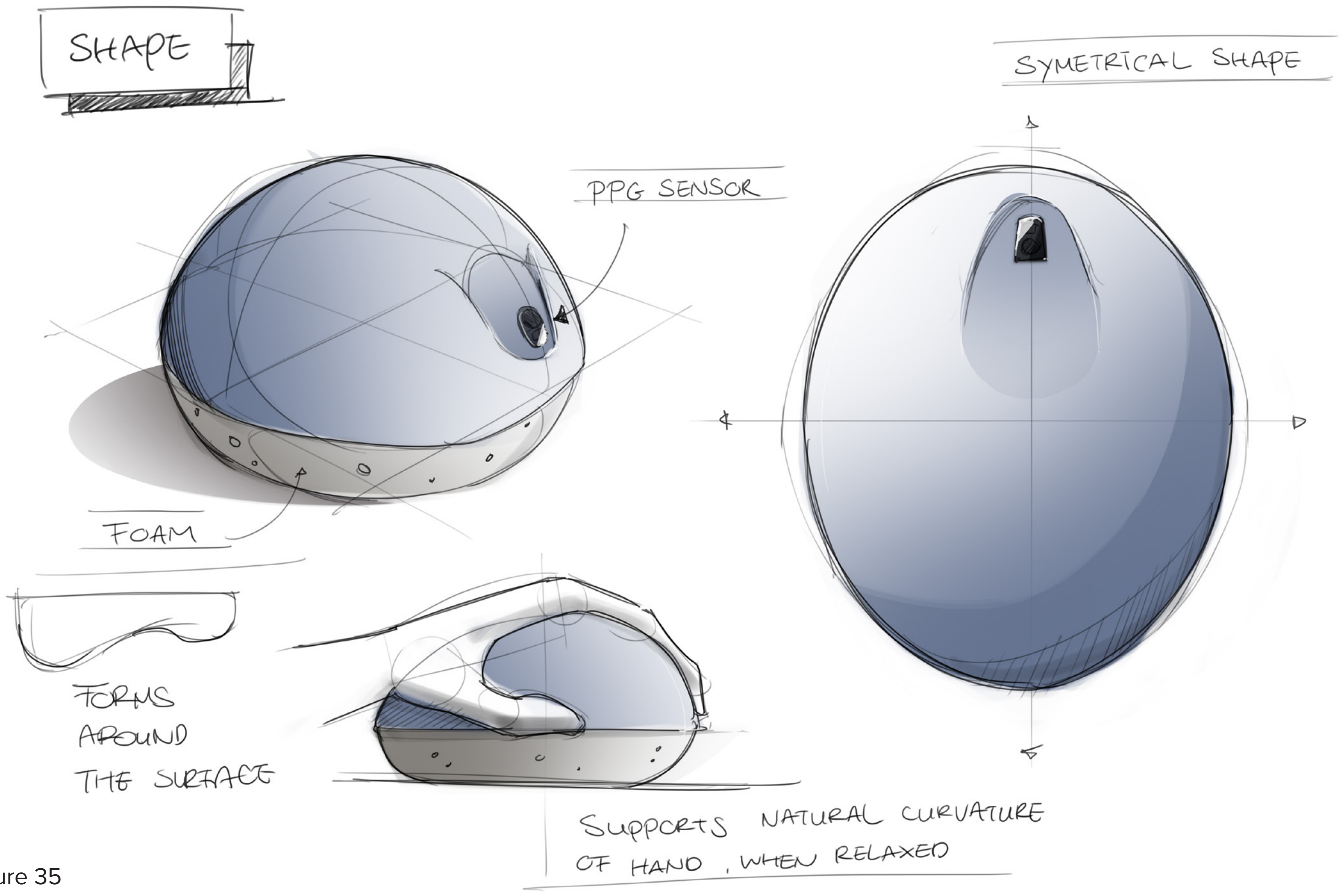


Figure 35

Visualization of the symetrical design

3.2.1.2 the feedback system

In concept 1, the feedback system consisted of a visualizer on the companion app, which plots the HRV of the user on a time axis. By looking at the visualizer, the users can interpret whether the exercise affects their body, thus indicating that the exercise is performed correctly. Keeping the data as transparent as possible was to allow users to deduce the reason behind data misinterpretations from the system. However, in our tests, we found that users perceived this as distracting. Furthermore, we also observed that participants tend to close their eyes when trying to relax. To use visual feedback contradicts this behavior.

Considering these insights, I explored ways in which I could simplify the feedback system. In essence, the feedback only needs to tell the user whether they are performing the exercise correctly or not. In that sense, the feedback system only requires two states: One state to indicate that the user is performing the exercise correctly, and another state to indicate that the user is performing the exercise incorrectly. Since visual feedback is not ideal we considered using auditory or haptic feedback as an alternative. However, the problem with auditory feedback is that it produces noise, and therefore it is not suitable for public spaces such as the office or train. We can avoid this problem by adding a headphone connection, but this would mean that the feedback system is not functional when the user forgets or does not have headphones.

The only valuable option left is haptic feedback. I built a quick prototype using an Arduino and vibration motor to explore ways to reflect the two states mentioned above. I played around with the vibrations' strength by changing the output voltage of the Arduino and the duration of the vibrations. A similar process to the ideation of the shape was used, in which we quickly alternate between making and evaluating.

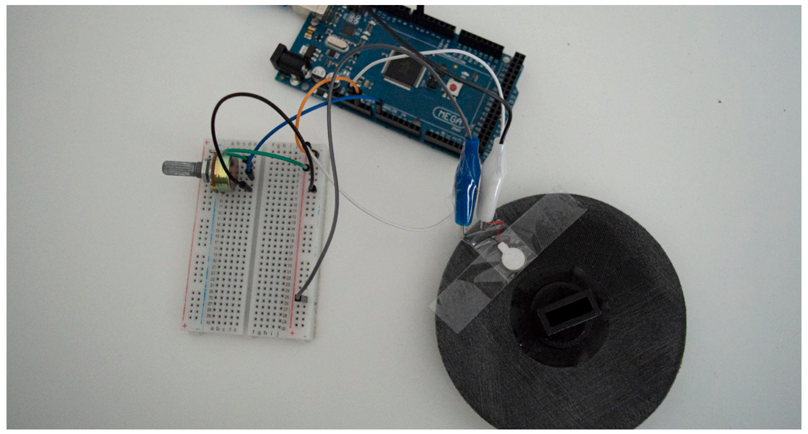
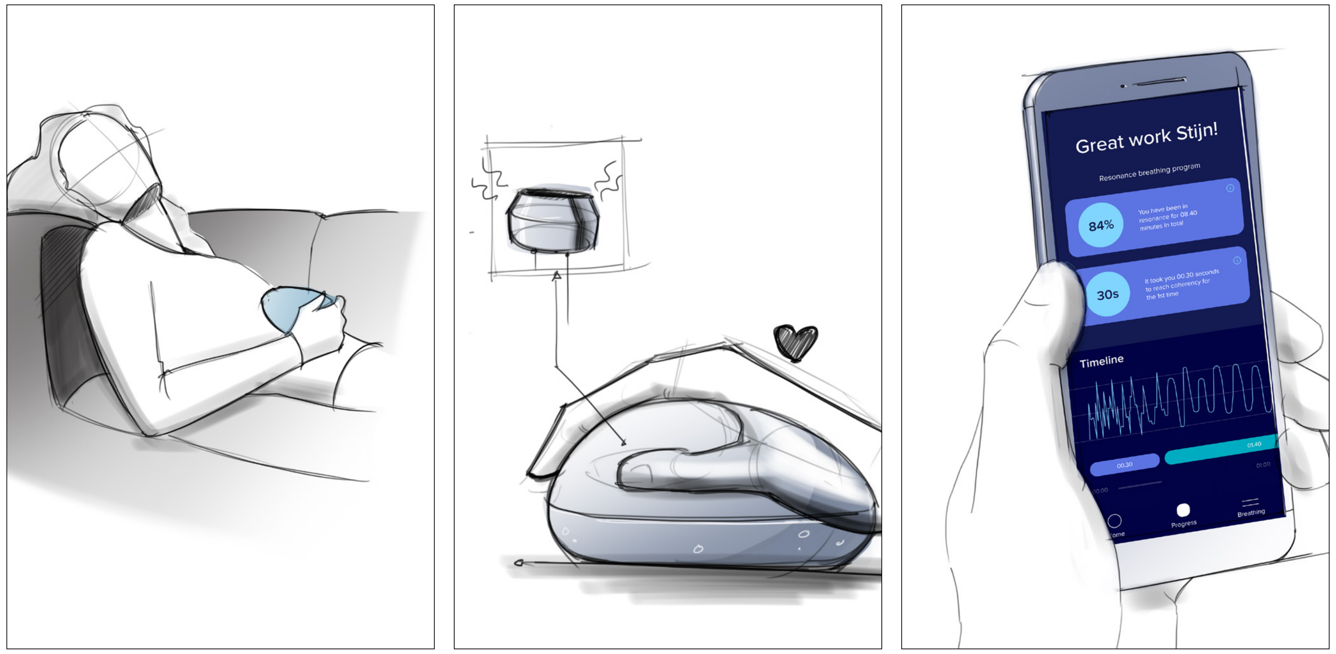


Figure 36 - A vibration motor has been attached to the functional prototype of iteration 1. A potmeter was used to change the strength and frequency of vibrations

The explorations resulted in the “heartbeat concept.” The vibration motor mimics a heartbeat by vibrating in intervals. The heart rate of the device reflects the HRV state of the user. When the user reaches synchronization, meaning increased relaxation, the device’s heart rate will slow down. Furthermore, this concept is also backed by science, as some studies suggest that feeling a heartbeat-like vibration can reduce self-reported anxiety (Zhou, 2020).

Initially, I wanted to mimic a human heartbeat on average 50 – 70 BPM. However, when evaluating this, we found that this fast BPM increased stress. Using a “trial and error” approach, I found 30 breaths per minute a suitable starting frequency. I lowered this to 12 breaths per minute when RSA is observed.

Nevertheless, I still believe it is essential that the system is not a black box. The raw data should, therefore, still be shown. This data would not be shown during the exercise, but rather at the end, as suggested by our participants from the previous iteration. So when the feedback system acts ‘weird’, the user can see the raw data and deduce why it might have malfunctioned.



The user finds a comfortable position to practice slow breathing

Next to the breathing sensation, the user feels a subtle heartbeat that slows down as she becomes mores relaxed

After the sesion, the user receives a report on her performance and progress

Figure 36 -The envisioned journey for the concept

3.2.1.3 conclusion: concept 2

The ideation resulted in the following concept: concept 2 is a hand-sized device. The device has a soft, textured surface on the top where the user can put his hand. This surface moves up and down to simulate a breathing pattern of 0.1 Hz. The bottom of the device is a soft padding, and allows the user to put the product anywhere comfortably. The user can use it while taking a nap, sitting on the couch, and even behind his office desk.

Through the PPG sensor on the device, the system can monitor the HRV of the user. The system can identify when RSA is induced by recognizing the wave patterns of the HRV.
While practicing with the device, the user feels a subtle heartbeat. This heartbeat has a frequency of 30 BPM. When the system identifies RSA, the heartbeat drops to a frequency of 12 BPM. This change indicates that the user’s relaxation response is stimulated, suggesting that the exercise is taking effect and that the exercise is being performed correctly.

After the exercise is finished, the user receives a report that shows how the user performed and gets an insight into the raw data. Furthermore, the user can also use the companion app to track his/her progress of their stress recovery.

3.2.2 prototyping

The interaction has been changed significantly compared to the last iteration. I changed the feedback mechanism, the form of the device and embedded the PPG sensor into the product. A semi-working prototype of this concept was developed to re-evaluate the interaction with our target audience.

I 3D printed a surface where the person would rest their hand on. I modeled this form after the final clay model that we made. This surface was then attached to a servo mechanism that pushed it up and down. A cardboard mechanism was made to support the surface. A vibration motor was attached to the bottom of the surface. The vibration pattern was controlled using an Arduino.
The envisioned product will be able to recognize the pattern of the HRV. When the HRV is a harmonic wave with a frequency of 0.1 HZ (6 breaths per minute), the system would recognize that the user is 'relaxed' and change the heart rate of the Somnox mini accordingly. However, prototyping such a system would require much time. To limit the prototyping time, we decided to mimic this product behavior using a wizard of oz method, which we will elaborate on in the next section.

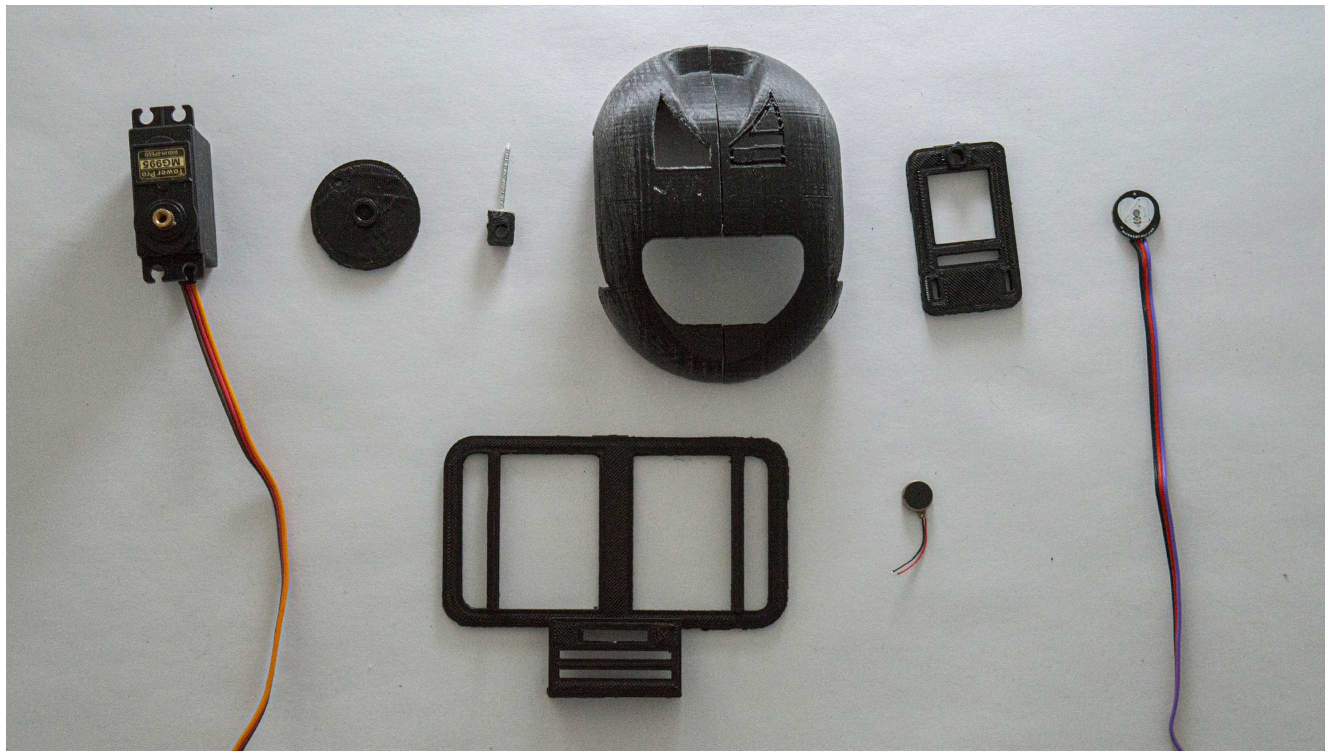


Figure 37 -Parts of the second prototype

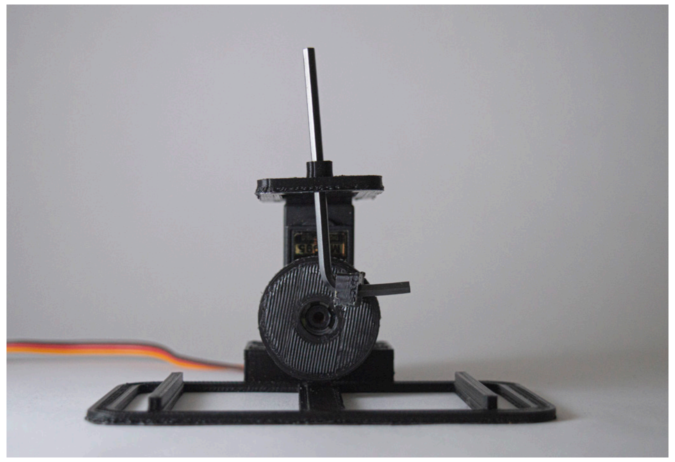


Figure 38
The mechanism that actuates the breathing plate. The rotation of the servo causes the Allen key. The Allen key is limited by a form-fitting, such that it only allows a vertical movement

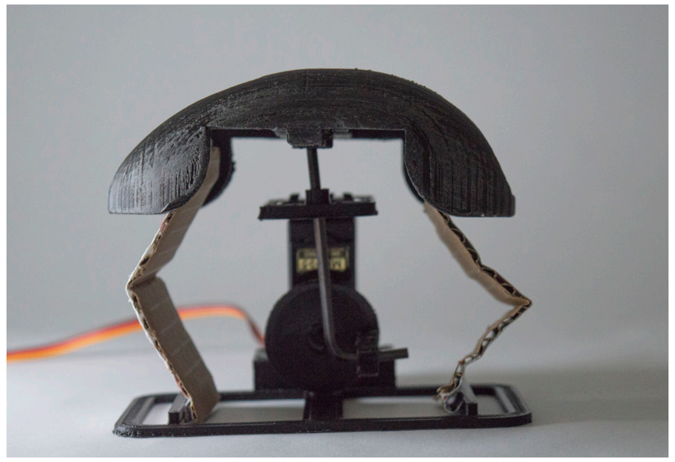


Figure 39
The Allen key is attached to the breathing plate. By rotating the servo, the plate moves up and down.

Two card board hinges were made to support the plate.

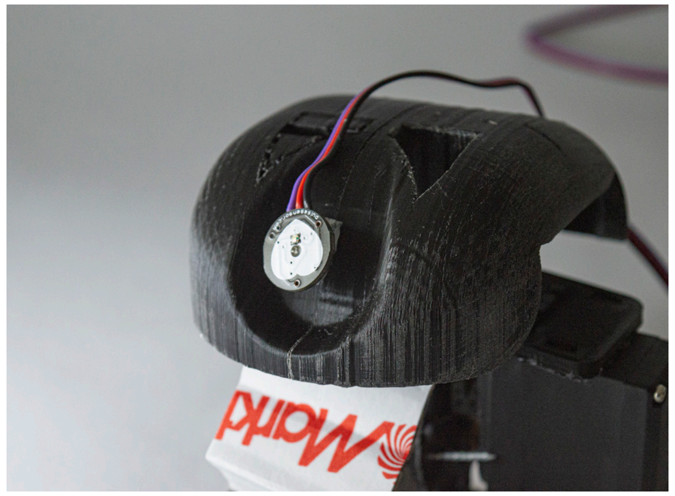


Figure 40
The PPG sensor was attached to the front of the breathing plate

3.2.3 user testing

3.2.3.1 introduction

The interaction has been changed significantly compared to the last iteration. A user test was performed using the functional prototype to assess the changes that we have made in our concept.

3.2.3.2 method

The test was done with 3 participants. All participants were young (25 – 26) professionals. It should be noted that one of the participants had participated in the user test from the previous iteration. The COVID-19 pandemic caused some logistic issues in recruiting participants, as the tests were physical.

The participants were asked to perform the exercise for 5 minutes using the device. This time we did not show real-time data to the user. While the participant was performing the exercise, I looked at the serial monitor that plotted the heart rate variability.

When RSA was seen, I manually changed the vibration frequency. Afterward, a semi-directed interview was conducted to evaluate the experience. A recording of the HRV data was used to lead the interview. Using the HRV data I could see whether the person could achieve RSA, and disruptions in the RSA (which indicates moments of stress/distraction) and ask specific questions based on the data.

Timeline of method

1. Users were asked to perform the exercise for 5 minutes
2. The HRV visualizer was recorded using a screen recorder
3. After the exercise, the data recording was shown to the user
4. A conversation was started based on the data recording (e.g., if we saw that RSA was disrupted we would ask why it was disrupted)
5. A semi directed interview was held to ask about the heartbeat cocnept and product shape

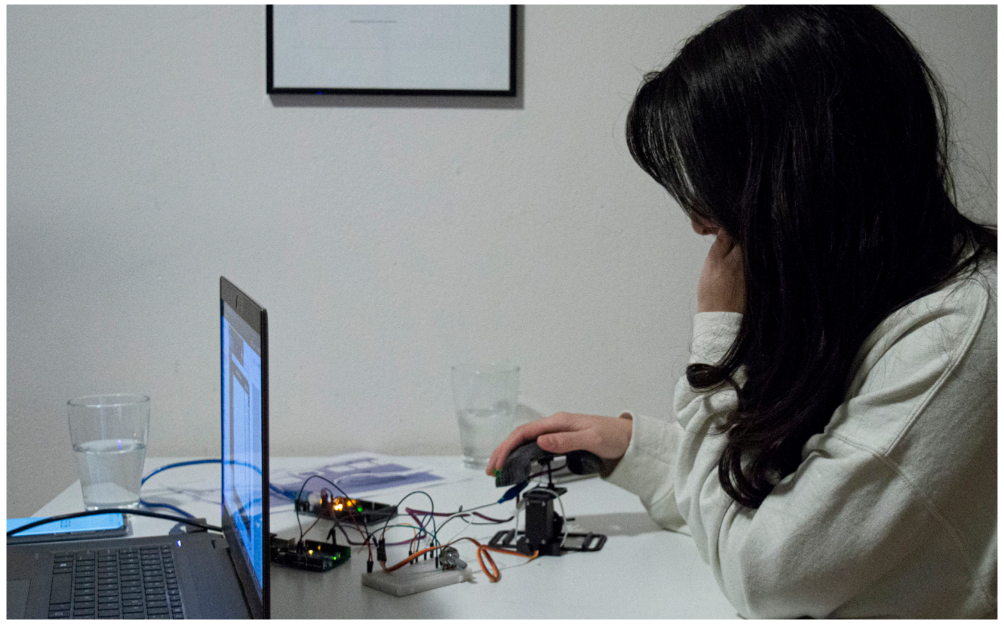


Figure 41
Impression of the user test
The participant could not see the visualizer.

When RSA is detected, the feedback state was manually changed using a potmeter.

3.2.3.3 results

Insight 1: The finger sensor was challenging to feel, and the shape was not optimized for larger hands
The surface showed multiple problems. One participant mentioned that the slot where the finger is placed is too big. As a result, she had trouble placing her finger correctly on the sensor. Secondly, the shape is not optimized for bigger hands. One participant had to “awkwardly” bend his finger to place it on the sensor correctly.

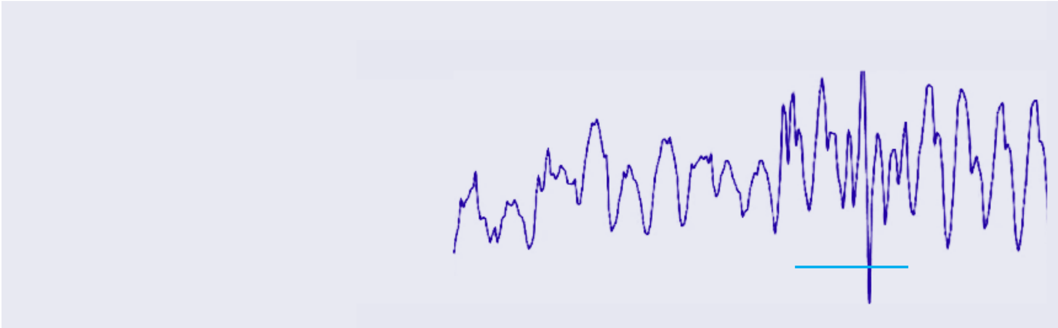
Insight 2: The prototype was able to induce relaxation in 2/3 of the participants
Two participants mentioned that they felt relaxed afterward. One of those participants said that she even almost fell asleep.

Insight 3: The heartbeat had a soothing and relaxing effect
Participants perceived the heartbeat as soothing. One participant mentioned the following: “It made it seem that I had something alive in my hands, which gave me a feeling of safety,”

Insight 4: The change in a heartbeat was too abrupt
The change of the vibration frequency was too abrupt, which temporarily disrupted the relaxation. This was also seen in the HRV visualizer. : “I was expecting a heartbeat, but it did not come; I thought I broke it.”

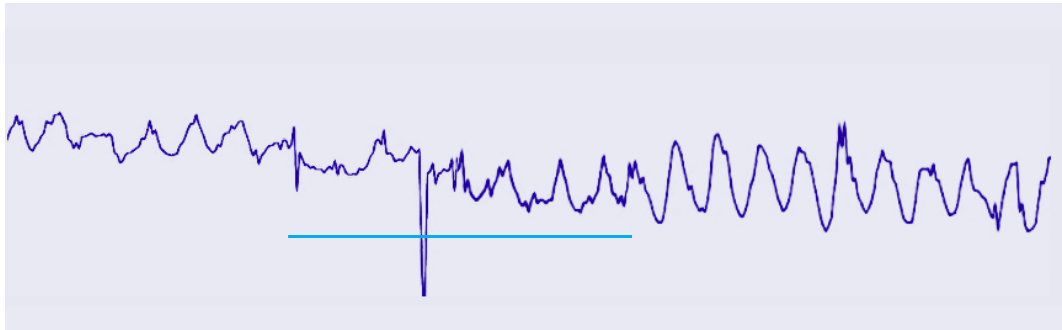
Insight 5: The terms on the app are difficult to understand and require more explanation
Like the previous iteration insights, we saw that data helped them demystify breathing exercises for them, and they said. Therefore, it was valuable. However, the terms that are currently used on the application are not relatable (e.g., heart rate variability, coherency). These need to be changed to more relatable terms or be clearly explained.

The following graphs show the data recordings during the test. Unfortunately, the prototype was very fragile. The prototype broke multiple times during the test, which resulted in a fragmentation of the data as seen in the figures below. I was not able to collect valuable sensor data from participant 1, as she was not able to correctly place her finger on the sensor



Participant 2

The graph visualizes insight 4. We can see a clear interruption of the HRV wave at the moment the I changes the heartbeat frequency. This interruption is important to keep it mind as it can be seen as a stressor or moment of uncertainty that only increases stress rather than decreasing it.



Participant 3

Participant 3 slowly starts getting into RSA; however, midway, it gets interrupted. She mentioned that during this time, she felt a stomachache.

3.2.4 evaluation

The insights from the previous iteration helped us to define our concept further. The most significant change that we made to our concept is the feedback system, which now relies on a subtle heartbeat that tells the user whether the exercise is performed correctly or not. Furthermore, the user tests from the previous iteration also inspired me to use a pet as a metaphor, which has helped me define our user-product interaction and our product's embodiment.

From the user test, I believe that the concept is heading in the right direction since the prototype was able to induce RSA and made the participants feel more relaxed (and even sleepy) afterward.

Nevertheless, there are still multiple things that need to be addressed. First of all, I need to dive deeper into our product ergonomics, as we found that it was not easy to feel where the sensor should be placed and that the shape is not optimized for larger hands. Secondly, the change in a heartbeat was perceived as too abrupt, which disrupted the relaxation. The transition of the two states (correct/incorrect) needs to be refined.

Based on all the insights that we gathered, I updated our list of requirements that we use as the basis for our final iteration.

Key functionalities

1. The product should contain a physical breathing guide (in other words, it should have a similar system as the Sleep Robot to guide the user during the breathing exercise).
2. The breathing guide should clearly indicate the breathing frequency to the user.
3. The product should contain a feedback system that tells the user whether he or she is performing the exercise correctly.
4. The feedback system should not distract the user from the breathing exercise
5. The feedback should be understandable even with the user's eyes closed
6. The product should be able to collect the user's HRV.
7. The system should be able to identify RSA based on HRV wave patterns.
8. The product should be able to communicate with a companion app.
9. The product should contain a Bluetooth module.

Economy

10. The product should be deployable to the market in 2026 (which is based on the fact that the development is planned to start in 2024).
11. The product should not exceed a retail price of €320,- (which is based on the most expensive product found in our product category).

Form qualities

12. The product should be portable.
13. The product should not be larger than (16cm x 21cm x 7cm which are based on the average dimensions of a small women's handbag)
14. The product should not weigh more than 1 kg.
15. The product can be used in public spaces.
16. The noise levels of the product should not exceed 40 db when measured from a distance of 30 cm (which is based on the sound levels of the Somnox Sleep Robot).
17. The product can be used in multiple positions.
18. The product should contain a soft padding at the bottom.
19. The product should not have the appearance of a medical device.
20. The product should have companion-like qualities.
21. The product can be set-up and removed within 10 seconds.
22. The touch of the product should feel comforting.
23. The top-surface should be covered with a soft cloth
24. The product can be comfortably used by left and right handed people.
25. The product should only require one hand to use.
26. The product should feel comfortable for at least p80 hand.

Safety

27. The product should limit the risk of hyperventilation as a result of using it.

Table 3 -list of requirements 2

03.03

iteration 3

We have come to the final design iteration of the project. In this iteration, I refine the product based on the user insights gathered in the previous iteration and propose a final concept. Furthermore, I specify the technologies required to achieve the intended product behavior and functionalities. After that, I make a rough cost estimation of the production price of the product.

Lastly, I create a set of prototypes to validate the concept with end-users to see whether we have achieved the goals that we have specified in the beginning. These goals were to (1) guide users to perform the exercise correctly and (2) ensure that users have the feeling that they are doing it correctly.

3.3.1 Refinement

We identified several problems from our previous user test. In terms of the product's shape, we found that it is not comfortable for people with larger hands. The participant with the largest hand stated that to place his finger on the sensor, his finger had to be bent in an awkward position, as shown in figure 42.

Furthermore, one participant had difficulties placing her finger correctly on the sensor. She mentioned that the finger slot that guided the user's finger placement was too broad. There was a lot of space for her finger to move, and therefore she could not feel where she had to place her finger precisely. Furthermore, the angle of the sensor was too steep. From a sitting position, the sensor was not visible. Thus, apart from her not being able to feel the finger placement, she could also not see it.

In terms of the feedback system, we found that the transition between the different feedback states was too abrupt. After taking a couple of breaths with the product, participants become adjusted to the rhythm of the steady heartbeat. Because the beats came at a constant interval, users would predict when the next beat occurs. However, when we changed the feedback state, the beat interval changes from 2 seconds per beat (30 BPM) to 5 seconds per beat (12 BPM). Participants were expecting the next beat, but it did not occur, which caused a moment of alertness and doubt. For instance, participant 2 mentioned that he thought he broke the prototype. In the following sections, we will address how we have solved each of the identified problems.

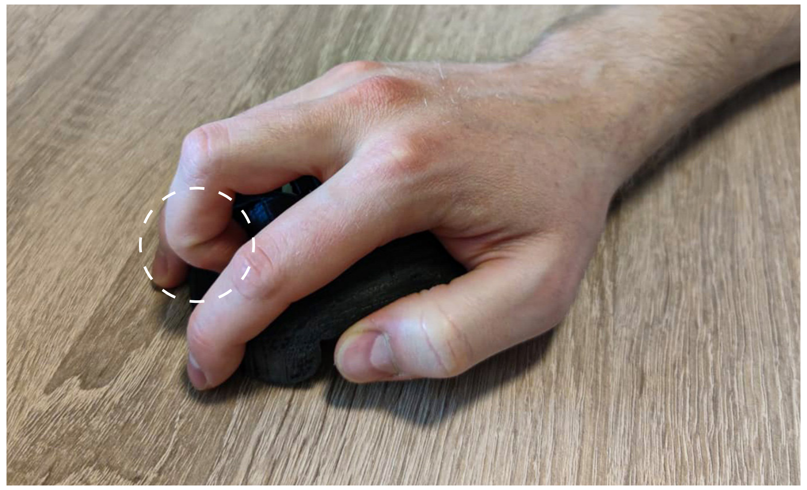


Figure 42
The participant had to akwardly bent
his finger to touch the PPG sensor

3.3.1.1 Optimizing the product to be used for different hand sizes

In the previous design iteration, I oversaw the need that a variety of hand sizes will use the product. To optimize the shape such that this variety of hand sizes can comfortably use it, we first need to quantify these sizes.

We used DINED (an anthropometric database from the TU Delft and TNO) to identify these. Within DINED, we selected the Dutch adult dataset (2004) and set our age group from 20 to 60-year-olds. Ideally, we would have chosen a dataset that only includes 25 to 35-year-olds since this is our target demographic. However, this dataset was not available. According to the selected dataset, hand sizes range from 130 mm to 242 mm.

As you see, there is an extensive range of hand sizes. An ideal solution to optimize the product comfort to this wide variety of sizes would be to develop the Somnox Mini in multiple sizes. By doing this, we can tailor the product size to specific hand size ranges. For instance, having a Somnox Mini for hand sizes between 130 mm to 150 mm, another one for 150 - 170, etc.

Unfortunately, this would be a very costly solution, especially for a small company such as Somnox. Having multiple product sizes would likely require new tooling (e.g., dies and molds) for each size. This results in high upfront costs. According to Edupack (2020), these upfront costs become negligible after a batch size of around 10,000 (see figure 43). In other words, if Somnox can sell 10,000 units of the Somnox Mini per size, developing the production of multiple sizes would be a feasible option taking into account that the retail price cannot exceed €320,-.

However, there are two problems with this condition. Firstly, we need to consider that Somnox Mini is not Somnox's flagship product. Their flagship product is the Somnox Sleep Robot (and its successive generations). We, therefore, expect that Somnox will spend most of the marketing resources on the Sleep Robot. Secondly, Somnox is a small company. Over the past 2 years, Somnox has approximately sold 8000 units of their Sleep Robot. Therefore, the assumption that Somnox will sell 10,000 units per size for a non-flagship product is a high-risk assumption, considering that the product will be launched in 2025. Although this is the best solution to optimize comfort, I do not recommend this solution to Somnox considering the reasons explained above.

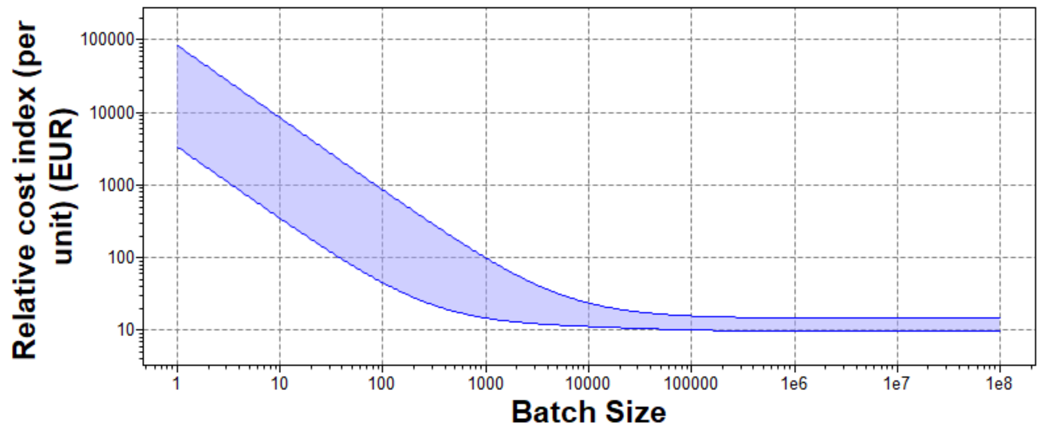


Figure 43 - Relationship between costs and Batch size for injection moulding (Edupack, 2020)

The alternative is to develop a 'one-size-fits-all' solution. However, we believe it is challenging to achieve this with the current range of hand sizes. The difference between the smallest and largest hand is 110 mm. We believe this difference is too big to develop a product size that would be comfortable for both extremes.

Therefore, the first step in approaching this challenge is to scope down to a range that would allow us to create this 'one-size-fits-all solution. We used the normal distribution graph provided by DINED for our specified dataset. To scope down to a more acceptable range, we decided to neglect the 'tails of the curve.' These curve tails included hand sizes that deviate from the most common hand size but only include a small percentage of the dataset. We set the border of these tails to P10 and P90, equal to 168 mm and 204 mm, respectively. By removing these tails, we have lowered the size range from 110 mm to 36mm, thereby decreasing the size content by 67% while still maintaining 90% of the dataset, which we believe is a good compromise.

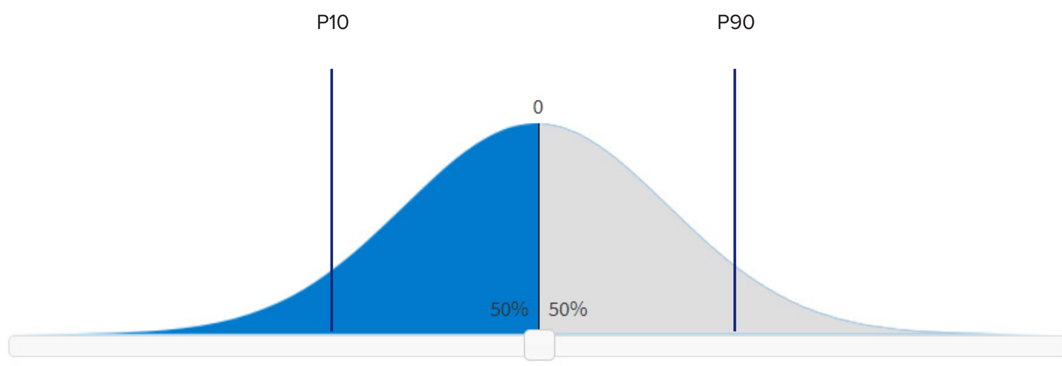


Figure 44 - the bell curve provided by DINED (2004). The bell curve is cut at P10 and P90 to get more realistic range of hand sizes.

Now that I have specified a more reasonable hand size range, the next step is to determine our product's shape. I modeled the shape in our previous design iteration after a clay model, which was based on one hand size. As a result, the curvatures were tailored towards that specific size.

The curvature of the design needs to be changed such that it is comfortable for multiple hand sizes. To determine the curvature, I looked into the designs of computer mice. Our product's hand position is very similar, if not identical, to that of the computer mouse. Both devices require the user to rest their hand on curved surfaces. Computer mice are meant to be used for an extended period of time; thus, hand comfort is a crucial part of mice designs to prevent the development of complications such as repetitive strain disorder (RSI).

We analyzed 5 ergonomic mouse designs from different brands on their proportion and curvatures. We based our selection on different web shops' comfortability ratings (coolblue.nl/ bol.com and mediamarkt.nl). From our analysis we saw that most computer mice share similar proportions and curvatures. In fact, the proportions and curvatures from 3 out of 5 computer mice were close to identical (see figure 45). We took the latter as a basis for the curvature design of the Somnox Mini.

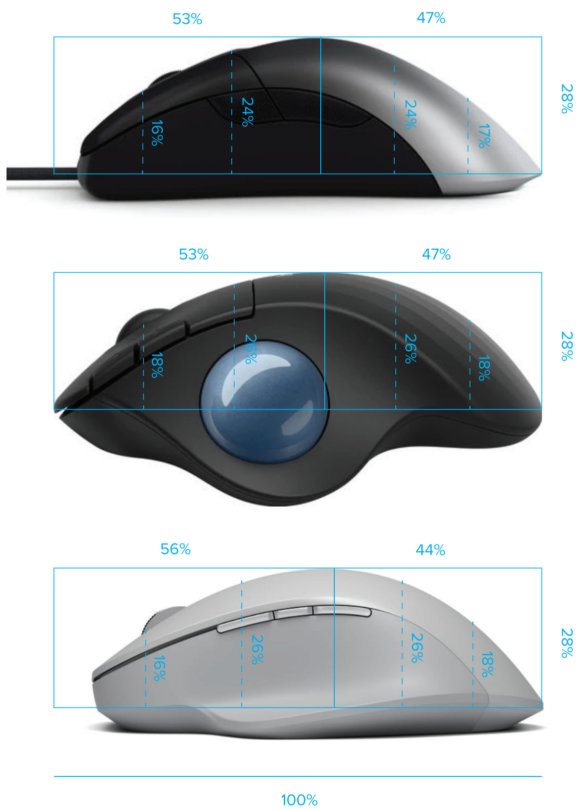


Figure 45 - Shape analysis of different ergonomic mice

Copying the exact proportions and curvatures from computer mice designs would result in a product that looks like a computer mouse. I made some slight adjustments while staying close to the proportions and curvature that we have identified.

These adjustments were the following: The computer mice that we analyzed were not symmetrical. The front was more angular compared to the back of the mouse. This created a dynamic composition. These compositions are often used in product designs that want to portray speed and energy, such as gaming gear, vehicles, or sport shoes. I believe that such a composition does not fit the purpose of our design.

I slightly changed the proportions such that the product became symmetrical, thereby making the product appear more static. I also slightly increased the curvature, thereby making the shape more friendly, emphasizing our product's companion-like character. These changes resulted in the shape shown in figure 46.

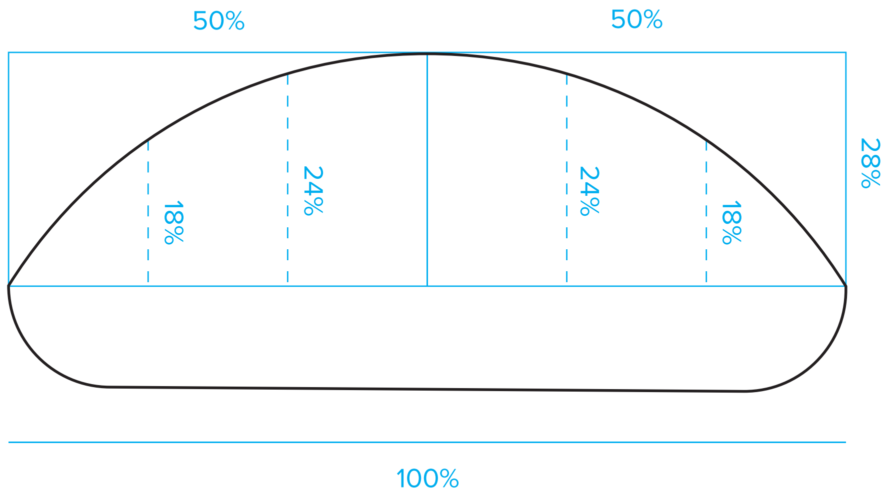


Figure 46 - The finalized shape that is based on the proportions and curvatures of ergnomic mice. Small adjustments were made to keep the companion-like character of the product.

Now that we have established the proportions and curvature, the next step is to determine the Somnox Mini size. To assess the size, we made two cardboard prototypes using the specified proportions and curvature. One prototype was based on the P10 hand size (169 mm), and the other was based on the P90 hand size (204 mm), as shown in figure 47.

I planned to assess both prototypes with a P10 and a P90 hand. We expected that the P10 model would be too small for a P90 hand. This would likely cause discomfort in certain places (e.g., the finger or wrist). Similarly, we expected that the P90 model would be too large for a P10 hand. This would also likely cause discomfort in certain places. The test's goal was to identify these places of discomfort and see where we could further improve our shape to ensure that it would be comfortable for both extremes.

Unfortunately, I could not recruit participants (n = 2) with precisely a P10 and P90 hand. The hand sizes we recruited were 169 mm and 201 mm, equal to P11 and P85, respectively. I asked the participants to try the different prototypes and rate the comfortability on a scale from 1 to 10. Furthermore, I also asked them to point out the places where they felt discomfort.

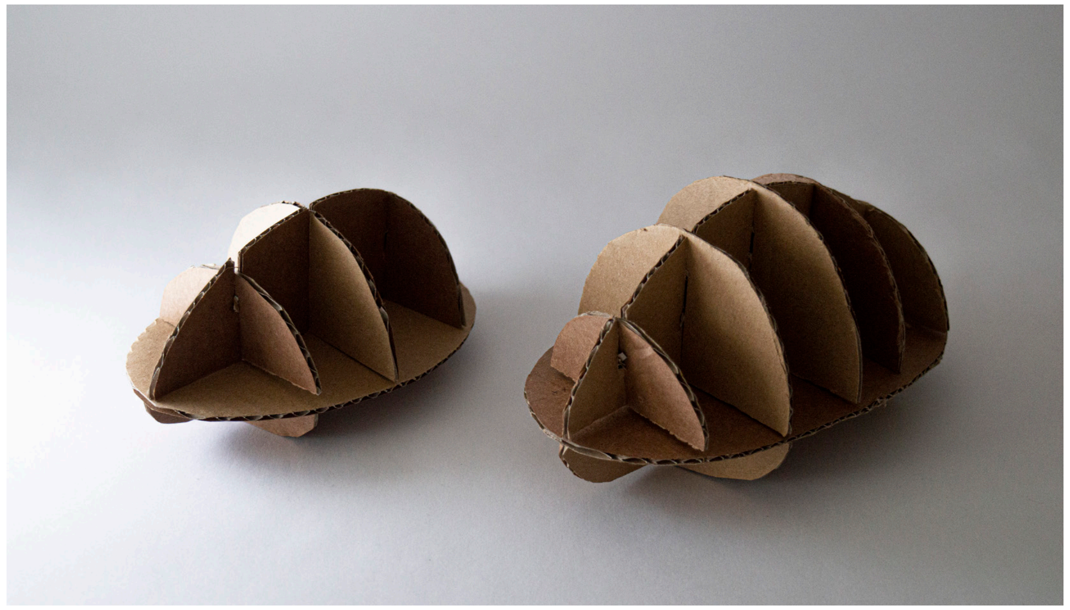


Figure 47 - On the left you see the P10 model, and the right the P90 model. The edge of the curve for each model is equal to the length of their respective hands.

3.3.3.3 Results & conclusions

The assessment resulted in the following scores for each model, as shown in table 4.

In contrast to our hypothesis, the P10 model was comfortable for both the P11 and P90 hand sizes. The P90 model, on the contrary, caused discomfort in the wrist of both participants. Furthermore, the P90 model was also perceived as 'too bulky' to be considered a portable device. I decided to use the P10 model as our finalized shape of our product from our quick assessment results.

Assesment by P11 hand	
P10 prototype	8
P90 prototype	1

Assesment by P89 hand	
P10 prototype	8
P90 prototype	5

Table 4 - Scores that were given to each model

Figure 48A - P10 hand on a P10 model

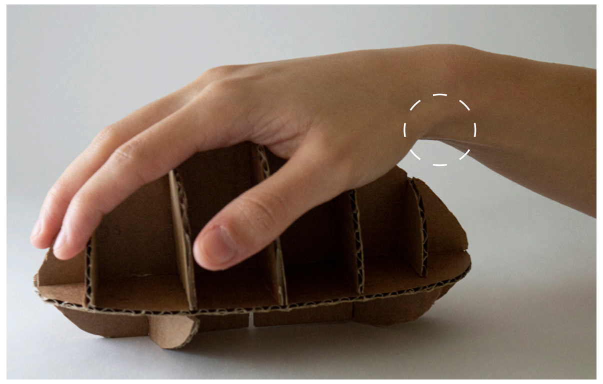


Figure 48B - P10 hand on a P90 model. There is a unnatural flexion of the wrist which causes discomfort.

3.3.1.2 Refining the feedback transition

Now that we have refined our product's shape, the next step is to address the problems that we identified regarding the feedback system. As mentioned before, the feedback system's problem is that the transition between the different heartbeat states is too abrupt, which resulted in increased alertness and feelings of doubt. The transition needs to be redesigned such that these do not occur.

The prototype that I used during iteration 2 was re-used to experiment with different transitions. The experimentation was done together with another person to prevent a strong bias for personal preference. For readability purposes, the starting state is referred to as state 1. This state has a heartbeat frequency of 30 BPM. The state in which RSA is recognized is referred to as state 2. This state has a frequency of 12 BPM.

Transition 1

The first concept that we experimented with was a gradual transition between the two states. With each heartbeat, we increased the time interval between each beat until it reached the frequency of state 2. To illustrate: state 1 has a beat interval of 2 seconds (30 BPM). The interval increased by 1 second with each beat until it reached a beat interval of 5 seconds (12 BPM). (see figure 49).

Upon evaluation, we found that the increase of 1 second per beat was too significant, as it still caused an increase of alertness and, therefore, disrupted the exercise's relaxation. We tried multiple iterations. We incrementally decreased the beat-interval difference by 100 ms - to clarify, the first iteration had a beat interval of 1 second, the next iteration had a beat interval of 900 ms, the next had a beat-interval of 800 ms, etc. We found that the problem disappeared when the beat-interval difference decreased to 200 ms. However, at this interval duration, we identified another problem: it takes approximately 35 seconds to transition from state 1 to state 2. This creates a significant delay between the actual HRV state of the user and the feedback.

Transition 2

Ideally, there should be no feedback delay, but this does not allow us to create a smooth transition between the two states. To give us room to make this smooth transition while minimizing the delay, we say that the transition should not exceed 8 seconds, translating to approximately 3 beats.

To achieve this, we changed the frequency of state 2. Currently, we set it to 12 BPM. However, to transition within three beats with a beat interval difference from 200 ms, from a frequency of 30 BPM, this would mean that the frequency of state 2 would be equal to approximately 23 BPM.

When we evaluated this however, we found that it is very difficult to distinguish the different states from each other. We believe that this slight difference is therefore not sufficient to clarify to the user whether RSA is detected or not. To solve this problem, we amplify the difference by gradually changing the vibration's duration and strength, as shown in figure 51. We believe that the latter adjustments resulted in a smooth transition between the two states while maintaining a clear difference.

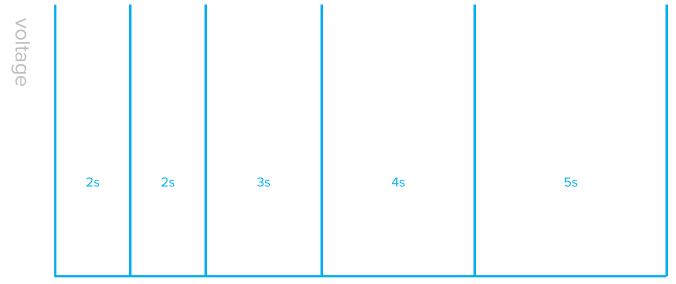


Figure 49 - Transition concept 1. The steps are too big, and still caused a disruption of rhythm

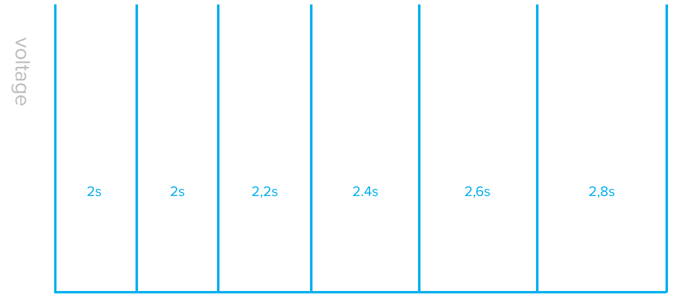


Figure 50 - Transition concept 2.1 The steps are made smaller, but it teakes more than 30 seconds to reach state 2

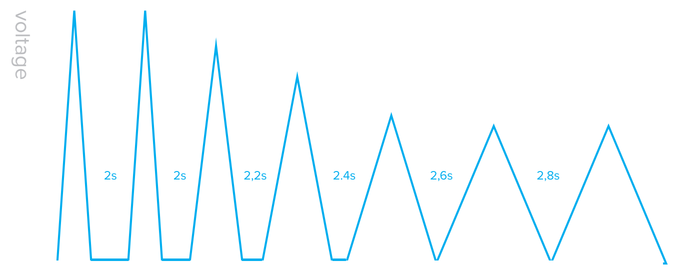


Figure 51 - Transition concept 2.2. We have amplified the difference by adjusting the strength and duration for each beat

3.3.2 Concept proposal

We have been through several design iterations. In each iteration, we have explored multiple options and made incremental changes to improve the product. In this section, we summarize the insights that we have gathered and decisions that have been made so far into a final concept proposal. Before we start, however, let's recap on why the Somnox Mini even exists.

3.3.2.1 Raison d'être

Sleep deprivation has a detrimental impact on human wellbeing and, thereby, the quality of life. It is estimated that currently, 20% of the population is suffering from sleep deprivation. Somnox has set itself to tackle this societal problem by providing medication-free, companion-like technologies that improve sleep quality through breathing regulation.

Chronic stress is one of the most critical risk factors for developing sleep disorders. By tackling chronic stress, we can therefore eliminate one of the root causes of sleeping disorders.

When we look at statistics, we see that the most significant demographic suffering from chronic stress and stress-related disorders are working millennials. One of the reasons this demographic is so prone to stress is that they lack the experience and know-how to properly coping with it. We have learned from our expert interview that finding a coping strategy is difficult. There are many options, but not all are effective.

3.3.2.2 The solution: Somnox Mini

Somnox can help this demographic by providing them an easy, effective, and healthy solution to manage stress and reduce the stress-related symptoms they already have - this is the Somnox Mini.

The Somnox Mini is a portable, companion-like breathing regulation device. The product teaches its users how to properly perform slow breathing, a breathing exercise in which the breathing frequency reduces to 6 breaths per minute. Breathing at this particular frequency induces RSA, which is the synchronization of the heart and breathing and signifies that the body's relaxation response is activated. Multiple studies have shown that slow breathing, if practiced regularly, can balance an overactive stress response, increase stress resilience and improve sleep quality.

The Somnox Mini teaches its users how to perform the exercise by providing a physical breathing guide. The device has a plate that moves up and down, simulating a natural inhalation and exhalation. By resting the hand on the top surface, the user can feel a rising and falling sensation and breathe along with it.

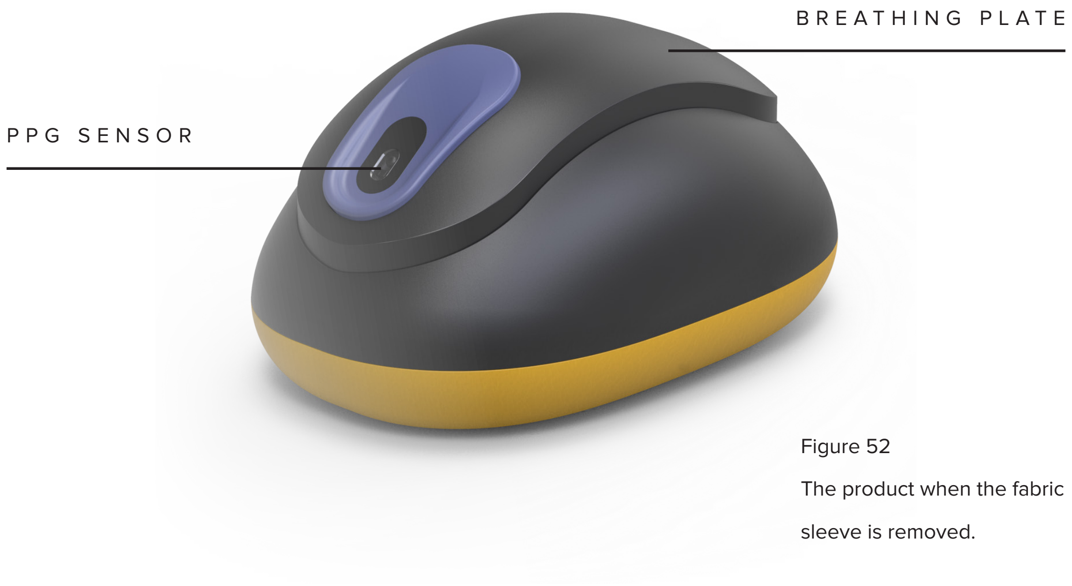


Figure 52
The product when the fabric sleeve is removed.

The PPG sensor is located on top of a finger slot. The purpose of this slot is to guide the user's finger towards the PPG sensor so data can be collected. It should be noted however that the PPG sensor requires a fixation of the finger. Movement in the finger can cause poor data collection. To minimize this problem it was decided to put the PPG sensor on top of the breathing plate, so that the finger moves along with the hand as the plate moves up and down. By doing this we remove the relative movement between the finger and the palm.

Next to our guide, the Somnox Mini also provides feedback that tells its users whether the exercise is performed correctly or not. Using an integrated PPG sensor, the device is able to detect RSA through the user's HRV. The intelligent system is able to recognize the RSA by analyzing the waveforms that are created when plotting the HRV of the user on a time axis. RSA is present when the waveform follows a harmonic wave of 0.1 HZ.

The feedback takes the form of a subtle heartbeat - which is simulated through a vibration motor. Zhou (2020) has found that feeling the sensation of a heartbeat can reduce feelings of stress and anxiety. The heartbeat is a reflection of the user's state. When RSA is detected, meaning that the user's relaxation response is activated, the Somnox Mini's heartbeat will gradually slow down and reduce in intensity. The Somnox Mini relaxes as the user calms down.

In previous user studies, we found that this heartbeat was perceived as soothing by our end-users and gave the feeling of trust and protection since it felt like they were holding a living entity rather than just a gadget.

Figure 53
Based on the HRV feedback, the product provides a feedback output in form of a soothing heartbeat

Instead of having a plastic surface, the Somnox Mini is covered with a soft fabric sleeve. This sleeve makes the product more pleasant to touch and further emphasizes the product's companion-like character.

The bottom of the product contains a memory foam padding. This padding allows the user to comfortably place the device anywhere on their body, so it can be used in multiple positions, as shown in figure 55.

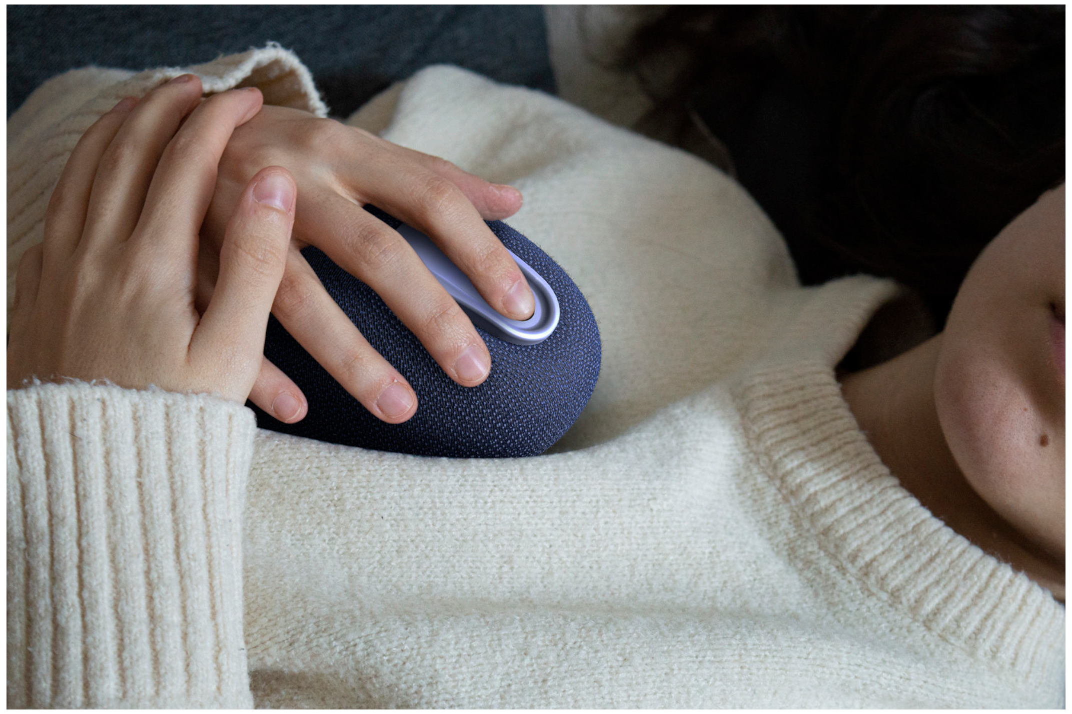


Figure 55 - Impressions of how the Somnox Mini is used in context

Lastly, the product also comes with a companion app, which we will discuss in more detail in section 4.1. After each breathing session, the user receives a report containing insights about their performance and the HRV data that was collected during the session. Showing these insights brings two key benefits.

The first benefit is that it allows users to deduct why the heartbeat feedback behaved the way it behaved during the session. This is especially important if the feedback malfunctions or does not behave the way the user expects it to behave. When the data interpretation is a black box, the users might think the product is broken or is placebo, as we have seen in the negative reviews from some of our competitors (see section 2.3.2). On the contrary, by being transparent, the user can identify why it showed that behavior and might conclude that they did not place the finger correctly on the sensor.

The second benefit is that the report shows the impact of the breathing exercise on the user's physiology. In our previous user tests, we found out that many participants were not aware of breathing exercises' physiological impact. Showing them the raw data changed their perception of these exercises. As one participant mentioned: "I always found myself not to be the right person to practice breathing exercises. It was too abstract. But seeing the data makes the exercise much more graspable" Breathing exercises are often strongly associated with spiritual and religious practices. By showing the biometric data, we aim to break these associations and emphasize the hard science behind breathing exercises, thereby increasing their perceived effectiveness.

SUMMARY

An overview of how users performed during each breathing session

DATA ANALYSIS

To make it more understand-able, the app interprets the waveforms through the col-ored bars. A green bar means that RSA has taken place

Figure 56 - The data summary on the companion app after the breathing session

3.3.2.3 Specifying the critical technologies

Now that we have specified the qualities and behaviour that our product should have, the next step is to determine the technologies required to facilitate these.

The Somnox Mini has two critical technologies. The first one is collecting the user's HRV through the PPG sensor and the back-end system that can detect RSA based on this data. We already addressed the PPG sensor in our first iteration (see section 3.1). We have elaborated on the reason why we selected this technology. Furthermore, we have also validated that it can be used to identify RSA in our previous prototypes.

Next to the data collection, the product also requires a smart back-end system that can detect RSA based on the wave patterns of the HRV data. As mentioned, RSA is present when the HRV (plotted over time) follows a harmonic wave of 0.1 HZ. Although I did not build a prototype to validate this, I am confident that existing algorithms can do this. This confidence is based on the argument that existing products can analyze HRV data; an example is the EliteHRV app (figure 57) or EmWave2.

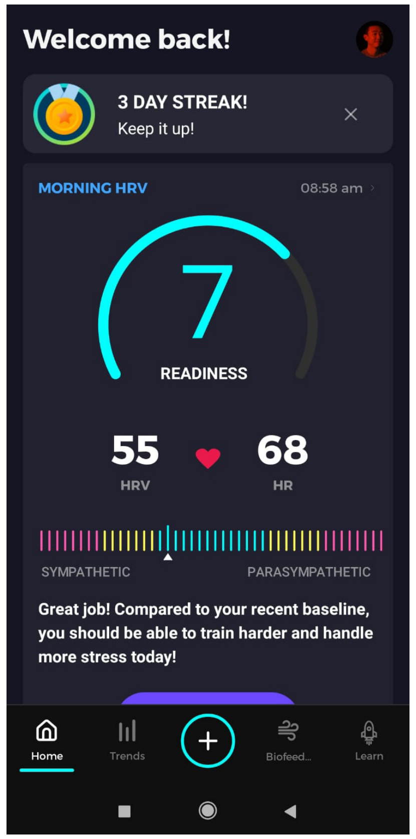


Figure 57 - Elite HRV application gives recommendations on how the user should go about their day, by analyzing the user's HRV using compatible sensors.

The second critical technology, which has not been addressed yet, is the linear actuator that drives the movement of the breathing plate. The reason why we have not addressed this yet until now, is because the shape and size of the product determines which actuator can be used or not. This shape has only been determined during the final iteration.

To find a suitable actuator, I established a list of potential actuators together with Somnox. This list was based on prior research that they have done, shown in table 5. To see which actuator might fit the Somnox Mini the best, I assessed each actuator based on three requirements.

1. The actuator should be able to lift at least 1.6 kg. We based the requirement on the average hand-weight, which is 0.6 kg (Plagenhoef et al., 1983). We take 1 kg as a safety margin.
2. The actuator should be as small as possible and should not exceed a dimension of 5cm x 5cm x 5cm. This requirement is based on the current measurements of the Somnox Mini.
3. The actuator should be as cheap as possible and should not exceed the price of 15 euros per unit. This requirement is based on the fact that the retail price cannot exceed €320,-, and that Somnox aims to take a 80% profit margin, meaning that the product price cannot exceed €80,- per unit.

Actuator	Requirement 1	Requirement 2	Requirement 3
Air pump	Yes	No, requires sound muffler/valves/bag	Yes
Servo	Yes, in combination with a gearbox	Yes	Yes
DC motor	Yes, in combination with a gearbox	Yes	Yes
Piezo electric motor	Yes	No	No (> €100)
Linear stepper motor	Yes	No	No (> €30)
Magnetic linear actuators	Yes	Yes	No (> €100)

Table 5

I found that the most suitable solutions are likely to be a servo motor or a DC motor from this assessment.

However, both DC and Servo motors are rotational actuators. As our breathing plate's motion is linear, we need to translate the rotational motion of the actuators into a linear motion. To achieve this, I suggest building a rack and pinion, as shown in figure 58. A rack and pinion consist of a linear gear that is engaged by a circular gear attached to the rotational actuator. We have also used this system in our first functional prototype.

Next to the rack and pinion, we also need a gear transmission system. The DC motors that we found within the specified dimensions had a maximum torque of approximately 100 gcm (RS components), which is insufficient to lift a weight of 1.6 kg. Using a gear transmission system, we can amplify the torque on the DC motor by adjusting the gears ratio (see figure 58).

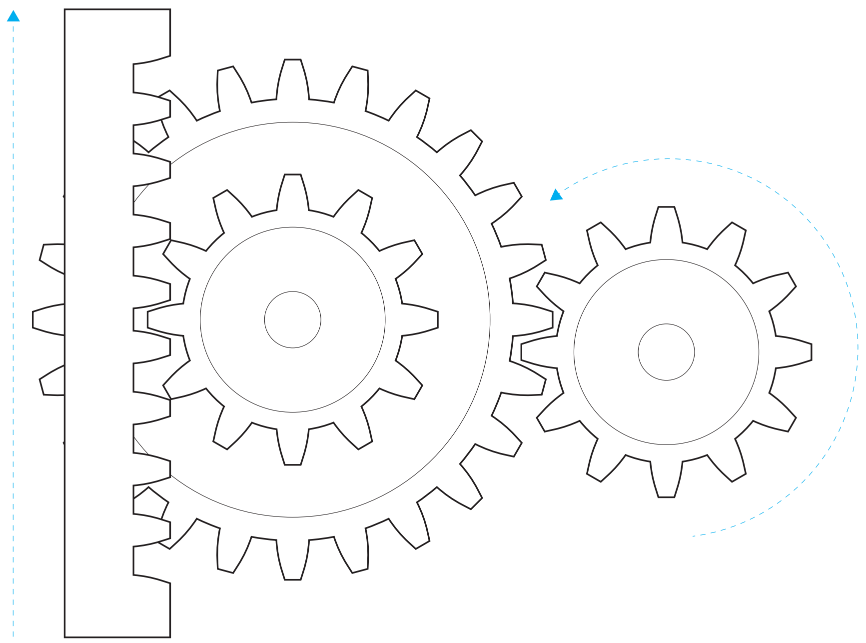


Figure 58 - An example of a gear transmission system in combination with a rack and pinion. If we assume the gears are 100% efficient, the system shown in the figure is able to multiply the servo torque by 2.

On the contrary, I was able to find a strong servo motor within the specified dimensions that can lift a weight of 1.8 - 2.2 kg (Towerpro MG90S). Nevertheless, we still recommend a gear transmission to amplify the torque to optimize battery life. The reason for this is, the higher the torque, the more voltage it draws. Therefore, by minimizing the motor's output torque required to lift the hand, we can decrease the battery's voltage draw. I recommend optimizing the battery life so that the user can use it for 2 hours minimum before recharge. This is because the recommended time for breathing exercises ranges from 10 to 20 minutes, once or twice a day (Jerath, 2019; Russo, 2017) - which equates to a total usage time of 20 to 40 minutes per day. 2 hours seems like a good safety margin.

I should mention that this is a recommendation. Before we can implement this system into the Somnox Mini, we need to specify further the gear transmission system's configuration and further research whether a DC motor or Servo motor is the optimal solution. The specification of this was outside the scope of this project.

3.3.2.4 Cost estimation

For our concept to be viable, the product should not exceed a retail price of €320,-. This price is based on the maximum of our competitors. Somnox aims at taking a 80% profit margin. This means, to not exceed the retail price of €320,-, the production price cannot exceed €80,-

To check whether it is possible to meet this requirement, I made a rough cost estimation. It should be emphasized that this is a ROUGH estimation since a lot of things are still unknown such as the exact brand and model number of each component, the exact material of the foam, fabric, and plastics, the number of assembly parts, and the internal constructions of the plastic casing. The cost estimation is shown in table 6.

The electronic components' prices are based on prices found on electronic suppliers such as RS, mousers, and Farnell. The plastic parts, assembly parts, foam, fabric, assembly labor, and packaging are based on the existing cost list of the Somnox Sleep Robot. Because the Somnox Mini is likely less complex than the Sleep Robot and is significantly smaller (therefore requires less material), I took 50% of the price of each of the components on Somnox's existing cost list.

According to our rough estimation, the total product price is €53,22. I believe that the actual product price will be slightly lower. This is because we used Farnell, RS Components, and Mousers to determine the electronic components' price. These are resellers and likely ask for a small margin per component. I believe the electronic components can be significantly cheaper when ordered directly from their manufacturers.

	Components	**Price**	**Source**
1	PPG sensor	3,- (per 100 units)	mousers
2	Servo/DC motor	1,50	RS components
3	PCB (including bluetooth module and microcontroller	10,-	Somnox
4	Rechargable battery	9	mousers
5	Charger	2,86	Somnox
6	Plastic parts (including gears)	3,28	Somnox
7	Assembly parts	1,13	Somnox
8	Foam	2,35	Somnox
9	Fabric	3,00	Somnox
10	Assembly labour	15,00	Somnox
11	Packaging	2,10	Somnox
	Total costs	53,22 per unit	

Table 6 - cost estimation

3.3.3 Final prototype

To conclude our project, I created a final set of prototypes to assess the proposed concept. With these prototypes, I wanted to validate whether we have solved the problems that we identified in the research section: is the Somnox Mini able to guide its users in performing slow breathing correctly? And did we increase the self-efficacy of the users in the breathing exercise?

Furthermore, I also wanted to assess whether we have solved the problems we identified in iteration 2. We wanted to check if there is still any discomfort, if users can correctly place their finger on the PPG sensor and if the heartbeat transition still disrupts the relaxation.

To assess the aspects mentioned above, we developed two prototypes: one functional prototype and one form prototype. The functional prototype is used to communicate the product behavior and functionalities, whereas the form prototype was only used to assess the comfort.

3.3.3.1 functional prototype

The prototype consisted of the following parts, which were FDM printed: (1) the shell, (2) the breathing plate, (3) the base, (4) the rack and pinion, (5) a plateau for the servo, and (6) the finger slot (see figure 60).

The breathing plate is displaced up and down by a rack and pinion, engaged by a mini servo, as shown in figure 61. The rack is inserted into a slot that is attached to the breathing plate. Underneath the breathing plate, we have secured the vibration motor that is responsible for simulating the heartbeat. The PPG sensor is attached to the finger slot, which is attached on top of the breathing plate.

The breathing plate is closed in by the shell. The shell's purpose is to limit the degrees of freedom of the breathing plate to only a vertical movement). This shell is attached to the base using several slots.

The base contains a slot for the rack and a plateau for the servo, which is attached using a clicking system. As you see in figure 60, the base contains a lot of slots. These slots were created to minimize printing time.

We used a similar setup to control the electronic components of the prototype. Two arduinos control the electronics. One Arduino controls the PPG sensor, whereas the other controls the vibration motor and the servo.

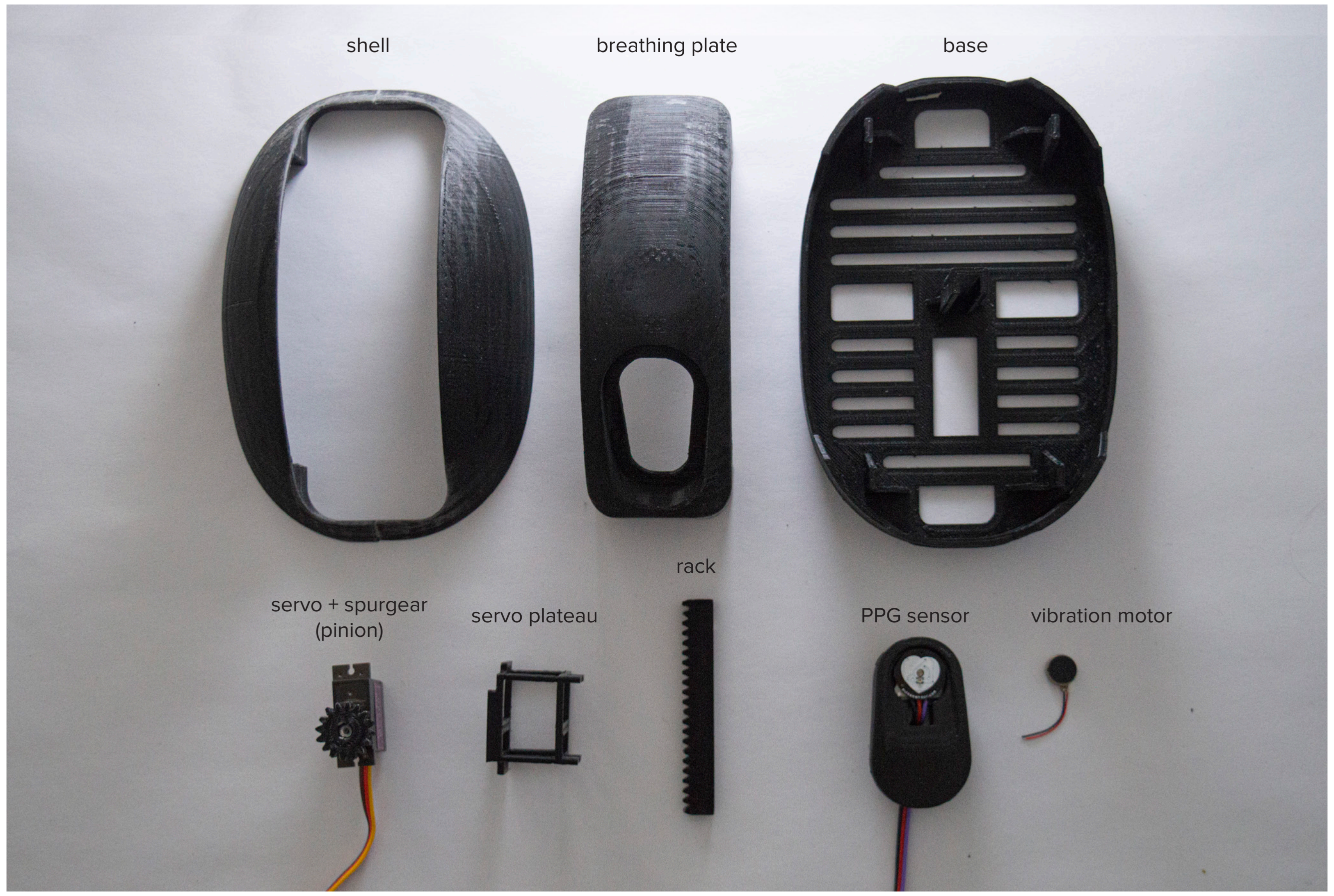


Figure 60 - An overview of the parts of functional prototype 3

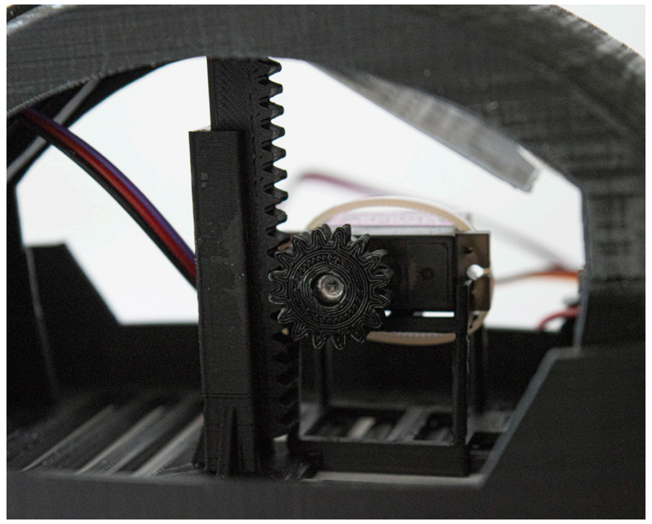


Figure 61 - The breathing plate is actuated through a rack and pinion system that is driven by a mini-servo.

Figure 62 - The fully assembled prototype

3.3.3.2 The form model

I printed the shape using an FDM printer (see figure 64). On the bottom, I attached a piece of memory foam on the bottom and then wrapped the product in fabric, which resulted in the prototype shown in figure 65. It should be stressed that the memory foam and fabric used for the prototype are not the final materials for the actual product.

The fabric I selected was a fabric with a relatively large texture to increase its tactility. For the memory foam, I used the foam that is also used in the second generation Sleep Robot. We picked this foam out of a selection of 4 foam samples that we have ordered online. Due to logistics reasons, these were the only samples that we could get our hands on within the given time left for the project. Ideally, we would have visited different showrooms to assess a wide variety of foam samples; unfortunately, this was not possible due to the COVID-19 measures. We selected the foam of the 2nd generation Sleep Robot because of its density. Although all the foam samples were soft, the other foam samples had a low density. The low density made it appear as a low-quality foam and made it appear as a kitchen sponge. From this quick assessment, we learned that the foam density significantly impacts our product's perceived quality. Therefore, when selecting the final foam sample, we should prepare a soft, high-density foam.

Figure 64 - We printed a shell using a FDM printer. On the bottom we attached a piece of foam shown in figure 63.

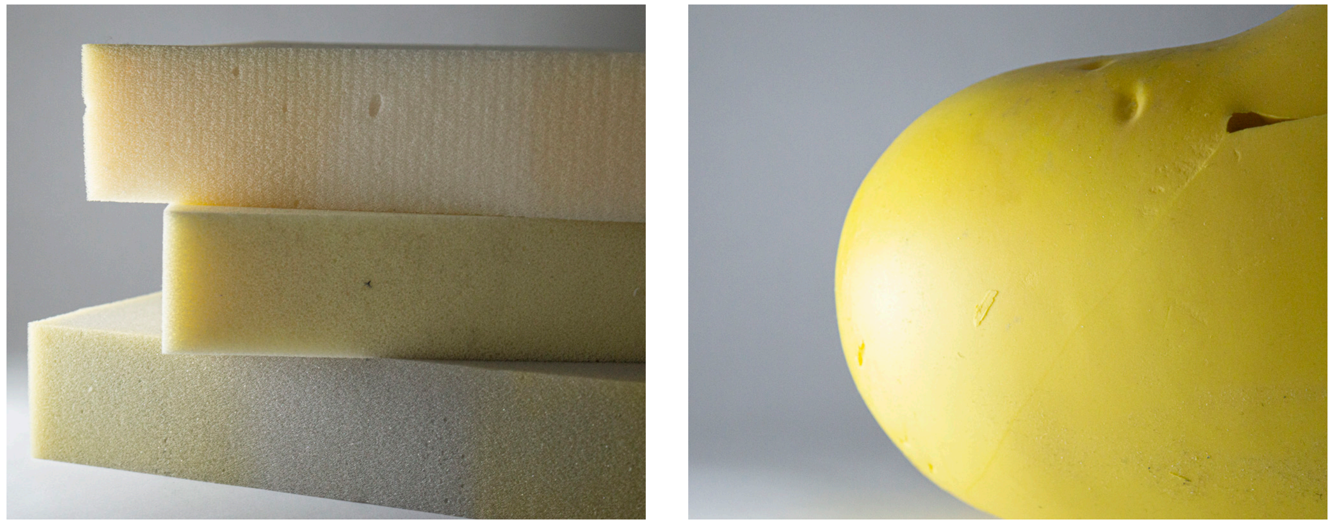


Figure 63 - the Foam samples that we have acquired. The right shows the foam that is used for the form prototype.

Figure 65 - the final form prototype after it has been wrapped into a piece of fabric.

3.3.4 Final user test

3.3.4.1 Introduction

A final user test was performed to validate whether the concept can solve the problems specified in the research phase. I want to validate whether people can correctly perform slow breathing using the Somnox Mini and whether the feedback helps people feel confident that they are performing the exercise correctly.

Furthermore, I also want to assess the adjustments that we made in the final iteration. I want to determine if the shape of the product feels comfortable and determine whether we have created a seamless transition between the different heartbeat states.

As you can see, this user test is a combination of four research goals. For each research goal, I used a different method, which will be discussed separately in the sections below. We conclude the section by giving an overview of how we have combined the various methods into one test session.

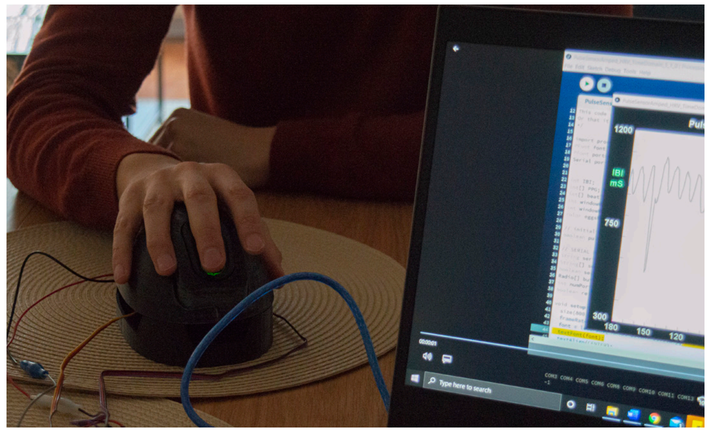


Figure 66 - An impression of the final user test. Similar user test 2, the user did not see the visualizer. The feedback was manually changed using a potmeter.

Figure 67 - An impression of the form test. Users were asked to 'play around' with the protype and imagine how they would use it.

3.3.4.2 Method

3.3.4.2.1 Participants

The final user test was conducted with 5 participants. Each participant mentioned that they suffered from regular stress and had stress-related symptoms occasionally, such as poor sleep, anxiety, and reduced patience. Due to COVID measures, it wasn't easy to set up a fixed test location. The tests were therefore performed in the house of each participant.

3.3.4.2.2 Test set-up

The user test was done with the prototypes that we have previously elaborated on in section 3.3.3. We used the functional prototype to communicate the breathing guide and feedback mechanism. Similar to the user test in iteration 2, we used a wizard-of-oz technique to mimic RSA detection. The PPG sensor is connected to the processing visualizer. The visualizer was not shown to the user. Whenever RSA was visible on the visualizer, we would manually change the feedback state using the connected potentiometer. (figure 66)

The form prototype was used to assess the comfort of the product. (figure 67)

The user's answers were collected using note-taking. I used a custom interview template to maintain a similar structure for each participant, making the analysis more efficient. You can find this template in appendix B.

3.3.4.2.3 Procedure

Validating whether people are able to perform slow breathing correctly.

To validate whether the participants were able to correctly perform the exercise, we made a recording of the HRV visualizer.

We first took a baseline measurement of the user's HRV. We asked the participant to place their finger on the PPG sensor. To get a good sample, we asked the participant to hold their finger on the sensor for 2.30 minutes. The breathing guide was deactivated. We then activated the breathing guide and asked participants to breathe along with the prototype for 2.30 minutes. If users performed the exercise correctly, the HRV visualizer should show a harmonic wave with a frequency of 0.1 HZ.

Validating whether the feedback helps users to feel confident that they are performing the exercise correctly.

We applied the following method to validate whether the feedback increased the participant's self-efficacy in the exercise. We let the participant perform a breathing session of 2.30 minutes with two different versions. One version included the heartbeat, we refer to this as prototype A. in the other version the heartbeat is deactivated, this is referred to as prototype B. To prevent an order-bias we alternated the prototype order for each participant.

For each prototype: we asked the participants to score the following statement from 1 (strongly disagree with the statement) to 5 (strongly agree with the statement). "I felt confident that I was performing the breathing exercise correctly". If the feedback helps the users to feel confident that they are performing the exercise correctly, the score of the prototype A should be higher than that of prototype B.

Assessing the feedback transition

To assess the feedback transition, we asked the participants the following questions based on their interaction with prototype A:

1. We asked participants whether they felt the heartbeat was distracting them from the exercise, and asked them to elaborate on their answer.
2. We asked participants whether they noticed the difference between the two states, and if they could point out what exactly changed.

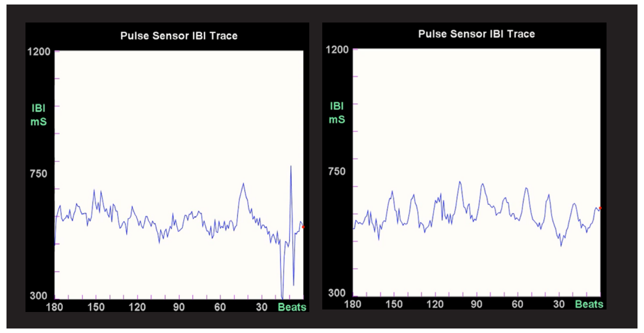
The feedback transition is successful when the heartbeat is not distracting from the exercise, and there is a clear noticeable difference between the two states.

Assessing the product comfort

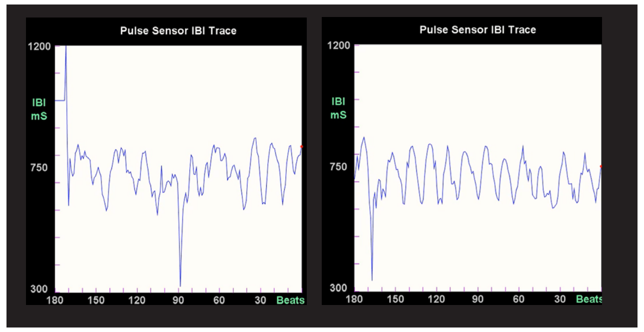
The form model was used to assess the product comfort. We presented this prototype to our participants and asked them to rest their hand on it. We encouraged them to try different positions. Afterwards we asked them if they felt any discomfort, and asked them to rate the comfort from a scale from 1 to 10, in which 10 is the best.

Timeline of method

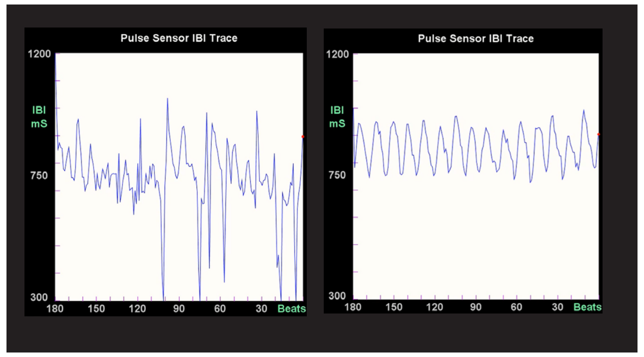
1. Baseline measurement for 2.30 minutes
2. The visualizer was recorded
3. Using prototype A/B for 2.30 minutes
4. The visualizer was recorded only with prototype A
5. Participants were asked to rate the 'confidence score' from 1 to 5
6. Using prototype A/B for 2.30 minutes
7. Participants were asked to rate the 'confidenc score' from 1 to 5
8. Questions were asked regarding the heartbeat concept
9. Participant were asked to 'play around' and imagine how they would use the form prototype
10. Participants were asked to rate the comfort of the form prototype and ellaborate on their choice



Participant 1

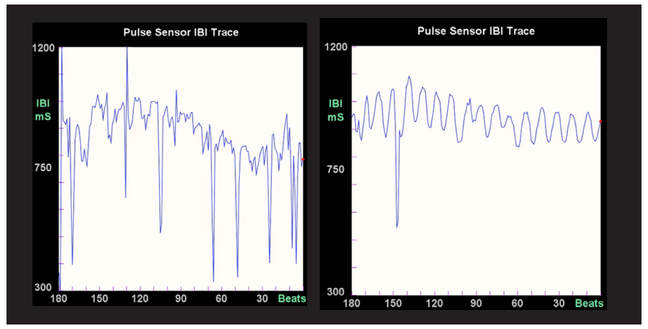


Participant 2



Participant 3

Participant 4



Participant 5

Figure 68 - Data recordings of the user test. The left shows the baseline measurement. The right shows the HRV during the exercise

3.3.4.3 Results

Insight 1

As seen in the graphs shown in figure 68; all participants were able to induce RSA. This validates that our product can stimulate a physiological relaxation response in its users.

Interestingly, all participants almost immediately induced RSA, despite that none of them practiced slow breathing before our tests. This insight is in contrast to our previous findings, in which we found that it could take up to 1 minute to induce RSA. One of the reasons that can explain is that this prototype is much more robust than the previous prototypes. This prototype allowed the participant to comfortably rest and put the full weight of their hand on the prototype. This might have sped up the relaxation process.

Insight 2

On the statement: “I felt confident that I was performing the breathing exercise correctly”, prototype A received an average score of 5/5, whereas prototype B had an average score of 4.2/5.

The heartbeat did increase confidence. However, the impact is minimal. Participants mentioned that the breathing guide alone was sufficient to ensure the feeling of confidence in the exercise. Only two participants noted that the feedback helped them to increase their confidence in the exercise slightly. To illustrate: one participant mentioned that she was worried about whether she was correctly following the breathing plate when the heartbeat was not present.

One participant mentioned that he found the heartbeat to be annoying. The heartbeat was too harsh for him, which distracted him from the exercise.

Insight 3

Despite that the heartbeat did not have a significant impact on the confidence levels of users in the exercise, it still had a positive contribution to the exercise in general. Similar to the previous user test findings, the heartbeat was perceived as very soothing by most of the participants. One participant mentioned, for example, that the heartbeat created a feeling of trust and familiarity since it felt like a living object rather than just a gadget.

Another participant was not aware that the vibration represented a heartbeat. Instead, he thought the vibration simulated a cat's purring due to the low frequency the vibration motor produced. Nevertheless, he perceived it as relaxing.

Insight 4

In our previous functional prototype's user test, it was visible on the data recordings that participants got stressed when the feedback state changed. This stress did not occur in the current user test. Only 1 out of 5 participants mentioned that the heartbeat was annoying, which was more about the general heartbeat concept and not the transition.
Furthermore, all participants were able to point out what changed between the different states. In that sense, I believe that we have created a smooth transition while maintaining a clear difference between the states.

Insight 5

In terms of comfort, the average rating was 8.5. None of the participants had any negative remarks on the shape of the product. Participants were mainly enthusiastic about the fabric that has been used on the surface. The participants perceived this fabric as pleasant to touch.

3.3.4.4 Conclusion

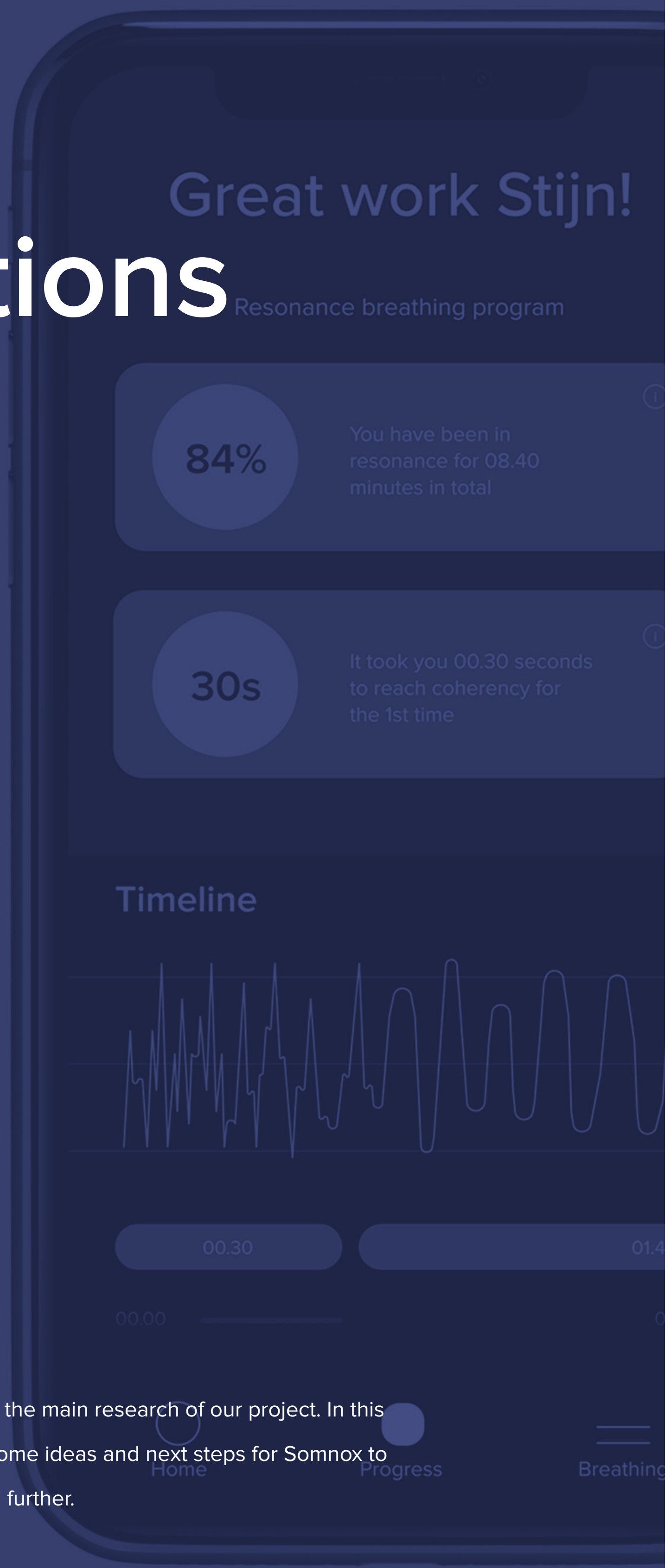
All in all, I believe that the concept can solve the problems that we have initially specified.
The product can help people correctly perform the exercise, which could be seen in the data. Furthermore, all participants mentioned that they felt confident that they were performing the exercise correctly.

Although the heartbeat has a minimal effect on the confidence level, I still recommend keeping it. The feedback is beneficial for confidence in the exercise and can also help users improve and reflect on their breathing practice. A typical problem during these exercises is that the mind starts to wander and might start thinking about stressful situations. The heartbeat can act as a reminder for the users to bring their focus back to breathing. Moreover, the heartbeat gives users a feeling of safety, protection, and trust mentioned in the current and previous user tests.

The heartbeat still needs some extra attention, as one participant mentioned it to be annoying. Compared to our previous functional prototype, the heartbeat of the current prototype felt slightly harsher. I speculate that the thickness of the material causes this. The last functional prototype had a wall thickness of 5 mm, whereas the final one had a wall thickness of 2mm. This thickness difference had a significant influence on how the vibration is transferred towards the user's hand. In the next iteration, Somnox needs to investigate the influence of material property on the vibration and create a warmer and more soothing heartbeat. We will elaborate on this in section 4.3.

04

reccomendations



We have concluded the main research of our project. In this section, I propose some ideas and next steps for Somnox to realize Somnox Mini further.

4.1 The companion app

The first thing that I would like to address is the role of the companion app. In our main research, we have vaguely touched upon the topic. The companion app is used to provide a summary of the user's performance after the breathing exercise. However, I believe it can be much more valuable through some additional features. One of these features is a reminder and reward system to encourage users to adhere to our product.

As mentioned in our research phase, the exercise needs to be performed daily for slow breathing to be truly effective. Regular practice helps balance the overactive stress response, increase stress resilience and reduce stress-related symptoms such as poor sleep. From the research phase, I learned that adherence to relaxation exercises is, unfortunately, very low.

Hence, for the Somnox Mini to be successful stress coping device, we also need to encourage the users to use the product regularly. Due to the project's timeframe, we did not put the project's emphasis on solving this problem. Nevertheless, we have conducted literature research about this problem and come up with a potential solution which we on the following page.

4.1.1 Contextual reminders

As mentioned in the research phase, we can increase adherence by turning slow breathing into a habit. By looking into several habit-forming frameworks, I have learned that habit formation can be encouraged through reminders linked to a specific context and rewarding the user after performing a behavior to encourage motivation.

Reminders help because you can remind the person to perform the behaviour when the user is in that specific context. For example, if you want a person to perform breathing exercises in the kitchen, you can provide a reminder every time that person is in the kitchen. After the habit has been formed the user will automatically associate breathing exercises with the kitchen.

The challenge is the fact that our product is used in different contexts. Unlike the Somnox Sleep Robot which is only used in the bedroom, the Somnox Mini can be used anywhere. As seen in our research, some users indicate that they would like to use it in the office, others in the train and others right before sleep. The context in which the product is going to be used, differs per user.

Therefore in order to provide these contextual reminders, we need to have a system that is adaptive. We can for example achieve this by having the system logging the time, day and geo-location every time the product is being used. Gathering this data allows the system to predict the moment in which the user is most likely to perform the exercise. For example: the system will know that the user is most likely to perform the breathing exercise monday morning while commuting to work. The system will then only send reminders to the user during those specific moments.

4.1.2 Intrinsic reward

The second element to build the habit is the reward. A reward is needed after the behavior to encourage motivation. There are many ways of rewarding the users. According to Deci and Ryan (2012), there are two types of rewards, (1) intrinsic rewards and (2) extrinsic rewards. To explain the difference, we take the example of a professional athlete: professional athlete A is motivated to pursue his sport because the sport itself makes him feel good, and he likes seeing himself getting better at it - his rewards come internally - these are referred to as intrinsic rewards. On the other hand, professional athlete B is motivated to pursue his sport by the fame and salary he is receiving.

In contrast to athlete A, athlete B is motivated by extrinsic rewards. Studies have found that intrinsic rewards are superior to extrinsic rewards. More specifically, athletes who are intrinsically motivated are much more likely to sustain their careers (Calvo, 2010). Furthermore, we also see that extrinsic rewards elicit motivation at first, but eventually hinder a behavior's habit-forming (Piao et al., 2020).

Therefore, these studies suggest that to help our users successfully form the habit of using the Somnox Mini daily, we need to provide a system that can encourage the development of intrinsic motivation. A way to increase intrinsic motivation is by visualizing progress (Locke, 1996; Zhang, 2019), For example if we look at other principles such as sports and dieting. In both principles, seeing progression towards a goal feels rewarding. For example, in sports, this would be getting better every time, and in diet, this would be stepping on a scale and seeing that you are losing weight.

The main goal of buying the Somnox Mini is to manage and reduce stress. However, unlike sports and dieting, stress is a much harder parameter to track. With sports, you can easily track your records, and with dieting, you can take measurements of the waist or step on a weight scale, this is not the case with stress. Nevertheless, stress can be quantified and measured; however, the required tools are not very well known to the public.

HRV, next to the measurement of RSA, can also be used to quantify stress. As indicated earlier, the HRV is a reflection of the user's autonomic nervous system. A low HRV is associated with an imbalance of the SNS and PNS and is an indicator of stress, whereas the high HRV is associated with the opposite (Wienecke & Nolden, 2016). Studies found that you can increase one's HRV by practicing slow breathing regularly (Nagarajan, 2014; Chien et al., 2015). Therefore, if we periodically track the HRV of the user, we can visualize the progress the user makes in terms of 'stress recovery. The limitation, however, is that the HRV varies during the day. Therefore, to show improvement, we need to ensure that the measurement is taken each day consistently.

It should be emphasized that these concept proposals are based on literature research. These concepts need to be further validated in terms of desirability and technological feasibility. Nevertheless, we believe that these concept proposals are well supported through literature and can be used as a basis for further iterations.

4.1.3 Other breathing programs

The breathing guide of the Somnox Mini can easily be programmed such that it can also facilitate other breathing exercises by changing the movement patterns of the breathing plate. For example, 4-7-8 breathing is a breathing technique that requires the user to inhale for 4 seconds, pause for 7 seconds and exhale for 8 seconds. We can provide a guide for this exercise by mimicking this pattern through the breathing plate's movement, moving up for 4 seconds, pausing for 7 seconds, and moving down for 8 seconds. Similarly, we can provide other breathing exercises such as Buteyko, box-breathing, or yogic breathing.

Despite that the Somnox Mini can facilitate other breathing exercises, we decided to only focus on slow breathing for the following reasons. Firstly, we should remind that Somnox Mini's target users suffer from chronic stress and stress-related symptoms. We do not believe that the main incentive for buying the device is to explore different breathing exercises. The user is mainly interested in finding an effective solution for their stress. We decided to focus on slow breathing since this exercise has the most substantial scientific evidence that it effectively manages stress and reduces symptoms.

However, we still recommend Somnox to offer different breathing exercises that can be selected through the companion application. We can imagine that, as people become more comfortable with slow breathing, they might get bored with the exercise. As an example, we give headspace, one of currently's biggest meditation apps. The app provided guided breathing exercises. When we analyze its reviews, we see that many of its negative reviews are caused by the fact that the application lacks variety in exercise and becomes less attractive for experienced users. By providing a variety of exercises, we can maintain the interests of these experienced users.

Nonetheless, the Somnox Mini's emphasis should be maintained on slow breathing, and the other exercises should be moved to the 'background'. As mentioned before, the end-users are primarily interested in an effective solution for their problem. We do not want to bring confusion through an information overload by focusing on multiple breathing exercises. There should be a clear hierarchy in the exercises. We can achieve this by having slow breathing as the default exercise and emphasizing slow breathing in the user interface of the selection menu as shown in (figure 69)

Again we need to highlight that the aforementioned are concept recommendations—these need to be further validated through extensive user testing.

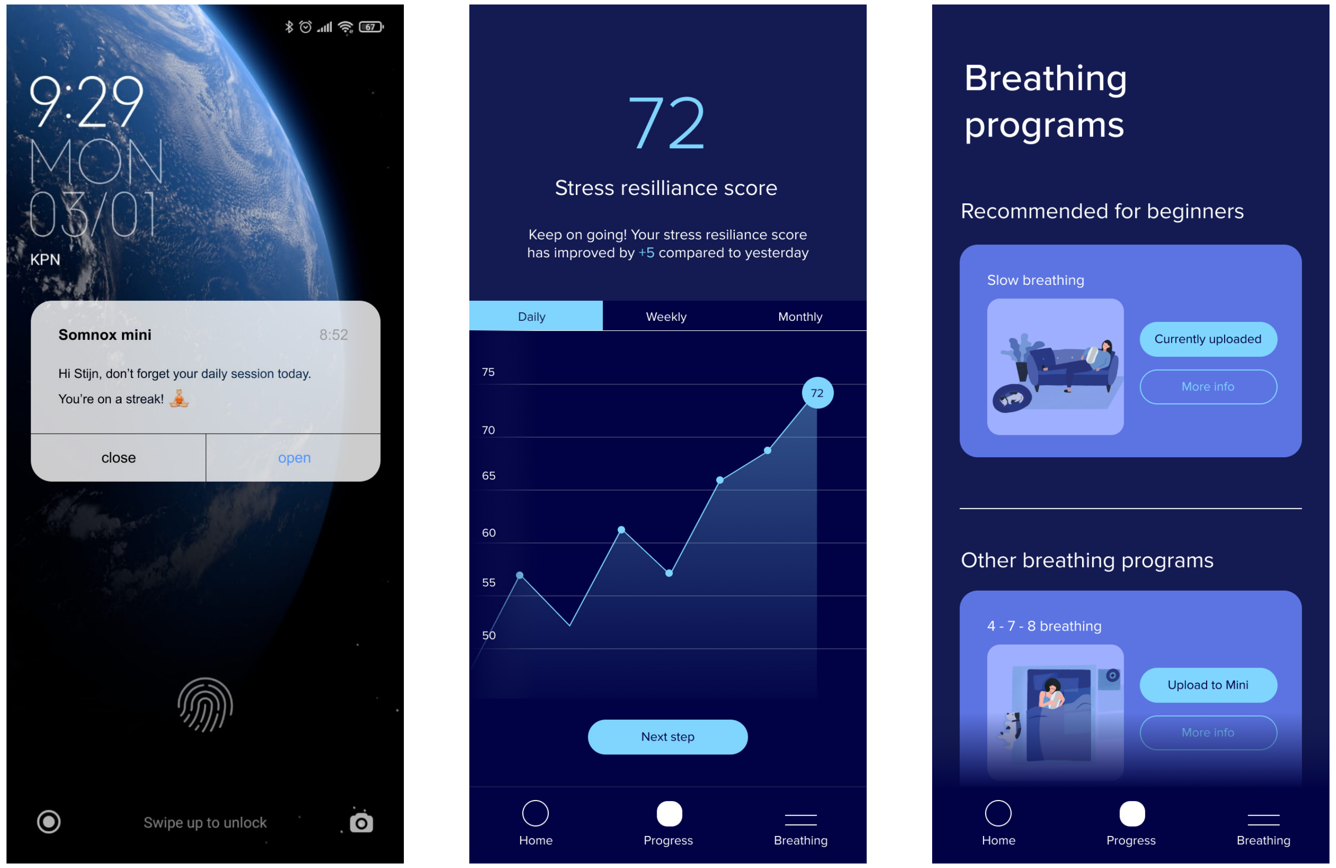


Figure 69 - An impression the user interface of the companion app

4.2 Market positioning

Stress is an increasing societal problem. As seen in the Dutch Government's statistics (CSB, 2018), stress has increased in the past decade. Especially with the uncertainties that the COVID pandemic had brought along, this is only expected to increase further.

Unfortunately, we see that the current medical systems, specifically in the Netherlands, are not keeping up with the increasing demand for professional help. This is reflected in the long waiting times of the GGZ (The Dutch mental healthcare system). At the same time, we also see that people take a more proactive attitude towards their health and take things into their own hands. For instance, we see that wearable technologies (such as health trackers) are expected to increase to a value of $60 billion in the coming years. Similarly, we see that the global alternative therapy market (including relaxation therapy) is expected to surpass $269 billion by 2027 (Vennare,2018)

The facts above show a great business opportunity for Somnox. Their medication-free products - based on scientifically proven methods to reduce stress - provide an effective alternative for the limited supply of professional help. We also have an increasing demand for these health innovations.

Somnox is not the only company that capitalizes on this business opportunity. In our competitor analysis, we have seen that there are many innovations on the market to improve well-being by reducing stress. Furthermore, we also see more and more competitors coming up in the form of new start-ups (e.g., Moonbird, Mindnap, breathe with B). Because this competitor landscape is growing, marketing and positioning become more critical to stand out above its competitors.

The question is: how do we market the product? To understand, we first need to understand the uniqueness of the Somnox Mini in relation to its competitors. The Somnox Mini is not the first biofeedback device. As we have seen in our competitor analysis, there are multiple already existing breathing guides with biofeedback.
What disguises the Somnox Mini from the rest is its companion-like qualities. As seen from our competitor analysis, most biofeedback devices appear to be very medical (e.g., EmWave2, RESPeRATE). Instead, we have masked a device with the effectiveness of a medical product into a companion-like object. Taking this companion as a metaphor during the design process has resulted in intuitive and familiar interactions. For example, most biofeedback devices use visual cues such as lights, showing data on the screen. Instead, we have used an intuitive metaphor, the heartbeat, to communicate this feedback.

Next to just acting as a feedback, we have also found that this heartbeat emphasizes feelings of relaxation and creates the feeling of safety, protection, and warmth, which other products do not have. This is a unique attribute of our concept and should be emphasized in Somnox's marketing strategy to stand out from its competitors.

Moreover, we should stress that we must communicate the Somnox Mini as a stress management device instead of a breathing regulation device. We have seen in our research that breathing exercises are strongly associated with spiritual and religious practices. As a result, people doubt the effectiveness of these exercises.

We aim to break these associations by showing the physiological impact of breathing exercises through biofeedback to its users. However, this is only applicable after the user has purchased the product. To even consider the purchasing product in the first place, we need to communicate in the marketing strategy that it is an effective and proven solution and break the associations to spiritual and religious practices.

4.3 The next step

The graduation project's goal was to bring the rough idea of a portable breathing regulation device into an advanced concept design. Through an iterative design process, we have specified the product functionalities and behavior. However, there are still many steps ahead before the concept is a manufacturable and marketable product. In this section, we discuss the most logical next steps for the Somnox Mini.

4.3.1 An additional iteration

I have done a total of 3 design iterations during this graduation project, which is all validated with user tests. Nevertheless, I still suggest Somnox to perform an additional user test and design iteration with a larger participant pool before starting the embodiment phase. The reason for this is that I did all the tests with a small number of participants. In total, we have tested with 8 different participants. Some participants were 'recycled' for each user test. As a result, the final proposed concept might have become biased towards this set of users.

Haptics is an essential aspect of our concept. Therefore, to assess the product, we required our participants to touch and physically experience our product. As a result, the tests had to be done in person. With the COVID-19 outbreak, I did not think it was responsible and did not feel comfortable to have contact with a large number of different people, which is why the user tests were done with a small group of people.

4.3.2 Embodiment design

If the concept does not significantly change after the additional user test, the next step would be to specify the design's technical aspects. This graduation project has mainly focused on finding a viable market and designing a concept with desirable functionalities and user experience. We have touched upon the critical technologies that it should contain; however, there are still a couple of essential areas that need to be investigated further.

4.3.2.1 Specifying the linear actuator

First of all, we need to dive deeper into the linear actuator. We have stated that a DC motor or Servo motor are viable options, however, we have not specified yet which one of the two is the best actuator for the Somnox Mini. To decide on this, prototypes need to be built and tested. Unfortunately, that was out of the scope for the graduation project.

One crucial point that needs to be considered when selecting the actuator is sound and vibration. In the final prototype, we found that the mini-servo we have used produced a high-pitched sound, which is not desirable for relaxation. The servo also had a lot of vibrations, which sometimes masked the heartbeat vibration. When looking into the linear actuator, we should make sure that these problems are addressed.

4.3.2.2 Influence of material on the vibration

Secondly, we need to look into our design's material properties since this has a significant impact on the heartbeat vibration perception. Although using the same vibration motor and identical strength values, I found that the heartbeat felt different across the three functional prototypes that we have built. I suspect that this is caused by the thickness of the material used across the prototypes. Prototype 2, for instance, had a wall thickness of 5mm, whereas the final prototype only had a wall thickness of 2mm. The vibration in prototype 2 felt much warmer, whereas the final prototype's vibration felt a lot harsher.

The call to action for Somnox would be to research the influence of the material (type, density, and thickness) on the vibration's feeling and test different prototypes with users to identify the most desirable feeling. However, the vibration should still meet the following requirements:

1. The vibration should contribute to relaxation
2. The vibration should not distract
3. The difference between the two heartbeat states should remain clear.

4.3.2.3 RSA detection

Lastly, Somnox needs to investigate how the system should analyze the data collected by the PPG sensor. For all our user tests, the detection of RSA was done manually. In the actual product, this detection is done by the back-end system of the product. The system can do this by checking whether the waveform has a frequency of 0.1 Hz. However, when we look at the HRV data from our user tests, we see that the data sometimes contain noise. The challenge is to find out how the system will deal with this noise and how it can distinguish noise and the user's actual HRV.

To conclude the project; The initial brief of the assignment was to turn the rough idea of a portable breathing device into an advanced concept design. We approached this by adopting an iterative approach in which we quickly ideated, built prototypes, and validated these with users. This approach has led to the final concept: the Somnox Mini. The Somnox Mini is a companion-like breathing device that teaches people how to perform slow breathing. Science has proven that slow breathing helps manage stress and reduce stress-related symptoms, including poor sleep.

Although the concept still needs more work to be manufacturable and marketable, I hope that the research and insights that I have provided in this graduation project are valuable to Somnox. I am grateful for the opportunity that Somnox has given me to apply my design and engineering expertise to contribute to its ambitious and beautiful mission to help 100 million people sleep better by 2030.

To end the report. I want to thank my supervisors Stijn Antonisse, Lye Goto, and Jacky Bourgeois, for their excellent guidance and engagement during the project. Your positive attitude made me feel confident about my process even during these challenging times of a pandemic. Finally, I would like to thank the whole Somnox team for always showing interest in the project and checking up with how I was doing. Even though we all worked remotely, you still made me feel part of the Somnox family. You are genuinely a pro-sports team!

Bryan Yip

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