Master Thesis

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F3

Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

User interface for a smart mouse pad designed to prevent carpal tunnel syndrome

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Supervisor: doc. Ing. Zdeněk Míkovec, Ph.D.
Field of study: Open Informatics
Subfield: Human-Computer Interaction
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ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Trejdl** Jméno: **Tomáš** Osobní číslo: **466813**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra počítačové grafiky a interakce**

Studijní program: **Otevřená informatika**

Specializace: **Interakce člověka s počítačem**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Uživatelské rozhraní chytré podložky pod myš pro prevenci syndromu karpálního tunelu

Název diplomové práce anglicky:

User interface for a smart mouse pad designed to prevent carpal tunnel syndrome

Pokyny pro vypracování:

Na základě předchozího návrhu chytré podložky pod myš, určené k prevenci syndromu karpálního tunelu při práci s počítačovou myší, navrhněte sadu kvalitativních experimentů, které ověří použitelnost návrhu chytré podložky pod myš a pomohou získat vhled do chování cílové skupiny. Aplikujte metodu formativní evaluace a UCD (User centered design). Zdokumentujte uživatelskou cestu. Na základě výsledků experimentů navrhněte vylepšení designu podložky a související aplikace pro komunikaci s uživatelem a konfiguraci systému, zaměřte se na zlepšení uživatelského prožitku. Navržená vylepšení implementujte ve formě prototypu. Návrh a implementaci průběžně vyhodnocujte s cílovou skupinou formou uživatelských testů.

Seznam doporučené literatury:

1. Elizabeth Goodman, Mike Kuniavsky and Andrea Moed: Observing the User Experience, Morgan Kaufmann, 2012.
2. Colin Ware: Information Visualization, perception for design, Morgan Kaufmann, 2004.
3. Bill Buxton: Sketching User Experiences, Morgan Kaufmann, 2007.
4. Miroslav Disman: Jak se vyrábí sociologická znalost: Příručka pro uživatele, Karolinum, 2002.

Jméno a pracoviště vedoucí(ho) diplomové práce:

doc. Ing. Zdeněk Míkovec, Ph.D. Katedra počítačové grafiky a interakce

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **14.08.2022** Termín odevzdání diplomové práce: ______________

Platnost zadání diplomové práce: **19.02.2024**

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prof. Mgr. Petr Páta, Ph.D.
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III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

.

Datum převzetí zadání

Podpis studenta

Acknowledgements

I would like to express my gratitude to my supervisor, doc. Ing. Zdeněk Míkovec, Ph.D., for his guidance, patience, and support throughout the course of this thesis. His insightful comments and suggestions were invaluable in shaping the direction of my experiments and improving the quality of my designs. I would also like to extend my thanks to my friends Vasil Kostin and Tom Kuna, whose contribution was vital in the conception of the idea that formed the foundation of my thesis. Lastly, I would like to thank my family and friends for their constant support and encouragement.

Declaration

I declare that the presented work has been developed independently and that I have cited all the literature used in the work.

23. May 2023

Abstract

This thesis is part of research that focuses on the problem of Carpal Tunnel Syndrome when working with a computer mouse. This thesis is concerned with the analysis of an existing smart mouse pad solution and the design of qualitative experiments that will evaluate the usability of the mouse pad design and help gain insight into the behavior of the target group. On the basis of the results of the experiments, the thesis further discusses the design improvements of the mouse pad design and the related application. The thesis proposes improvements and implements the proposed solution in the form of a prototype that includes both hardware and software components. This thesis concludes with the results of continuous testing with the target user group.

Keywords: smart mouse pad, mouse pad, mousepad, carpal tunnel syndrome

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Abstrakt

Tato diplomová práce je součástí výzkumu, který se zaměřuje na řešení problému Syndromu Karpálního Tunelu při práci s počítačovou myší. Tato práce se zabývá analýzou existujícího řešení chytré podložky pod myš a návrhem kvalitativních experimentů, které ověří použitelnost návrhu podložky pod myš a pomohou získat vhled do chování cílové skupiny. Na základě výsledků experimentů se práce dále zabývá návrhem vylepšení designu podložky a související aplikace. V rámci práce jsou navržena vylepšení a provedena implementace navrhovaného řešení v podobě prototypu, který zahrnuje jak hardwarovou, tak softwarovou část. V závěru práce jsou popsány výsledky kontinuálního testování s cílovou skupinou uživatelů.

Klíčová slova: chytrá podložka pod myš, podložka pod myš, syndrom karpílního tunelu

Překlad názvu: Uživatelské rozhraní chytré podložky pod myš pro prevenci syndromu karpálního tunelu

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Chapter 1

Introduction

My research on Carpal Tunnel Syndrome (CTS) in the use of a computer mouse was motivated by my previous work in this field and my personal experience with wrist pain while using the mouse. This thesis builds on previous research on CTS and focuses on designing a solution for computer mouse users with wrist pain.

This thesis is organized into several chapters. Chapter 2 is focused on gathering insights from real users through interviews. In chapter 3, I describe the process that led me to a solution to the problem, a Smart mouse pad. In chapter 4, you will read about creating interactive prototypes of the proposed design. Chapter 5 describes the process and findings of testing prototypes with real users in the lab and also under real world conditions.

1.1 Motivation

Nowadays, many professionals depend on the computer as their primary mode of income, with the mouse and keyboard being their primary interface with the computer. Their livelihood is dependent on their hands staying healthy and uninjured. The problem is that the exact way they make money is at the same time harmful to the health of their wrists. A meta-analysis of CTS studies from 2015 in the Journal of the Neurological Sciences suggests that excessive mouse use might be a minor occupational risk factor for CTS[SFH15].

> Carpal Tunnel Syndrome is caused by pressure on the median nerve. The carpal tunnel is a narrow passageway surrounded by bones and ligaments on the palm side of the hand. When the median nerve is compressed, symptoms can include numbness, tingling, and weakness in the hand and arm. The anatomy of the wrist, health problems, and possibly repetitive hand movements can contribute to carpal tunnel syndrome.[Sta22]

Other studies found that the prevalence of CTS to be 13.1% (95% CI 10.5–15.7%) among Computer professionals[AS06]. People with more than eight years of computer work and people who worked more than 12 hours a day were at increased risk of CTS compared to other office workers[AS06]. Another study on the effects of computer mouse design and task on carpal tunnel pressure indicates that professionals such as CAD operators or graphic artists who use the mouse extensively may be at higher risk of developing CTS or aggravating existing symptoms [KBR99].

In recent years, vertical mice, gel mouse pads, and similar products have been marketed by several companies as a remedy or preventive measure for CTS. This may be a marketing tool, as studies on the effects of vertical mice and gel mouse pads on CTS have been inconclusive [SKJC15]. They concluded that the use of these devices remains subject to the user's personal preference and do not endorse recommendations for users with CTS.

1.2 Goals

The main objective of this thesis is to take an existing design of a smart mouse pad and the accompanying desktop application, evaluate the design through user testing, and improve the areas where users struggle to understand the application or the application fails to deliver on the user's expectations.

The evaluation and validation of the preventive effects of using this device are not a part of this thesis. I am not an expert on Carpal Tunnel Syndrome, and I do not make any claims about how effectively our solution prevents Carpal Tunnel Syndrome. Evaluation with patients is ongoing as a separate project by my colleague Vasil Kostin at the Third Faculty of Medicine at Charles University.

My work on this thesis focuses on understanding the problems of people with wrist pains who use the computer mouse extensively. The focus is on the interaction between the user and our software and hardware.

My objectives in this thesis are:

- conduct user testing in lab conditions to find major usability issues
- conduct a qualitative study to gather feedback on the utility of this solution
- assess the user's motivation to exercise
- design and evaluate new ways to motivate users to exercise

Chapter 2
Analysis

This chapter explores the problems associated with the use of a computer mouse and Carpal Tunnel Syndrome. I first define the problem, then describe the starting point of my thesis work, which builds on a previous project at Charles University. Then I explore an existing solution to the defined problem and assess its effectiveness. Then I start my research with user interviews and finish the chapter with the description of use cases.

2.1 Problem definition

This section serves as a starting point and a definition of the problem at hand.

2.1.1 Ergonomics of human-computer interaction

Ergonomics is an important part of designing any product with which humans interact, especially when the interaction occurs very often or for long periods of time. Poor ergonomic design can negatively impact the health of a user.

> Ergonomics is an applied science that focuses on designing and arranging things people use so that people and things interact more efficiently and safely.[mer]

> An ergonomically friendly environment is essential within the workplace as it promotes higher staff morale, fewer absences amongst employees from the workplace due to pain felt from working on a computer and increased productivity, which ultimately increases profitability. [Qui]

Computer usage has been increasing since the computer's inception. But the interaction model has not changed significantly since the invention of the mouse in 1964[Int22]. There was only one other invention that amassed big popularity, the touchpad (also known as a trackpad), first used in a commercial laptop in 1982.

Of all the ways to interact with a computer system: keyboard only, keyboard + mouse, keyboard + touchpad, touch screen, voice control, gamepad, virtual reality controller, hand gestures, and eye tracking. Only the keyboard + mouse/touchpad is suitable for productive work with a Graphical User Interface that most modern operating systems use, where precision and speed are required.

2.1.2 Evolution of the human hand

Derived changes in the human wrist can be explained as adaptations to throwing and clubbing and subsequent use of tools. Throughout evolution, the human hand was never meant to stay in a single position for hours on end, as happens regularly when we use a computer with a mouse. We use our hands to operate a computer because of the precision and sense of touch that we developed in our fingers through evolution.

Carpal tunnel syndrome is a condition that develops exactly due to the lack of variation in hand movements. Repeated and monotonic movements of the wrist cause swelling and later pain. Carpal tunnel syndrome is common in different professions that use their hands to perform similar tasks throughout the day: forest workers, rock drillers, chainsaw workers, and electrical and automotive assembly workers.[Pal11]

2.2 Previous work

This project aims to design and develop a solution to prevent carpal tunnel syndrome. The focus is on people who spend most of their work time on a computer, using a computer mouse.

The idea of researching carpal tunnel syndrome arose at a hackathon in which I participated. The team I was part of noticed that some people around us had wrist pain and problems doing their work on the computer. So this would be an excellent topic for the hackathon competition, which was focused on technology helping in medicine.

Our team included two medicine students who researched the causes of CTS and how the use of a computer mouse could contribute to the development of this disease. We researched studies that focused on CTS and concluded the following:

1. One of the main causes of CTS is monotonic, repeated motions of the wrist

2. CTS is a preventable condition, and the easiest methods of prevention are:

    a. Take frequent breaks and change positions.

    b. Exercise the wrist to relieve pressure or swelling around the carpal tunnel.

3. A vertical mouse or a mouse pad with gel wrist support can decrease subjective pain, but there is not enough evidence to suggest it can prevent CTS.

4. With increased screen time every year and more jobs moving to the computer, more people will have wrist pain.

A study showed that intercarpal pressure was a good indicator of whether a person develops CTS. The problem with the intercarpal pressure is that it cannot be measured externally. So, we brainstormed options to approximate it with external sensors. We finally decided to embed low-profile pressure sensors into a mouse pad because it is not obtrusive and most people are familiar with mouse pads. The sensors would only detect the pressure that the user of the mouse pad applies in one direction. However, we concluded that this information would be sufficient to detect positions of the hand, which we know apply too much pressure on the carpal tunnel (for example, we can detect whether the elbow is supported by the table or armrest).

The idea was to detect the position of the user's hand and notify them through our desktop application that they should change their position or take a break from work. The break interval would be calculated on the basis of the time the user spent using the mouse and the pressure applied to the mouse pad.

During the hackathon, we developed a prototype of a desktop application that would be used to calibrate the pressure sensors and deliver notifications to the user. Later, we extended this application to provide data visualization, wrist exercise tutorials, and tracking.

2.3 Acknowledgements

In this section, I will describe the design decisions that led to the design of the mouse pad and the application, which will serve as a starting point for my thesis work. The inception of the idea and the project was a collaborative effort, so I do not claim that the work and decisions described in this section are only my own. I collaborated with my team (Vasil Kostin and Tom Kuna) at the Global Smart Health hackathon, where this idea originated. To read about my independent work, which is the main focus of this thesis, continue to Section 2.6, where I go into detail about the validation of the design and the following prototype iterations. I included this section to introduce you, the reader, to the problem and describe the design decisions that served as a starting point for my thesis work.

2.4 Why a smart mouse pad?

We set out to help people who work with a computer mouse and have wrist pain. They may not be diagnosed with any disease, but pain alone can hurt their productivity and, in general, make their daily life unpleasant or difficult.

More importantly, professionals such as industrial designers, architects CTS, 3D modelers, motion designers, and graphic designers depend on the mouse in their work. The software that they use every day to do their job was designed with the mouse in mind and is not ergonomic to use with alternative input devices such as touchpads, trackpads, or touch screens. For these professionals, carpal tunnel syndrome can be very serious because when they cannot use the mouse, they cannot work at all.

According to some studies, 1 in 10 computer mouse users will have Carpal tunnel syndrome sometime during their life. The good news is that this disease can be prevented. Several online sources suggest that people can reduce their risk of developing CTS by taking measures to prevent repetitive stress on their wrists. These measures include avoiding repetitive and monotonic wrist movements, taking breaks, changing hand/wrist positions, and exercising the wrist.

We set out to design an aid for people who experience pain when working with a mouse. Many companies have made many mouse redesigns throughout the years, some more ergonomic than others.

We decided not to redesign the mouse again and instead focus on helping people avoid pain when using it. Therefore, we focused on building a solution that could help users take preventive measures and develop healthy habits.

We needed a way to monitor how the user uses the mouse and give them recommendations based on their usage patterns. This monitoring device had to be:

- unobtrusive - must interfere with the user's workflow as little as possible
- simple - our team was capable of developing a prototype of it
- inexpensive - must be cheap enough to make so that users can afford it

Hence we arrived at the mouse pad as a perfect item, where we could place sensors that would monitor usage patterns, and be unobtrusive as most people are familiar with a mouse pad even if they don't use it themselves. The following challenge was to find suitable sensors that fit inside a thin mouse pad and give us the needed data.

From our previous research, we learned that increased pressure in the intercarpal tunnel is an indicator of CTS risk. Our approach was to monitor the pressure applied directly onto the mouse pad by the user's hand and compare it to a previously saved nominal pressure. The nominal pressure would be acquired during the initial setup of the device, where the user is instructed on the proper position of the seat and the position of the hand. A position that would minimize the intercarpal pressure.

> The average position of the wrist associated with the lowest pressure was 2 +/- 9 degrees of extension and 2 +/- 6 degrees of ulnar deviation. [WGB+95]

This means that the wrist should be in a position of natural extension of the forearm. This is a position that is best accomplished by supporting the elbow with the table or armrests.

2.5 Existing solutions

With the Internet becoming a significant source of medical information for the general population[BF15], we need to examine the solutions that appear in the top results of search engines. A quick Google search reveals a plethora of articles that offer methods and products to relieve wrist pain or prevent and treat Carpal Tunnel Syndrome.

I used the following keywords to obtain a general picture of what a person with wrist pain could find on the Internet. I used a VPN along with opening every search keyword in a new Incognito window in Chrome to avoid distorting the searches with search engine personalization: wrist pain, wrist pain from mouse, wrist, pain from keyboard, wrist pain from typing, wrist pain from computer, carpal tunnel syndrome from mouse, carpal tunnel from mouse, carpal tunnel syndrome prevention, carpal tunnel prevention, Can I get carpal tunnel syndrome from a mouse, Can I get carpal tunnel from a mouse, How to relieve wrist pain, How to relieve wrist pain from mouse, How to treat carpal tunnel, How to treat carpal tunnel syndrome.

The methods and products found can be divided into the following categories:

1. behavior change tips
    a. reduce your force and relax your grip
    b. take short, frequent breaks
    c. watch your form, improve your posture
    d. change your computer mouse
    e. keep your hands warm
2. aids, gadgets, and devices
    a. splints, supports, gloves, and bandages
    b. vertical and other non-standard shaped mice
    c. gel mouse pads
    d. wrist rests
    e. exercise aids
3. medication
    a. ointments against pain and inflammation
    b. drugs and homeopathics

2.5.1 Are the existing solutions solving the problem?

We are of the opinion that the current (at the time of writing in 2022) wrist pain and Carpal Tunnel Syndrome prevention offering is insufficiently solving the problem for the general population. For many of the products that claim to prevent or treat CTS, we were unable to find public research support for their method. The research comparing traditional and vertical mice did not yet provide a statistically significant result that one or the other is better in the sense of CTS prevention.

Taking into account that the time spent working with the computer has been increasing for the past 20 years (the COVID pandemic even increased it further) and that the mouse is still the most precise pointing device in our graphical user interface era, we do not see the mouse (or touchpad) being replaced any time soon.

We concluded that the existing space of CTS prevention and treatment products leaves room for improvement. Where we see that our team has the greatest impact is in the education of the users and providing them with data and feedback. We see our initial concept of a smart mouse pad that can detect how much the user strains their wrist while working with a mouse, continuously monitor and notify the user of improper hand positions or take a short break, as having the potential to fill in a void on the market. With the addition of wrist exercises that we developed together with physical therapists, we believe that we can help users of our product have a healthy wrist and stay productive on the computer.

2.6 Research and design process

Before diving into the main part of my research, I would like to briefly describe my research and design process. I am following the User-Centered Design (UCD) process [use23], which consists of conducting user interviews to learn user pains and needs. Use case and hierarchical task analysis will inform the features and architecture of the design. Sketching and wireframing will allow me to explore many different ideas and solutions. In Lo-Fi and Hi-Fi prototyping, I tested my designs with users through usability testing in the lab. I iterated and modified the design of Lo-Fi/Hi-Fi prototypes between tests to learn which solution best suits user needs and is usable. I implemented the core part of the prototype in code to perform user testing under real-world conditions and gain valuable feedback from users using the mouse pad and application at home or at work.

2.7 User interviews

Interviews are a crucial part of the design process as it is where I learned what the needs of potential users of my design are.

The purpose of this research is to find out how users use the computer mouse and how they deal with potential wrist pain problems. These insights will then be used to design devices to prevent carpal tunnel syndrome when working on a computer.

2.7.1 Research objectives and methods

The main objectives are to find out the daily habits or problems of users while working on a computer and to get ideas for possible solutions to wrist pain when working on the computer for long periods of time.

We will focus on exploratory User Research[GR], to deeply understand our target user group (qualitative research) and generate new ideas.

The main method for us will be semi-structured interviews. We will not ask users what they would like the pad to do, but we will ask them how they work at the computer, what tools they use, what their biggest problems are, etc. From these findings, we will then derive possible solutions to their problems, create prototypes, and test their usability with the target group (User testing).

2.7.2 Research questions

1. Do computer users know the risks associated with poor hand position when using a mouse?
2. Are people concerned about proper posture and hand position while working on a PC?
3. Do people know what the correct hand position is and follow it?
4. How do people deal with discomfort or pain when working on a computer for long periods of time?

2.7.3 Research sample

The number of participants in the research sample will be 15-20. This number should give us a sufficient sample. Only people who work on a PC for at least 4 hours a day and have or have had wrist pain while using a mouse will be represented in the sample. For the purposes of user research, participants do not need to have a diagnosis of Carpal Tunnel Syndrome. We are mainly interested in their personal experience working on a PC with wrist pain.

Participants in this part of the research will be recruited through friends, social media, and also through hospitals. Furthermore, we will use the snowball method (we will ask the participants for acquaintances who might be interested in participating in the research).

One possible bias is due to the location of the research (Prague, Czech Republic). Participants will be mainly Czech, so the lack of cultural spectrum will be reflected in the data obtained. The data from this research will not be generalizable to the whole population (also due to the small sample size). Another potential bias is the coronavirus pandemic (this part of the research is conducted in the spring of 2020). For this reason, user interviews will be conducted mainly by phone, and thus the conditions will be different from face-to-face meetings.

2.7.4 Screener

A screener is a questionnaire that is used to filter out irrelevant participants. Each question has a goal written next to it, i.e., the person must meet the goal to be included in the research.

1. How many hours a day do you work on a computer with a mouse? (Target: more than 4 hours per day)
2. Do you have or have you had wrist pain in the past while working with a mouse? (Target: Yes)
3. Age (Target: 18+)

2.7.5 Interview script

The interviews will be semi-structured, i.e. we will ask participants open-ended questions and ask for details. The following is a list of main topics and specific questions. See the Appendix A for the full interview script.

2.7.6 Analysis of in-depth interviews

Fourteen participants who worked more than 4 hours on a computer and had wrist pain from computer work or had a diagnosis of carpal tunnel syndrome were included in the interviews. The interviews were conducted online through Google Meet.

These interviews will give us a deeper insight into the way we work on the computer than a simple questionnaire. We will not quantify the responses, as we have too small a sample for that. If we see commonalities in the responses, we can draw hypotheses from these and then test these on a larger sample of people, for example, using an online questionnaire.

Insights

After finishing all interviews and analyzing the interview transcripts, I compiled the following list of insights that will serve as the basis for my design work.

- Participants only find information about occupational hygiene when they develop symptoms of wrist pain (although some do not find out even when in pain).
- Some students have never received training on proper sitting at a computer.

- Those who worked in companies mentioned OHS training for computer work, but most did not follow the recommended procedures and interventions before the onset of symptoms.
- Active work with mouse and keyboard is mostly done at the desk (for longer work, participants prefer sitting at the desk), on the couch/bed, it is mostly just passive consumption of content (videos, movies, series, reading, etc.).
- Those who use a vertical mouse report a subjective reduction in pain.
- Some participants use tapes or bandages, subjectively reducing pain.
- The participants mentioned an increase in pain with increasing stress.
- Participants in the home office arrange their workstations according to their comfort.
- Some participants did not have a chair with armrests.
- Participants who use a mouse pad with a cushion under the wrist mention that it helps them.
- Aids for exercising and exercising the wrists (rings, balls, squeezers, ...).

Risks to the project

During the interviews, I also encountered information provided by participants that I would consider a risk to the viability of the following design work.

- Will participants really be able to take breaks from work? Risk of biasing exercises/breaks compliance due to employer requirements.
  - Not being able to take a break at work = avoided by delaying the break by a few minutes.
- Participant's work hygiene setup will not meet conditions (90-degree angle etc., chair without arms - more likely to be high school students, participants working in a field using computers tended to have an office chair with armrests).
  - Possibility of taking pictures of the working environment.
  - Questioning the participant during the investigation.
- With alternating home office/office work, there is a risk that the participant forgets their pad at home or in the office.
  - Preventable - the participant will have 2 pads (capacity risk).
  - Notification of not forgetting the pad (risk of annoying notifications).

Recommendations

The following are some ideas that resulted from conversations with participants during interviews and might prove useful in later work.

- Think about whether study participants should use a conventional mouse or a vertical mouse (or put a switch in the application and measure pressure differently for vertical).
- Study design goal: compliance only (control group will have all interventions except pad) vs. comprehensive design (control group will not have those interventions as primary).
- Must do (obligation to comply with the exercises in the study).
- You should do it (exercise recommendations = measure compliance).
- Add the ability to take a break of one minute / 5 minutes to the app.

2.8 Target user

The potential user of our product is anyone who uses a computer mouse for extended periods of time. With the percentage of office workers using a computer jumping from 40% to 60% between 1995 and 2015[MSZ18], the diversity of these users is expected to increase as well. Hence, our design should be easy enough to understand so that less tech-savvy users can benefit from our app. But we also want to provide additional information and data for those users, who are really interested in it. The highest prevalence of CTS is in middle-aged patients (40 to 60 years) [SWH+12], so this will be our primary target user group. One of the goals of our product is also CTS prevention, so our secondary user group is between 15 and 40 years old.

2.9 Use cases

A use case is a description of a specific task or goal that a user wants to achieve while interacting with a product. In this section, I will describe four different use cases that I identified as covering the core of the solution's features.

2.9.1 Use case 1: Receiving a notification to exercise

Preconditions:

- The user has finished the initial setup of the application.
- The application is running on the system.
- The mouse pad is connected to the PC via USB.

Description:

The user is at work and doing their tasks as they are used to. The user is working with a mouse and a smart mouse pad. The application runs in the background. The application analyzes the load on the user's wrist based on the pressure data from the mouse pad. After about an hour of work, the application sends a notification to the user that they should take a break in the next five minutes, giving the user an opportunity to finish any tasks in progress. When the user finishes their tasks and clicks on the notification, they are presented with an animated walk-through of wrist exercises. They can pause the exercise if they need to or skip to the next. After two minutes of exercise, the break is over, and the user continues working as before.

Basic path:

1. The system sends a notification, saying that the user should take a break in the next 5 minutes.
2. The user finishes tasks in progress.
3. The user clicks on the notification or opens the app.
4. The system presents the user with an animated exercise walkthrough.
5. The user exercises their wrist following the on-screen tutorial.
6. The system ends the exercise after 2 minutes.
7. The user continues to work as before.

Alternative paths:

1. The user does not finish their work in progress within 5 minutes of receiving the notification.
2. The system presents the user with a window.
3. The user can decide to start the exercise, remind in another 5 minutes (to give time to finish the task in progress), or skip entirely.

2.9.2 Use case 2: Taking a break

Precondition: None

Description: The application will enable users to view exercise tutorials even without having the mouse pad connected or configured.

Basic path:

1. The user opens the application.
2. The user navigates to the Exercises page within the application.
3. The animated exercise walk-through starts automatically.
4. The user proceeds to exercise their wrist.
5. The user can pause the exercise at any time, read additional text descriptions of the exercise, or skip to the next exercise.

2.9.3 Use case 3: Learning about exercising habits

Preconditions:

- The user has finished the initial setup of the application.
- The application is running on the system.
- The mouse pad is connected to the PC via USB.
- The user has used their computer for a couple of days.

Description: The application provides the user with historical data on their use of the mouse pad. Data include hours spent working on the computer, average pressure on the mouse pad, and the number of exercises completed and skipped.

Basic path:

1. The user opens the application.
2. The user navigates to the History page within the application.
3. The system presents aggregated data from the past month of usage.
4. The user can browse the data by month and open details for each day.

2.9.4 Use case 4: Check my posture

Preconditions:

- The user has finished the initial setup of the application.
- The application is running on the system.
- The mouse pad is connected to the PC via USB.

Description: The objective is to educate the user about proper sitting posture and hand position while working on the computer and using a mouse.

Basic path:

1. The user opens the application.
2. The user navigates to the Visualize pressure page within the application.
3. The system presents the user with a real-time graph of the pressure applied to the mouse pad.
4. The user changes their hand position and checks the pressure plot.
5. The user can read about what values are optimal and what to do in order to position their hand to decrease the pressure below a safe limit.

Chapter 3

Design

The results of the user interviews led us to advance the creation of a smart mouse pad equipped with sensors and a desktop application. A key finding was prioritizing user education regarding appropriate posture and hand placement during computer usage. This education will be integrated into the application through the onboarding process, tutorials for wrist exercises, and informative hints that are readily accessible throughout the interface for the user to review at their leisure.

Another topic we wanted to address is the personalization of the tips. In our interviews, the user's work environment and their peripheral devices varied significantly, so generic tips might not apply to every user and decrease their confidence in the application. So we decided to address this by asking the user about their desk and chair setup and mouse type when setting up the application and only showing them tips relevant to their setup.

3.1 Design requirements

Before jumping into the design, we compiled a mind map of features that our solution should provide to users, some functional, some non-functional. These features emerged from previous interviews and current standards for consumer devices interfacing with computers.

3.2 Managing compliance

The user is an unpredictable variable in the product's success. In the initial stages of development, we were concerned about compliance with the use of the product. By compliance, I mean the fact that the user won't ignore the app's notifications and that the user will actually perform the exercises. That is crucial to the effectiveness of the product in relieving wrist pain and potentially preventing carpal tunnel syndrome as well.

Convincing users to devote 4-10 minutes to wrist exercise every day is hard, especially when the user experiences no symptoms of pain. However, there are examples of such solutions that managed to do this. As an example of behavior change, let us look at toothpaste[Smi09]. Although brushing our teeth with a toothbrush is sufficient to remove plaque, marketers in the 1900s came up with flavored toothpaste to increase the percentage of people who brushed their teeth. The main benefit of toothpaste was the feeling of fresh breath; that was the reward that motivated people to brush their teeth every day.

The notion of rewards comes from the Hooked model, as presented by Nir Eyal in his book Hooked.

> Users Take Action Based On Anticipation of a Reward.[EH19]

> "The Hooked Model provides companies with a process for connecting a user's problem to their own product or solution in a way that can form a habit. The model has four phases: (1) trigger, (2) action, (3) variable reward, and (4) investment." [EH19]

3.2.1 Gamification

According to our tests, users who do not have immediate wrist pain are not very motivated to use the application and do not follow the exercises provided. We believe prevention is essential and that promoting compliance to help users build a habit of taking breaks and exercising their wrists is a worthwhile direction to take our product.

> "Gamification" is an informal umbrella term for using video game elements in non-gaming systems to improve user experience (UX) and user engagement. [DSN+11]

Gamification aims to make non-game activities more engaging and motivating by incorporating elements and principles of game design. Gamification seeks to tap into people's natural desires for competition, achievement, and social interaction and to use these desires to drive behavior change and improve user engagement. By incorporating game design elements such as points, levels, badges, leaderboards, and challenges into non-game activities, gamification can make these activities more fun, rewarding, and meaningful for users.

We will take inspiration from existing applications that successfully help users build habits, such as Duolingo, Headspace Strava, FitifyForest, and Sleeptown.

Duolingo

Duolingo is a mobile application for learning languages. It focuses on vocabulary and pronunciation, starting from absolute basics. Duolingo combines a

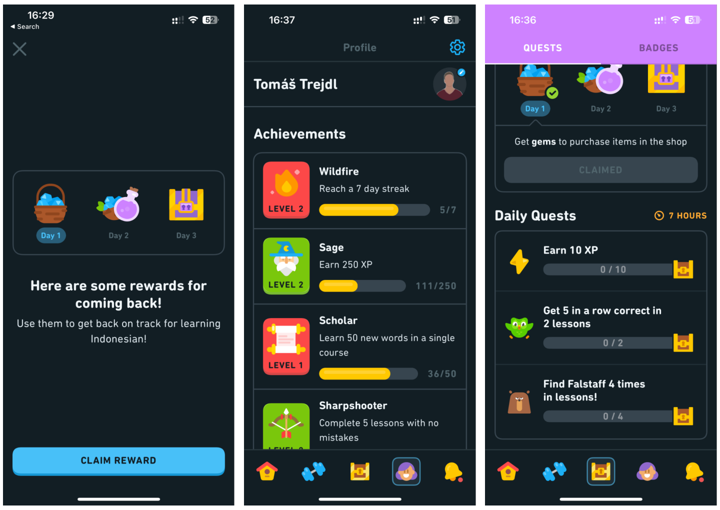


Figure 3.1: Screenshots from the Duolingo iOS application

learn-by-doing approach with personalization. Duolingo offers more than 40 languages, Spanish and French being the most popular.

The unique proposition of Duolingo over other language learning apps is its quick lessons, which only take a few minutes per day, and its many gamification features, which are designed to keep users engaged and coming back to the app, eventually building a habit of learning every day.

Gamification techniques used by Duolingo are achievements, quests, badges, streaks, leaderboards, and sharing with friends and family (see Figure 3.1).

Headspace

Headspace is a meditation and mindfulness app. It provides guided meditations of various lengths, from one minute to over an hour. Headspace provides thematic meditations for sleeping, relaxing or reducing anxiety and stress.

The gamification techniques used by Headspace are daily reminders, progress tracking, streaks, and challenges (see figure 3.2).

Strava

Strava is a sports tracking application that allows anyone to track their workouts on their phone. Strava also provides social features such as posting a workout to the user's profile and sharing it with friends, who can react and comment on the post. Strava offers tracking for more than 50 different sports, including running, cycling, hiking, skiing, weight training, and more.

Gamification techniques used by Strava are progress tracking, badges, challenges, leaderboards, and sharing with friends and family (see Figure 3.3).

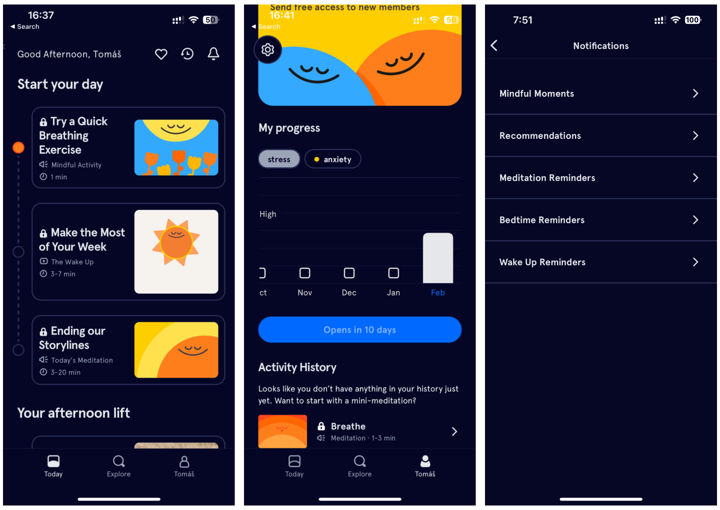


Figure 3.2: Screenshots from the Headspace iOS application

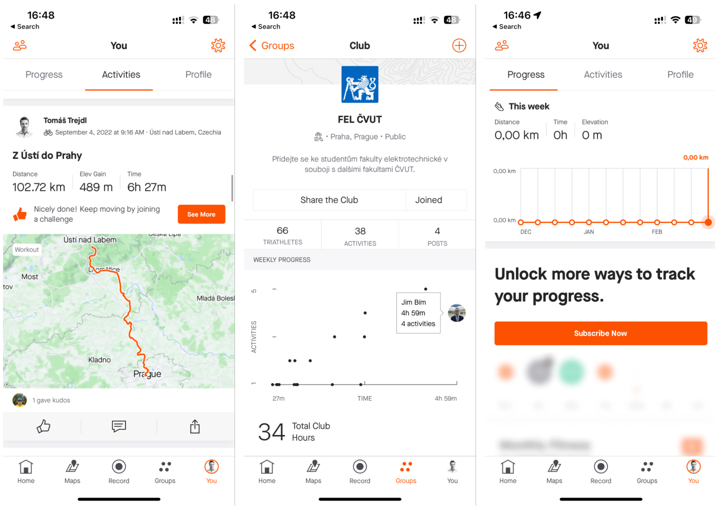


Figure 3.3: Screenshots from the Strava iOS application

Fitify

Fitify is a personalized workout app. It provides customized workouts based on user preferences, available equipment, and time. Fitify encourages users to exercise daily, if only for a few minutes. You can find pre-planned workouts for different muscle groups or general full-body and cardio workouts. Fitify also helps people lose weight with personalized workouts and healthy recipes.

The gamification techniques used by Fitify are daily reminders, progress tracking, and achievements (see figure 3.4).

Forest and Sleeptown

Forest is an application that helps with phone addiction. Sleeptown is an application that helps you build healthy sleeping habits. A single team

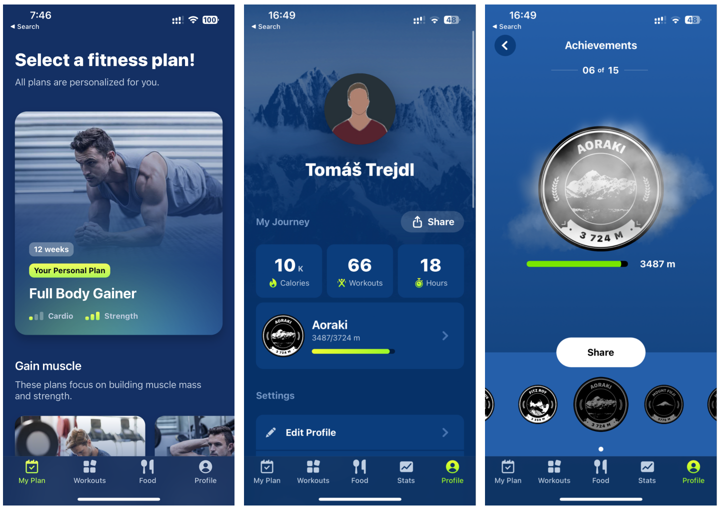


Figure 3.4: Screenshots from the Fitify iOS application

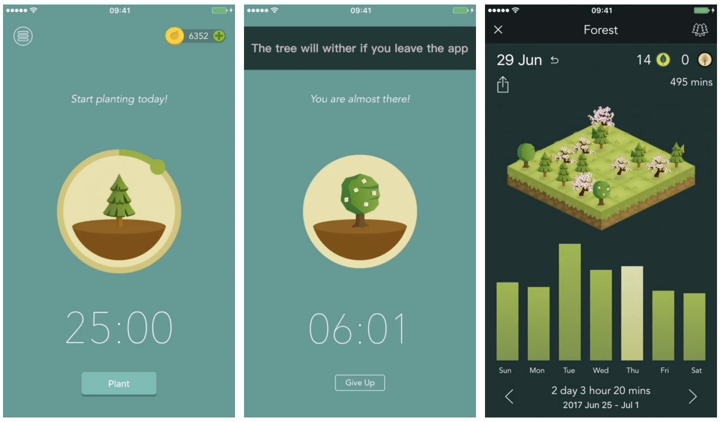


Figure 3.5: Screenshots from the Forest iOS application

develops them, and both utilize a cognitive bias known as the Sunk Cost Fallacy. By growing virtual trees and building virtual houses, the user sees the amount of time they invested in the app, and they do not want to see their trees die or their buildings fall.

> The Sunk Cost Fallacy describes our tendency to follow through on an endeavor if we have invested time, effort, or money into it, whether or not the current costs outweigh the benefits. [Lab]

The gamification techniques used by Forest and Sleeptown are daily reminders, progress tracking, achievements, and a shared experience with friends (see Figure 3.5).

Feature name	Duolingo	Headspace	Strava	Fitify	Forest
Achievements	✓			✓	✓
Quests	✓				
Badges	✓		✓		
Streaks	✓	✓			
Challenges		✓	✓		
Daily reminders		✓		✓	✓
Progress tracking		✓	✓	✓	✓
Leaderboards	✓		✓		
Sharing with friends	✓		✓		✓

Table 3.1: Gamification features comparison table

3.2.2 Comparison

Table 3.1 shows a summary of the gamification features identified in the analyzed applications. The most common features are Achievements, Daily reminders, Progress tracking, and Sharing with friends. I will try to implement them in my solution as well. Of all the examples above, I selected Daily reminders and Progress tracking to implement first, as they fit what I discovered during the analysis: People only begin to care for CTS when they develop symptoms, so advising them daily to exercise and maintain good posture will be a useful reminder.

Taking inspiration from Duolingo, Headspace, Strava, and Fitify, many of their techniques that promote users to come back to the application and build a habit also apply to our app.

- Daily reminders
- Progress tracking
- Streaks
- Social - leaderboards, sharing with coworkers encouragements and badges

Building on top of that, other motivational techniques worth exploring are:

- Virtual trainer - the application will provide feedback to the user in the form of programmatically synthesized text that summarizes the user's achievements and offers tips, similar to how a real exercise trainer or coach would do it.

3.3 Storyboards

Storyboards are used to communicate how we envision our users using the finished application.

Figure 3.6: Storyboard showing a person using the application

3.4 Hardware design

The development of the smart mouse pad hardware was a crucial aspect of the overall project, as the hardware represented the physical interface between the user and the accompanying desktop application. The hardware had to meet specific requirements to ensure that it was both functional and ergonomic for the user. This chapter outlines the desired features and reasons for the selected design of the smart mouse pad hardware.

3.4.1 Desired Features

The following are the desired features of the smart mouse pad:

- Ergonomic design to promote good posture and hand position while using the computer.
- Smooth surface to allow the mouse to glide easily.
- Durable construction to withstand everyday use.
- Low profile to maintain a clean and uncluttered workspace.
- Compatibility with a variety of computer setups and mouse types.

3.4.2 Selected Design

Based on the desired features, the following design was selected for the hardware of the smart mouse pad:

- Height: The maximum height of the mouse pad was set at 1.4 cm to keep the workspace uncluttered and maintain a low profile.
- Curve: The front of the mouse pad was designed with a slight curve for improved comfort and to promote good hand positioning.
- Surface: The top of the mouse pad is made of a soft fabric that is soft to the touch and allows the mouse to glide smoothly. This surface was selected for its durability and compatibility with a variety of types of mice.

Figure 3.7: Mouse pad design evolution: Pencil sketch, version 2, final version

Figure 3.8: Mouse pad prototype in a home office setting

The overall dimensions of the mouse pad were primarily dictated by the chosen manufacturing process, which was 3D printing and our access to 3D printers. We used the dimensions of the Original Prusa i3 printer bed (250 x 210 mm) as it was the most widely available in Czechia at that time. Our first testers expressed interest in a larger footprint mouse pad, especially for gaming, so we focused on parametric design so that we could make larger versions in the future.

We built and printed the first version of the mouse pad at the hackathon and assembled a second version with more fit and finish shortly after. At a height of almost 20 millimeters, this version was uncomfortable to use due to the height difference between both hands, one placed on the table and the other on the mouse pad. But what this prototype provided us was validation that we could read the data from the sensors in the mouse pad.

3.5 Application design

The desktop application is designed to reinforce one of the main goals of the product, the education aspect. The main functions are to guide the user through the device's setup when they first unbox it, provide tips on desk and chair setup, and educate them on proper sitting positions while working.

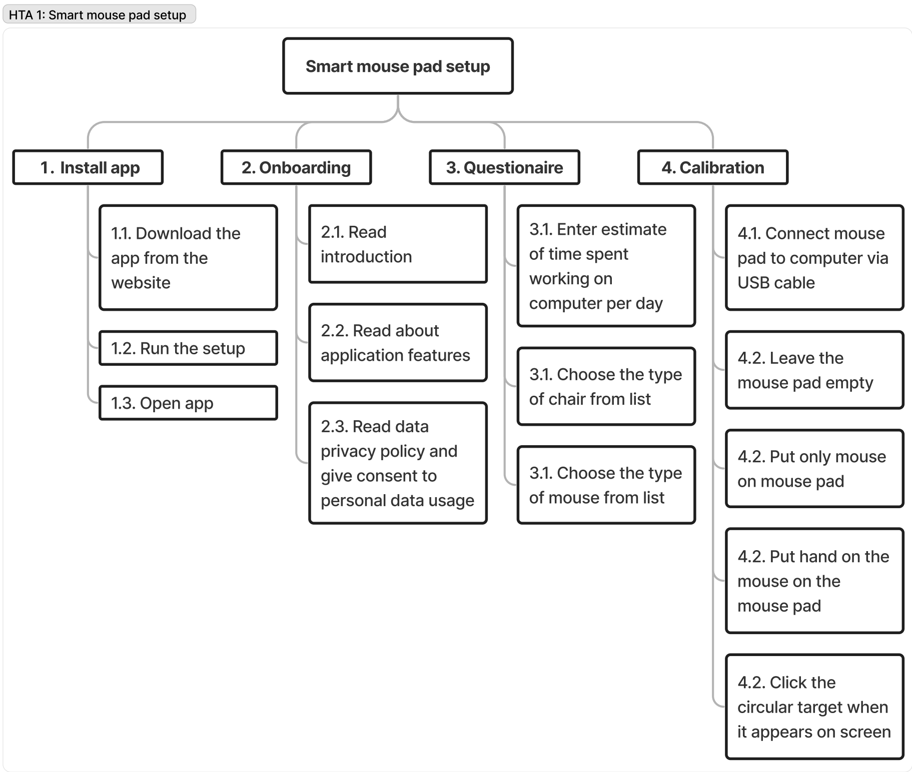


Figure 3.9: Hierarchical Task Analysis Diagram

The part of the application that the user will interact with the most is the exercise walk-through, which teaches the user how to perform pain-relieving wrist exercises through an animated character. When describing exercises, I am talking about a sequence of moves designed to relieve pain that the user performs during a break. A break is the act of the user not working on the computer for a small amount of time. Taking a break from work means not using the computer at all during the break time.

A critical part of the application is also the onboarding (also known as initial setup or initial calibration), which is a sequence of steps that the user needs to perform when they first run the application in order to learn how the application works. The user needs to perform actions to calibrate the sensors of the mouse pad to provide accurate feedback.

3.5.1 Hierarchical Task Analysis

Hierarchical Task Analysis (HTA) is a method to analyze sequences of tasks and break them down into smaller subtasks. The HTA diagram in figure 3.9 shows the deconstruction of the onboarding experience/flow.

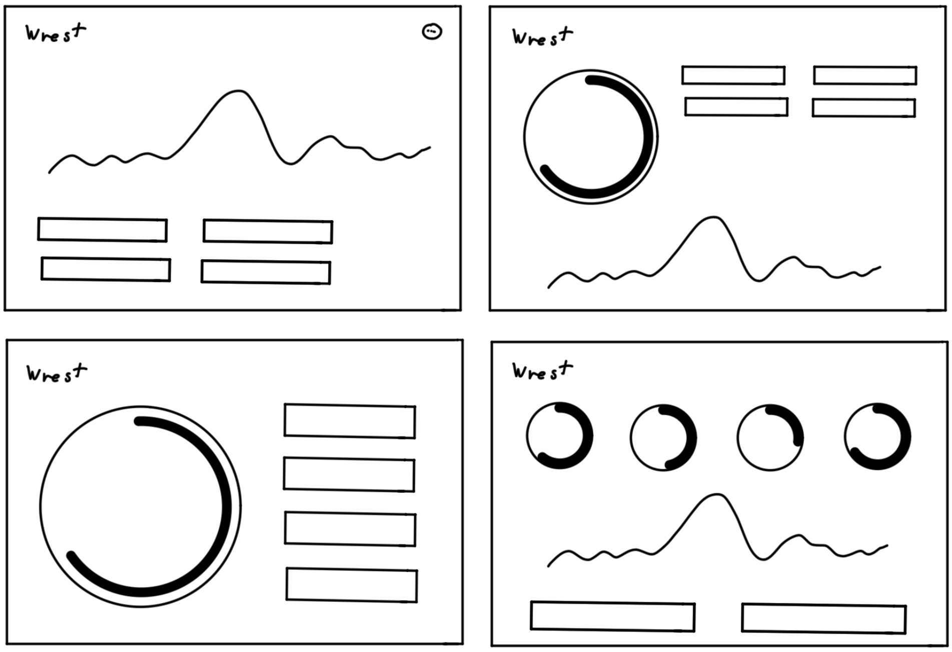


Figure 3.10: Sketching the application UI

3.5.2 Sketching

Before building digital prototypes, I first started with hand-drawn sketches of possible user interface layouts. Quickly drawing many different variants of information to display (see Figure 3.10) helped me explore and generate new ideas without investing too much time or effort into creating highly polished artifacts.

3.5.3 Lo-Fi prototyping

Low Fidelity (Lo-Fi) prototyping is a technique used in the early stages of the design process to quickly and inexpensively test and refine design ideas. These Lo-Fi prototypes (see figure 3.11 served as a stepping stone from sketches to finished Hi-Fi prototypes and helped me investigate multiple solutions without the extra work associated with creating a polished Hi-Fi prototype.

3.6 Documenting the user flows

Documentation of user flow in the form of user flow diagrams is helpful for communication in a team to track changes between versions and developer hand-off.

Onboarding (see Figure C.2)is a set of screens that every new user should go through and learn about how the application works and what its main features are. Calibration is a set of tasks that every new user must perform in

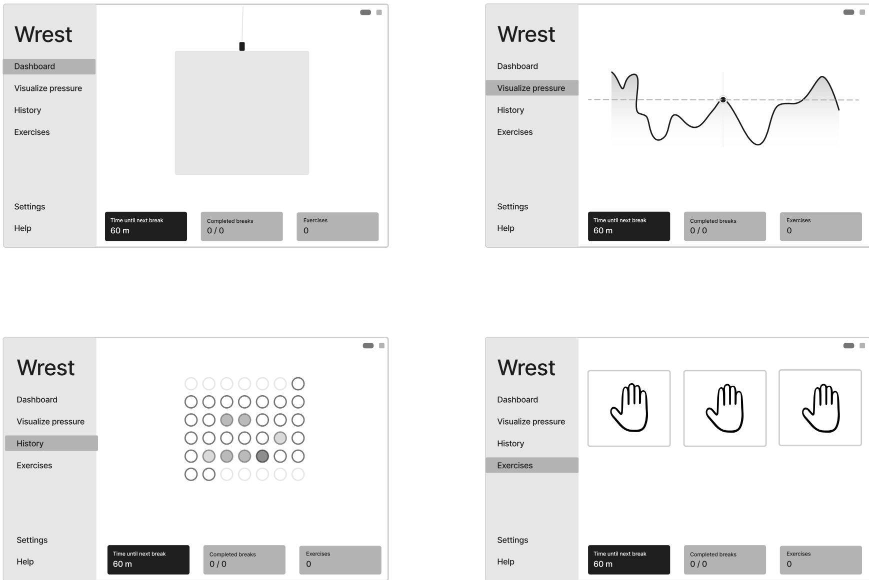


Figure 3.11: Lo-Fi prototypes

order to obtain the relevant information from the application. The application guides the user through these steps using visuals.

The exercise flow (see Figure C.1) is triggered every time the user clicks on a notification or starts an exercise from the Exercises screen. The goal is to walk the user through learning and doing new exercises correctly. The user can exit the training at any step.

3.7 Additional feature proposals

These features are proposed as Figma prototypes but have not been implemented in code and have not been validated with users during at-home testing.

3.7.1 Virtual trainer

The virtual trainer is a feature designed to motivate users to continue using the application and exercising their wrists regularly (see figure 3.12). The trainer provides statistical data about the user's compliance with the exercises and gathers feedback from the user on the following:

- Subjective pain levels.
- How entertaining the exercises are.
- What are the reasons why the user keeps returning to the application / does not return so frequently?

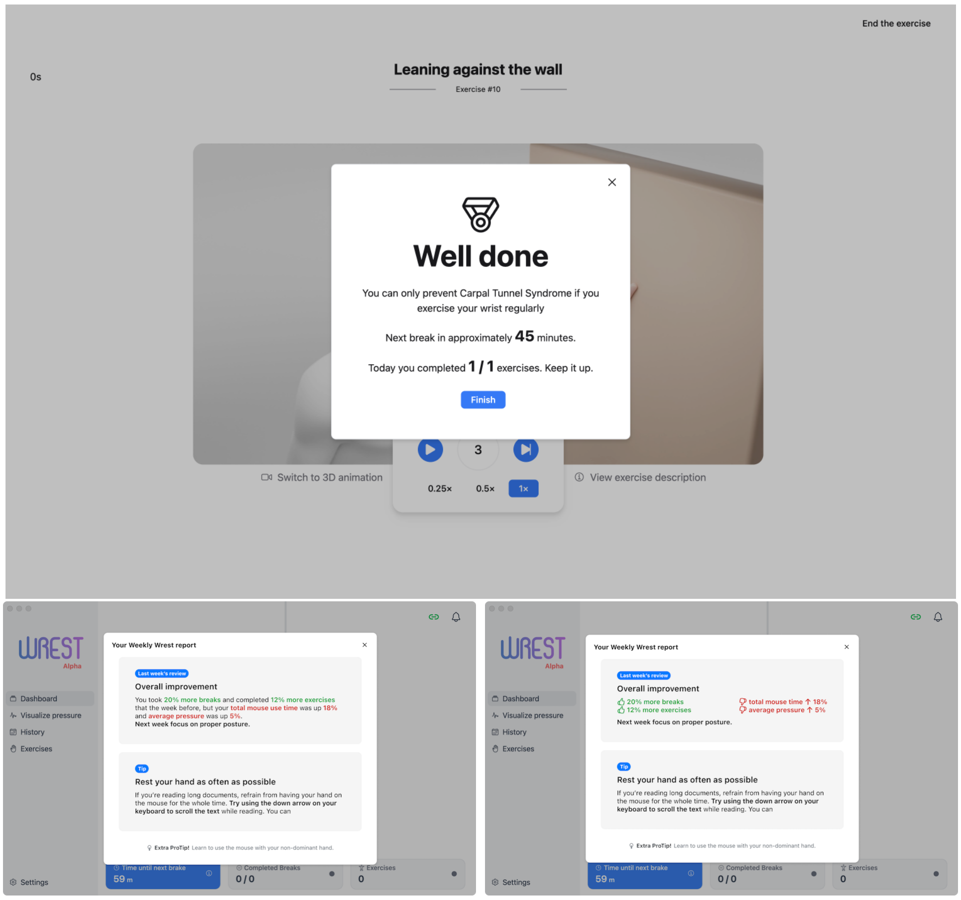


Figure 3.12: Screen designs for trainer feature

The trainer combines this information to provide a personalized motivational quote. The quote was synthesized from data from previous weeks of usage.

3.7.2 Educating users on proper posture and more

We also introduce short messages, ProTips, that deliver actionable information to improve the user's daily habits (see Figure 3.13). ProTips are sprinkled around the application and are present in many user flows. They are placed at locations where the user will notice them, but so that they do not clash with the primary goal of the flow. Visually, ProTips are muted compared to other text.

ProTip Examples

- ProTip! Learn to use the mouse with your non-dominant hand.
- ProTip! Use keyboard shortcuts like cmd + T to open new tabs and cmd + W to close tabs.

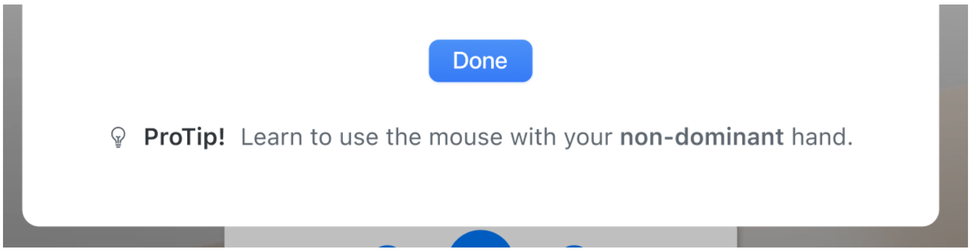


Figure 3.13: Screen designs for ProTips feature

- ProTip! Open apps and websites using Spotlight (cmd + space) instead of finding them with the mouse.
- ProTip! Use the home, end, pageUp, and pageDown keys to navigate text documents instead of your mouse. On laptops, you can use these by holding the cmd and using the arrow keys.
- ProTip! Use the home, end, pageUp, and pageDown keys to navigate text documents instead of your mouse.
- ProTip! Turn off notifications temporarily by right-clicking on the hand icon in your system menu bar and selecting Do not Disturb.
- ProTip! If you are receiving notifications too often or not often enough, recalibrate the mousepad in Settings > Recalibrate.

3.7.3 Streaks

Streaks are a way to show how many consecutive days the user has completed a goal, in our case, finished at least one exercise within the application (see Figure 3.14). Because the application is used primarily in a work environment, it would not make sense to strictly present the number of consecutive days because most users would lose their streak at the beginning of every weekend. Instead, we will provide a week-based streak, which ignores weekends and holidays, and keeps the streak going to motivate users to continue exercising.

The current streak length is visible on the dashboard, and milestones, such as a new week, are presented with notifications and pop-up modal windows. Pop-up modals appear only after just finishing an exercise, so as not to disturb the user at other times.

3.7.4 Leaderboards

A leaderboard shows the user's closest colleagues from the same office if they also use the smart mouse pad and have registered an account (see Figure 3.15). Leaderboards are a great way to promote positive competition between colleagues and motivate them to exercise more.

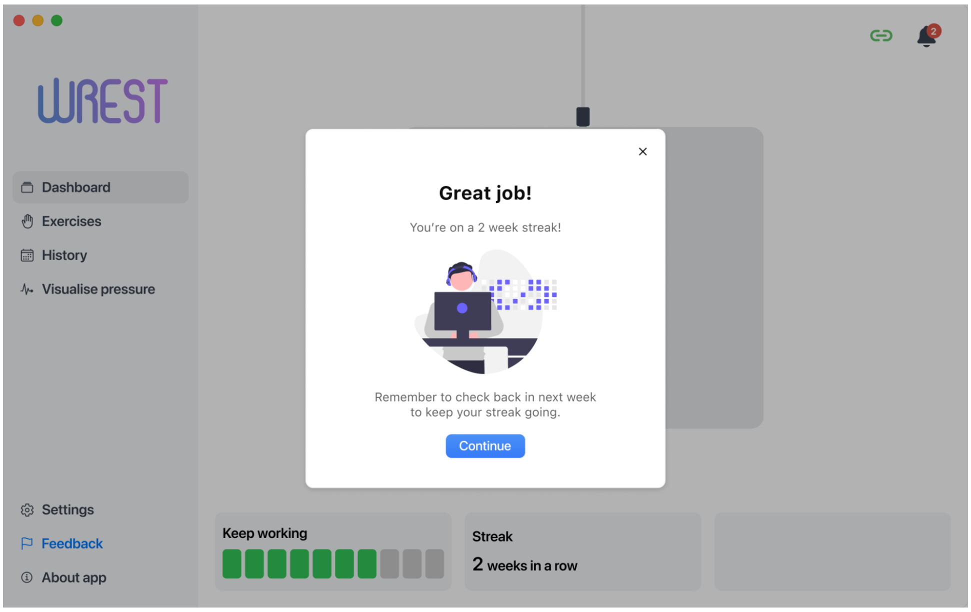


Figure 3.14: Screen designs for streaks feature

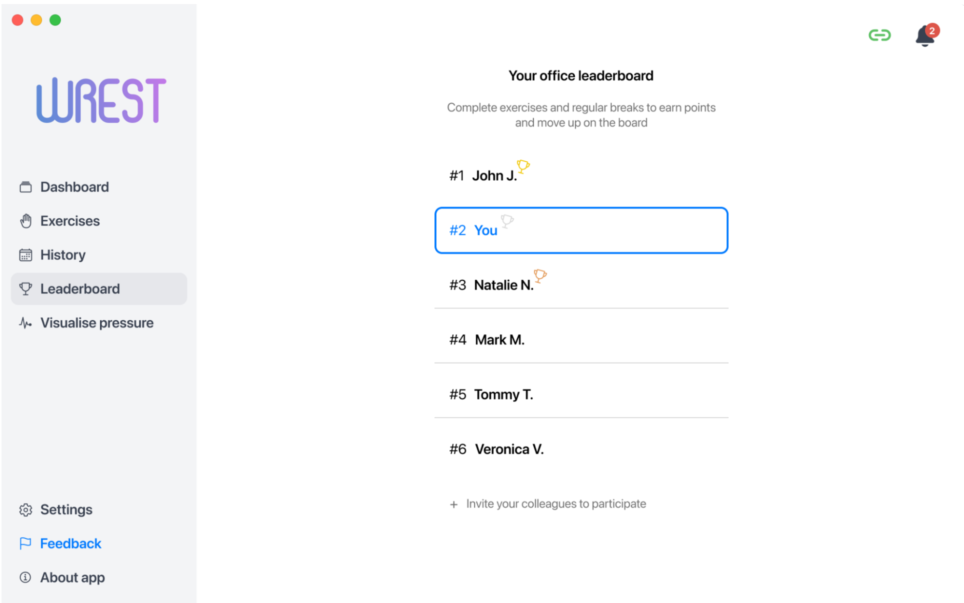


Figure 3.15: Screen designs for leaderboards feature

Chapter 4

Implementation

This chapter describes the implementation of the Hi-Fi prototype that was created following the Lo-Fi prototypes. This chapter does not go into detail concerning the code and algorithms used, as it is not a goal of this thesis. The Hi-Fi prototype's purpose was to evaluate the solution in real-world conditions with users using the application in their day-to-day life. That is why I implemented this prototype in code.

Although this prototype version is a fully functioning application, it is not ready for production deployment. The prototype can later serve as a specification for the final implementation.

This prototype version consists of two parts: the physical mouse pad device and a working desktop application.

4.1 Technologies

From interviews conducted at the beginning of the research phase, I knew that people from the target audience use Windows and macOS as their primary operating systems. For the solution to cater to a broader audience, I chose to implement the prototype with Electron.js, which is a cross-platform development environment that enabled me to build a desktop application with web technologies (HTML, CSS, and JavaScript/TypeScript) and run on all major desktop operating systems.

For the implementation of the user interface, I selected the Vue.js framework as it integrates well with Electron.js thanks to community plugins. To quickly and easily adjust the user interface, I opted for TailwindCSS. This popular utility-first CSS framework makes changes easy and is robust enough for production deployment. I also used other libraries, such as SerialPort.io, to interface with the underlying operating system and USB drivers from JavaScript.

4.2 Architecture

The application code is structured into two packages, resulting in 2 separate processes at run-time. The primary Node.js process runs in the background, handles communication with the mousepad, and analyzes the data for events. The second process handles the user interface of the application itself and runs only when the application is open.

Events are sent between the two processes using the Electron.js interprocess communication protocol.

Users can invoke the application window from the operating system's taskbar or menu bar. The primary Node.js process can also open the application window to display a full-screen notification to the user when the algorithm detects that the user should take a break from work.

4.3 User Interface

The User Interface (UI) of this Hi-Fi prototype has changed dramatically between the first user testing and the final version. Changes and updates are described in more detail in section 5.1.8 of chapter 5.

The application UI is divided into a sidebar and a main content area. The sidebar is permanent and common for most other screens. It contains the logo of the application and the navigation menu. The main screens available from this menu are Dashboard, Visualize pressure, History, Exercises, Settings, Feedback, and the About page. The content of the most important screens is described in more detail in the following paragraphs.

The Dashboard screen (see Figure 4.1) is the default screen that the user is presented with each time they open the application. The Dashboard's goal is to present relevant data in a visual way that is self-explanatory and can just be glanced at. In the middle of the screen is a visualization of the mousepad that displays the current pressure applied with green color signaling normal pressure and orange and red signaling pressure that is too high. In the updated version of the design, I also added the image of a mouse to signal to the user when the application is correctly detecting it. The Dashboard also contains a visualization of when the next notification for a break is going to come. In the first version, this was done by showing a number of minutes that our algorithm predicted based on the pressure applied to the mousepad by the user's hand over time, and based on user feedback, we later changed it to a bar which just shows the approximate time until next break. I also added an indicator to the top right corner of the screen to signal whether the mouse pad is connected via USB. The indicator turns red when there is a problem with the connection.

The History screen (see Figure 4.2) shows the user a calendar view with the circles around dates visualizing how many exercises and/or breaks has the user completed that day.

The Exercises screen (see Figure 4.3) displays a grid of all the available exercise animations. The animations are playing in a continuous loop. Next, the Exercise detail screen (see Figure 4.4), which opens after clicking any of the preview animations on the Exercises screen, shows a detailed walkthrough of the exercise. Controls under the animation enable the user to pause the slow down the animation to examine the proper technique. The same is available on the Exercise walkthrough screen (see Figure 4.5), with the difference that the sidebar is hidden and this screen is always displayed in full-screen mode to minimize distractions while the user is exercising.

For all high-resolution designs (including versions updated after testing), see Appendix B.

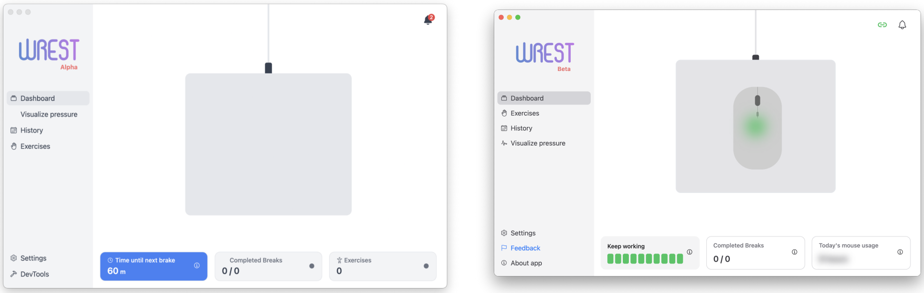


Figure 4.1: Comparison between first (left) and last (right) versions of the Hi-Fi prototype Dashboard screen designs

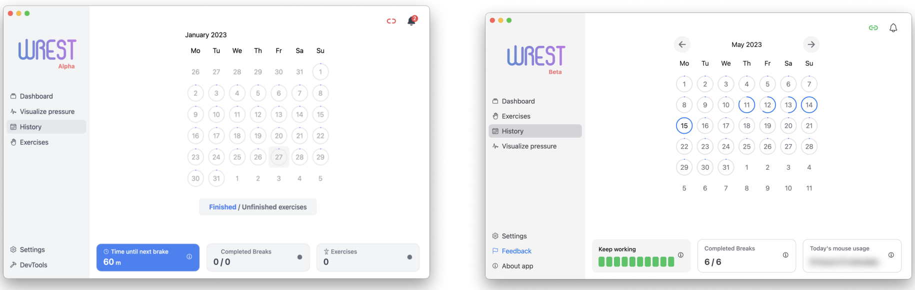


Figure 4.2: Comparison between first (left) and last (right) versions of the Hi-Fi prototype History screen designs

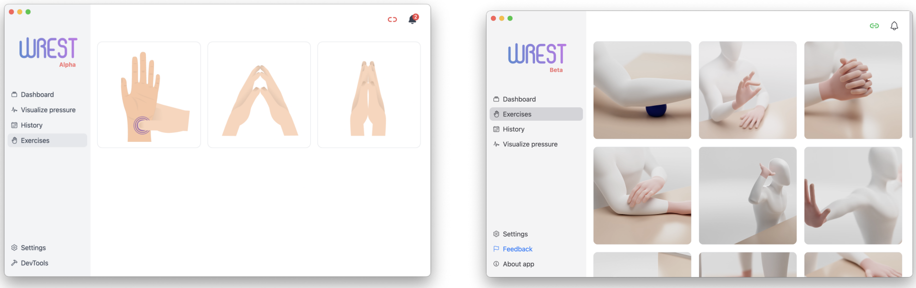


Figure 4.3: Comparison between first (left) and last (right) versions of the Hi-Fi prototype Exercises screen designs

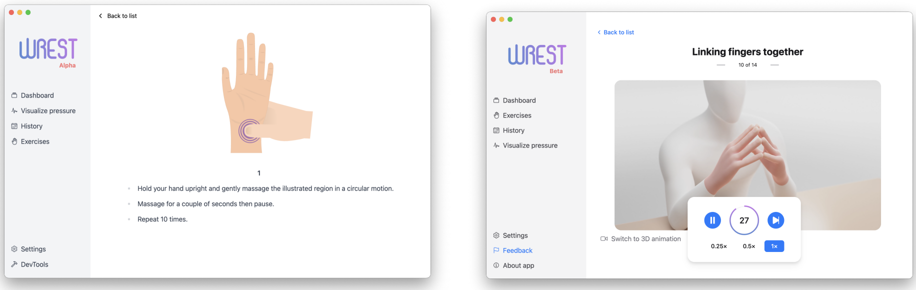


Figure 4.4: Comparison between first (left) and last (right) versions of the Hi-Fi prototype Exercise Detail screen designs

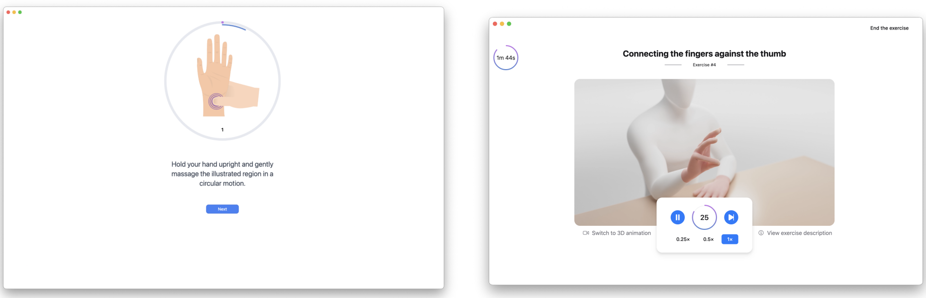


Figure 4.5: Comparison between first (left) and last (right) versions of the Hi-Fi prototype Exercise walkthrough screen designs

Chapter 5
Evaluation

This chapter covers the evaluation process and its results. The evaluation was carried out continuously according to the User-Centered Design (UCD) [use23] process. The UCD process is a design methodology that focuses on the needs, goals, and expectations of end users. The UCD process is iterative and involves continuous testing and refinement until the product meets the user's needs and expectations. By involving users throughout the design process, the UCD process ensures that the final product is usable, efficient, and effective. The evaluation methods used include a set of experiments designed to collect qualitative feedback from users. This feedback is used to validate the usability of the design and improve prototypes. User testing was carried out on an ongoing basis, and prototypes were updated between test sessions when inconsistencies, errors, or friction were found. The final design of the user interface was validated for usability and accessibility using heuristic methods [Fou21].

5.1 User testing in the lab

I conducted a qualitative experiment to validate the design of the smart mouse pad. The mouse pad was designed to prevent Carpal Tunnel Syndrome when working with a computer mouse for long periods of time. The solution consists of the mouse pad and an application installed on the user's computer. When the user applies too much pressure to the pad or works for a long time without taking a break, the application will notify them to rest and stretch their wrist and also provide tutorials for wrist exercises.

5.1.1 Research methods and strategy

The prototype was created on the basis of 20 in-depth interviews. During the lab tests, the focus was on assessing the usability of the prototype. For this, I prepared a moderated experiment followed by a short semi-structured interview with each participant.

5.1.2 Research questions and goals

The research questions and goals can be summarized into four main points. Firstly, to identify design features that are difficult to comprehend or simply unusable in order to make improvements. Secondly, to gain insights into how people use computer accessories, particularly in relation to a mouse and mouse pad. This information can be used to inform future designs and developments. The third goal is to gather inspiration for future features of the mouse pad and the application by understanding the needs and wants of users. Finally, the fourth goal is to identify ways to improve the general user experience, ensuring that the design of the mouse pad and the application is user-centered and tailored to meet the needs of the target audience. These goals were chosen to ensure that the final product is both usable and useful for users, improving their experience and overall satisfaction.

5.1.3 Features to be evaluated

By evaluating the following features, I can identify any usability issues and provide recommendations for improving the user experience. For example, if the pressure visualization is not understandable, I could suggest ways to make it clearer. If notifications are too disturbing, I could suggest ways to make them less intrusive. By evaluating the system's features and providing recommendations, I can help improve the user experience. From all the features that the application has, I will focus on the following:

- Configuration wizard (a set of screens that instruct the user how to setup their working environment, e.g., desk, chair).
- Pressure visualization - Is the visualization understandable?
- Statistics screen - What value do the implemented statistics provide to the user? What other data could we show to provide more value?
- Notifications - Are they too disturbing?
- Exercise walk-through - Are the exercises explained well enough for the user to learn them on their own correctly?

5.1.4 Research sample

- 5 participants
- working with a PC on average 4+ hours/day
- use a mouse most of the time (not a touch-pad or track-pad)
- have a healthy wrist without pain
- don't currently have a cast or a splint on their dominant hand

Participant selection strategies

I recruited participants through the following:

- students and staff of Czech Technical University in Prague
- list of people from last year's in-depth interviews (mainly students)
- Facebook and LinkedIn posts.
- seniors from lifelong learning classes

5.1.5 Description of the prototype

The mouse pad is 3D printed, and the top material is made of soft shell fabric. The prototype mouse pad is connected to the computer via a USB cable. The application running on the computer is fully interactive.

5.1.6 Experiment setup

The experiment was carried out on the grounds of the Faculty of Electrical Engineering of the Czech Technical University in Prague with the following setup (see figure 5.1):

- quiet room with good lighting booked not to be disturbed for at least 1 hour
- standard desk at standard height
- height adjustable office chair with armrests (ideally height adjustable as well)
- height adjustable external display (at least 25")
- standard keyboard with CZ layout
- standard universal mouse (for both left and right-handed use)
- software to record computer screen and microphone
- phone on a tripod to record the tabletop and participant's hands
- experiment outline on iPad for reference and notes (make other documenting photos with iPad)
- computer with macOS and Windows (to let the participant choose their preferred operating system)
- glass or bottle of water for participant
- the smart mouse pad with a quick guide

Figure 5.1: Lab testing setup

5.1.7 Testing procedure

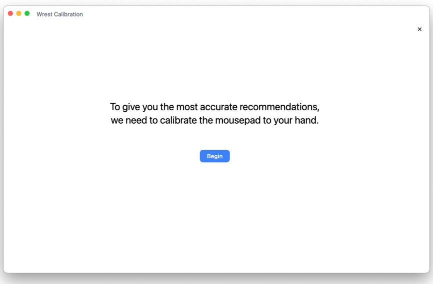
The testing was done at the Faculty of Electrical Engineering of the Czech Technical University at Karlovo náměstí in Prague. I chose a room with good lighting and a height adjustable office chair with height adjustable armrests. Armrests are recommended by occupational safety and health specialists. Although during my testing and interviews, I found out that it is rare for someone to have a chair with armrests and even rarer for them to be height adjustable. All participants used the same setup and were not instructed to set up the chair beforehand. The desk and chair set-up is the first flow in the application.

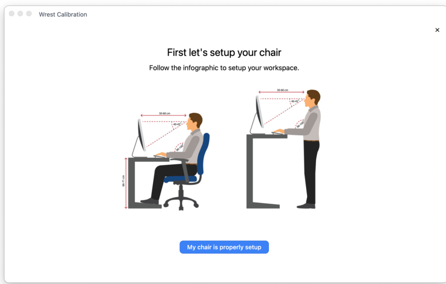
5.1.8 User tests Findings

In these examples, the image on the left is the first version I tested with the first 3 participants, and the image on the right is the second version that I modified based on findings from the 3 tests, and this second version I tested with the following 2 participants.

Calibration - Chair setup

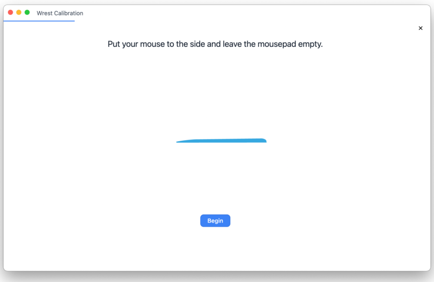
Problem: Participants did not read carefully and did not set up the chair properly. Suggested fix: Add an image with the correct set-up of the chair and arm position (visual aid). Problem 2: After adding the image participant was confused because his chair did not match the one in the picture. Suggested fix 2: Add another step to let the participant choose their current chair type (not more than 3-4 options).

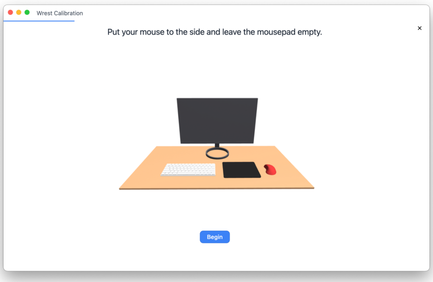




Calibration - Empty mouse pad step

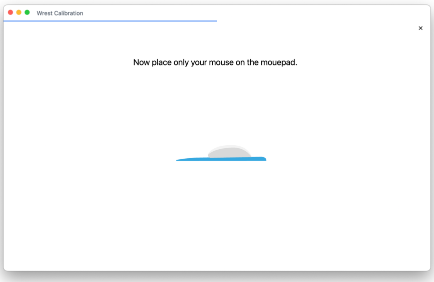
Problem: The participant did not recognize the image as an empty mouse pad and did not know what to do. Suggested fix: Add a 3D graphic of the mouse pad on a real table with usual accessories (mouse, keyboard, and monitor) with the mouse positioned next to the mouse pad, not on it.

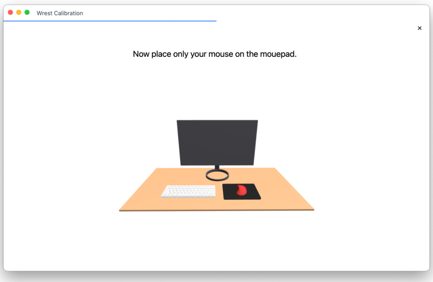




Calibration - Mouse only step

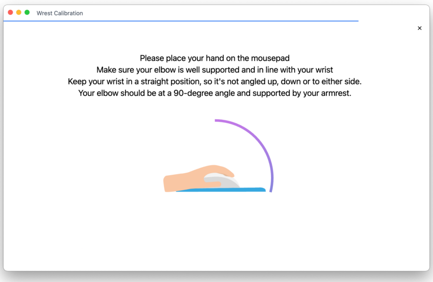
Problem: The participant was surprised that the mouse calibration started automatically. They expected the same behavior as in the first step, where the calibration starts only after clicking a button. Suggested fix: Unify behavior between all the steps in calibration. Either all start automatically, or all start after the button is clicked.

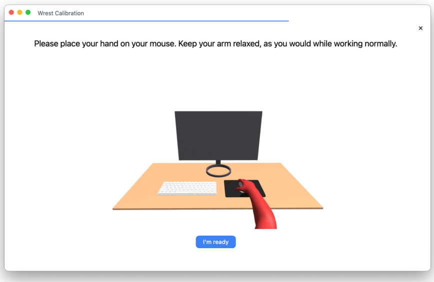




Calibration - Hand calibration step

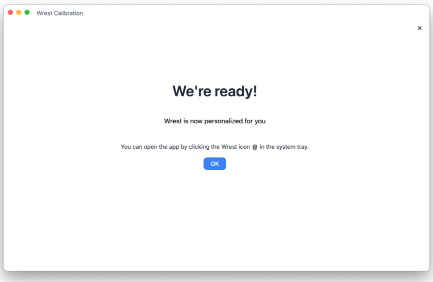
Problem: Participants were unsure how to position their hands on the mouse pad. Some expected the mouse pad to be positioned under their forearm and the mouse on the table. Suggested fix: Could be fixed by an image of a hand with a mouse and the mouse pad on the packaging to drive the correct expectations from the beginning. Or, use a 3D graphic showing the correct hand position in relation to the armrests and the mouse pad.

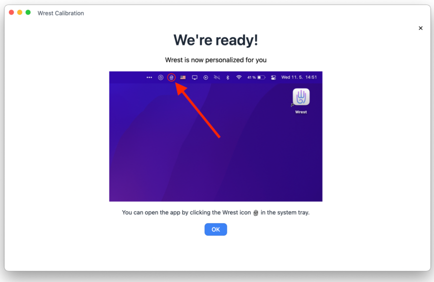




Calibration - Finished

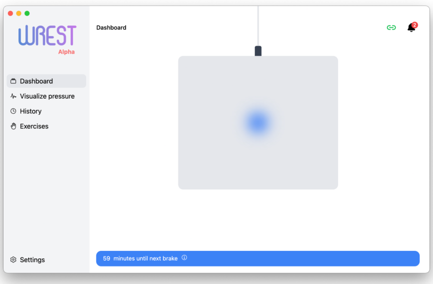
Problem: Some participants were unsure what to do when they reached this step. Suggested fix: Explain more clearly that the application will run in the background while users use their computers. Add a walk-through through the application dashboard and start the first exercise so they are familiar with the notifications and exercise explanations.

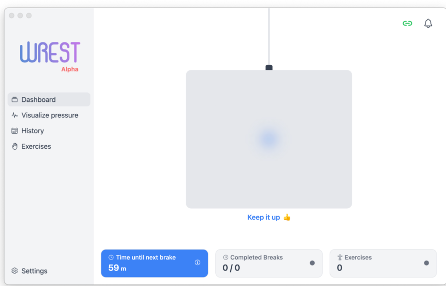


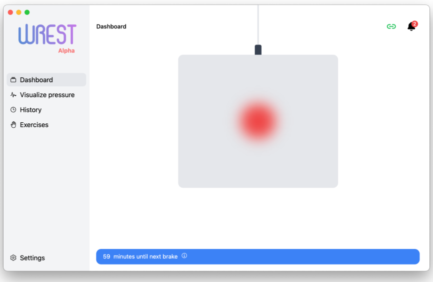


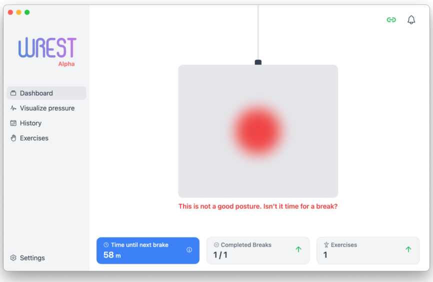
Dashboard

Problem: Most of the participants got stuck on the homepage right after finishing the configuration and played with the pressure visualization. Suggested fix: Add a walk-through onboarding that explains the main parts of the application and also explains that the user can close that application when he is done exploring because the application will run in the background and notify him later.



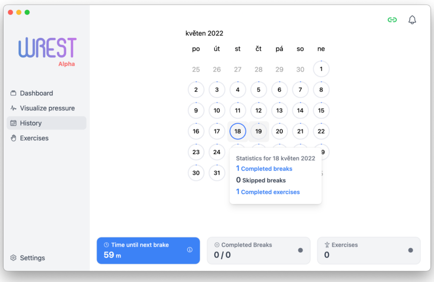


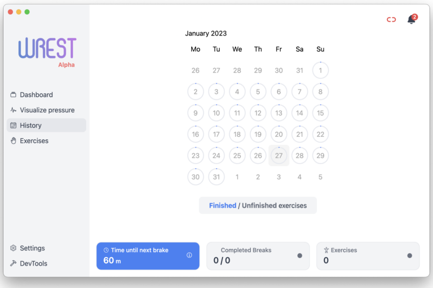




History - Month view

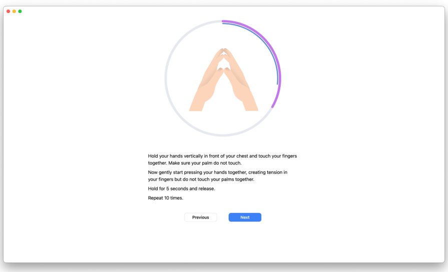
Problem: The circular visualization of completed/uncompleted exercises was not understood without additional description. Suggested fix: Add detailed statistics for each day available after clicking the date. This proved to be better understood, but lacked discoverability (some participants did not click on the dates). The statistics could be shown on hover in the next iteration.

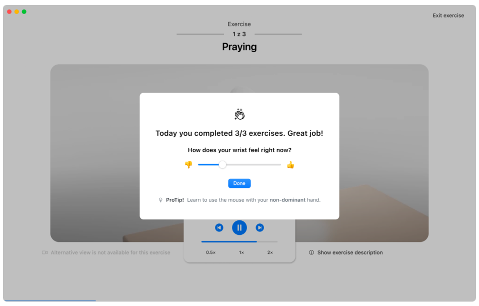




Exercise walk-through

Problem: The conclusion is that images and text descriptions are not sufficient. Some participants were not able to repeat the exercises precisely. Suggested fix: Videos or animations should provide more information to the user. We are in the process of creating animated 3D visualizations of hands performing the exercises.





5.1.9 General feedback on the mouse pad hardware

Although the prototype is approximately 1 cm high (which is considerably higher than a standard fabric or rubber mouse pad), the participants did not show any discomfort. When asked directly about it, most commented on the height, but ultimately it was not a big issue. They also evaluated the soft shell fabric as comfortable, which is an improvement over the previous prototype that used a different cotton fabric, and users commented that it was not too pleasant to touch.

5.1.10 User tests Conclusion

I received a lot of valuable feedback from the participants. The basic functionality of the smart mouse pad and the application was well understood. The participants quickly oriented themselves in the application and found the calibration process fairly straightforward (after the second iteration with images and 3D visualizations). They reported that the notifications were not too disturbing, which is what was wanted.

For the next batch of participants, I would like to rework the Exercise walk-through screens. Hopefully, adding animated hands to explain the exercises will help users to learn them more precisely. I will also need to tune the calibration process in the application so that right after the calibration, the user does not see any warnings about high pressure on the dashboard (assuming he maintained the same hand position as in the calibration procedure).

Improvements to the experiment setup could also be made. It would better reflect a real workspace with an external monitor. Also, something I found during the test was that many participants did not change the height of the chair and armrest when it was close enough to their height. Next time, I might try to set the chair way too high or low intentionally to see whether that would prompt the participant to actually change the chair height. If that will prompt them to make this conscious effort, then I need to find a way to motivate them to also set the height even if it is close enough for them. It is important for the calibration process that the chair and armrest height is set very precisely.

5.2 Field study

After evaluating the usability in the lab, iterating on the design, and evaluating again, I can confidently say that the users are able to set up the mouse pad and configure the application successfully without external help. At this stage, I want to evaluate the frequency of notifications and the frequency and quality of feedback that the user receives. Due to the nature of the solution, I proposed a 2 week testing period, during which I will lend the mouse pad prototypes to users to use at home or at work. This method was selected to test in an environment that is as close to real-world conditions as possible. I will collect anonymous data about the use of the application, and I will also interview users at the end of the testing period.

Users will receive basic instructions on how to install the application, but the rest of the process will be unsupervised, testing also how well the onboarding flow explains the features of the mouse pad and application.

Participants were recruited through friends and also through social media posts and previous interviews and tests. In total, 8 participants used mouse pads for at least 2 weeks and provided feedback.

5.2.1 Field study setup

For at-home testing to provide an experience as close to the final product as possible, we developed an application for Windows and macOS, that implemented a subset of the features proposed in prototypes. Features implemented include:

- notifications about too high pressure applied to the mouse pad
- notifications about time to take a break and exercise
- visualization of real-time pressure applied to the mouse pad
- onboarding and calibration flow
- pressure and event data collection
- exercise walk-through with animations and timers
- history view showing exercise compliance over the past month
- settings

In this testing, our aim was to validate the core experience of the application with all main flows. From setting up the device and learning proper posture to following the exercise walk-through and adjusting the settings. We did not focus on gamification features, as they are only a supportive element of the experience and a helping tool for some users who struggle with motivation. To test and validate the gamification features, another experiment must be performed with more participants in a more controlled manner with more data and more frequent feedback during testing.

5.2.2 Feedback form design

Feedback was collected through an online survey using a tool called Tally. Participants were presented with two questions at a time. The survey was conducted in Czech due to the location of the participants. The questions asked can be found in table 5.1.

5.2.3 Analysis of real-world testing results

Participants in this 2-week experiment included four students (two computer science students, one architect, and one law student), four designers (User Experience and User Interface designers), and one digital marketing specialist.

1	Based on your use of the application and mouse pad, how likely are you to recommend this product to a friend or colleague?	0-10 (NPS)
2	Please give 3 main reasons for your choice from the previous question.	Open-ended question
3	How do you rate the comfort of the mouse pad?	0-10
4	Describe your experience using the mouse pad (focus on the pad itself, we'll ask about the application in the next step).	Open-ended question
5	Rate the benefit of the application.	0-10
6	What did you like/dislike about the app? What would you change?	Open-ended question
7	Rate the simplicity and clarity of the application.	0-10
8	Have you had trouble understanding the app's features? What else would you like the smart mouse pad application to do?	Open-ended question
9	Rate the clarity of the wrist exercise animations.	0-10
10	Describe how you have used the animated exercises and how they have benefited you.	Open-ended question
11	Rate the frequency of alerts the application has shown you (high mat pressure, time to exercise, etc.)	0-10
12	Describe a situation where you received a notification from the application. How did you react to the alert? How did the exercises fit into your day?	Open-ended question

Table 5.1: Feedback form

The total Net promoter score[Net] was 0 (on a scale of -100 to +100). Individual responses were as follows: 3, 7, 7, 8, 8, 9. This is a neutral result showing mainly passives, who are satisfied but unenthusiastic customers.

Table 5.2 shows the averaged answers from the 9 participants (excluding open-ended questions).

What we can learn from these results is that the animated exercise tutorials (or exercise animations) were very popular and useful, also supported by participant quotes (translated from Czech to English by the author):

- The best of it all! Nice slow animation, very clear. Great choice of abstraction vs. realism of hands, beautiful work. Nice to watch and practice accordingly.
- Pleasant stretching, the release of slight tension, good feeling of taking care of my body responsibly and not forgetting about it during the work rush.
- The animations are great and illustrative.

On the other hand, what was a real problem for many users, was the frequency of alerts the application showed. As we can see from the results

	Question	Score scale	Average
3	How do you rate the comfort of the mouse pad?	0-10	6,6
5	Rate the benefit of the application.	0-10	6,4
7	Rate the simplicity and clarity of the application.	0-10	9,2
9	Rate the clarity of the wrist exercise animations.	0-10	10
11	Rate the frequency of alerts the application has shown you (high mat pressure, time to exercise, etc.)	0-10	3,6

Table 5.2: Summary of real-world testing results (higher score is better).

and the following participant quotes, the implemented algorithm that decided the time of alerts did not accommodate for the participant's daily routines, and thus the notifications were received at inconvenient times.

- The exercise didn't fit into the day at all. Since I work on the computer, I don't use it for fun, so it's really hard to tear myself away from work and go work out. I skipped the full-screen alert many times. And I haven't found an option in the application to change this behavior and cancel the alerts. . .

- Sometimes, I skipped an exercise because I didn't have time (I was signing up for a Zoom call). But one day, it was very useful for me because I realized that I should straighten up at the computer and exercise my back and eyesight at the same time.

5.3 Heuristic evaluation of the final application design

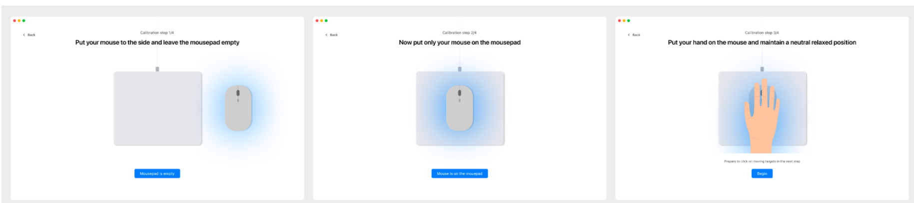
Heuristic or expert evaluation is a useful tool for user interface evaluation. These principles have been used in the industry for many years and provide a foundation for what a great user experience is. Performing a heuristic evaluation brings with it the bias of the expert who evaluates the design, but combined with user testing, it is a useful and inexpensive evaluation method. Passing the heuristic evaluation does not mean that the design is without problems, but it provides a baseline of usability considerations that every design should follow. I selected two heuristics to evaluate the design: Jakob Nielsen's Usability Heuristics for User Interface Design and Peter Morville's User Experience Honeycomb. These two were selected because they have been well tested in practical applications in the industry.

5.3.1 Usability Heuristics for User Interface Design by Jakob Nielsen

The most well-known set of heuristics was developed by Jakob Nielsen and Rolf Molich in 1990 [MN90] and later updated by Nielsen in 1994 [Nie94]. The heuristics have remained unchanged since the basic rules of human psychology still apply to modern website and application design. It is common to use Nielsen's heuristics for user interface design because they are widely recognized and accepted as a useful tool for evaluating the usability of software applications. Moreover, these heuristics have been extensively tested and validated through years of research and practical application.

1. Visibility of system status is achieved by the application icon in the operating system status bar (the icon is red if there is a problem with the mousepad connection and black/white otherwise) and by the icon in the top right corner of the application window (icon is red if there is a problem with the mousepad connection and green otherwise). The status of the system is also communicated to the user through native system notifications.

2. Match between the system and the real world is achieved by the dashboard of the application showing a low-fi version of the mouse pad with the USB cable coming out the back and overlaying a visualization of the applied pressure over it. In addition, in the onboarding flow, the placement of the mousepad, mouse, and hand is visualized, mimicking real-world objects.

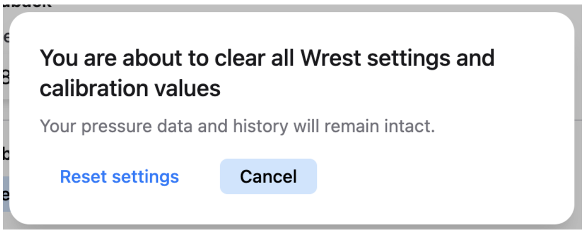


3. User control and freedom are achieved by reminding the user that the initial calibration can always be repeated later if any problems are found. In addition, the user can close the application at any time and no data will be lost.

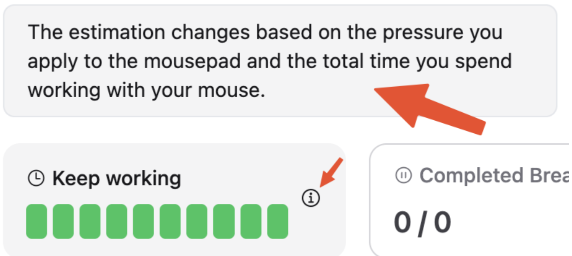
4. Consistency and standards are achieved by following the operating system conventions on both Windows and macOS (using the system status bar, using native system notifications, and following the system convention for

window management). The application prototype is built as a desktop application using web technologies such as HTML, CSS, and JavaScript and following the accessibility guidelines for the web, such as HTML semantics and keyboard navigation.

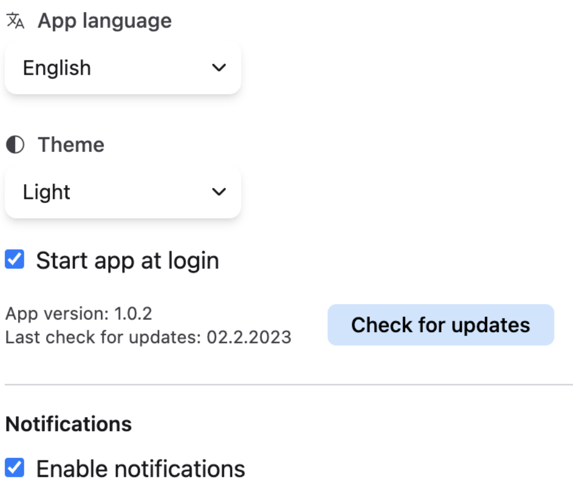
5. Error prevention is achieved by disclosing the next step to the user before any destructive action is taken (for example, when the user tries to clear all settings, we ask if they are sure).



6. Recognition rather than recall is achieved by tooltips throughout the interface that explain the interface element function in more detail when hovered with the mouse cursor.

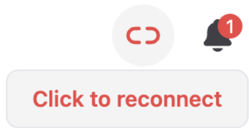


7. Flexibility and efficiency of use are achieved by letting the user customize the behavior of notifications in the application settings.



8. Aesthetic and minimalist design is achieved by using a minimal color palette, a design system of elements, and the system typeface. When testing with users, many said the application is simple and minimal without us asking the question. Adding a dark theme and following the operating system theme setting was also a big hit with users who are used to working in the evenings.

9. Help users recognize, diagnose, and recover from errors is achieved by errors being presented in red color with bolded text.



10. Help and documentation were provided to users on a case-by-case basis during the testing period. More thorough documentation would be needed for production deployment.

5.3.2 User Experience Honeycomb by Peter Morville

In his book Information Architecture for the World Wide Web [MR06] and related work, Peter Morville presents a set of seven principles for great User Experience design called the User Experience Honeycomb [Mor04].

The 7 facets of quality user experience, according to Morville, are:

1. Useful - see section 5.2.3.

2. Usable - see section 5.1.10.

3. Desirable - Some questions on the desirability of the product were asked during the interviews, and we have also had people reaching out with interest in buying such a product. However, more market research is required to assess whether we have succeeded, and this is beyond the scope of this thesis.

4. Findable - see section 5.1.10.

5. Accessible - Scoring a 98 in Chrome Dev Tools' Lighthouse Accessibility audit[Dev] and 100 in the Best practices audit. There is more to accessibility than just automated audits. Color contrast, keyboard navigation, and simple language were just a few things considered during the design process.

6. Credible - Working with my colleague Vasil Kostin at the Third Faculty of Medicine of Charles University, our aim is to support our design decisions with credible medical research studies. The exercises presented to the users in our application were created in cooperation with physiotherapists,

and we informed our first users of this fact. Credibility is extremely important for our users as we are dealing with users with a potential medical condition. It is important to educate users, that our product is not a certified medical device and that they should always consult their doctor or licensed physiotherapist.

7. Valuable - The value of the product is to be determined when first customers get it into their hands and will largely depend on the final price of the device.

Chapter 6

Conclusion

The research carried out in this thesis has highlighted the significant occupational risk factors for Carpal Tunnel Syndrome (CTS) associated with excessive use of the computer mouse. This research has also shown that current market solutions, such as vertical mice and gel mouse pads, have been marketed as a remedy for CTS, but their preventive effects are inconclusive.

My goals for this thesis, as defined in 1.2, were to perform experiments to evaluate the usability and utility of the smart mouse pad design. For results, see chapter 5. Additionally, I explored ways to motivate users to pay attention to their posture while sitting and do more wrist exercises. For my exploration, see section 3.7.

Through interviewing real users, I have successfully collected insights from real users, designed a solution to mitigate wrist pain using a mouse, implemented the proposed design as prototypes, evaluated the prototypes with real users in the lab and real-world conditions, and iterated the design with user feedback. I have continuously evaluated the design with users over time and updated the prototypes accordingly. I was successful in improving the design in areas where users struggled to understand the application or where the application failed to meet user expectations.

I have followed a user-centered design approach to address the problem of CTS in computer mouse users with wrist pain. I gathered valuable insights from real users by conducting user interviews and usability testing, which informed my design decisions. The use case and hierarchical task analysis helped me to understand how users interact with their computer mouse and identify pain points in the user experience. The sketching, wire-framing, and prototyping stages allowed me to iterate on the design and test ideas with users, leading to the development of a smart mouse pad. By implementing the solution in code and conducting user testing under real-world conditions, I was able to evaluate that the current solution is usable and accessible for the target audience. More research is needed to evaluate the desirability of the solution and the motivation of users to actually use it.

Future work should focus on designing, evaluating, and implementing the gamification features proposed in interactive prototypes and thoroughly evaluating them with users. Some gamification features were designed but not implemented in the prototype and not tested with users (see section 3.7).

It should be noted that this thesis was focused on the design and implementation of the smart mouse pad and did not include an evaluation of its preventive effects on CTS. I evaluated and improved the design in terms of usability, but further research and development, such as the ongoing evaluation with patients being conducted by my colleague Vasil Kostin at the Third Faculty of Medicine at Charles University, is necessary to fully validate the effectiveness of this solution in preventing Carpal Tunnel Syndrome and the utility and viability of the product as a whole.

Appendix A
Interview script

This script was used for user interviews at the beginning of the research phase. See 2.7.5for context.

Briefing (5 minutes)

Hello, I am Tomáš Trejdl. I am a human-computer interaction student at the Faculty of Electrical Engineering of the Czech Technical University in Prague. My colleague Vasil Kostin, a medical student, and I are conducting research under the auspices of the 3rd Medical Faculty of Charles University with the support of the Technology Agency of the Czech Republic.

Our project deals with working at the computer and focuses on the use of the mouse. During the research, we are looking for what problems people who work more than 4 hours at the computer every day have. This interview will last 15-30 minutes, and I will ask you about your day-to-day experiences working on the computer. If you don't want to answer a question, you don't have to, just tell me, and we will move on. There is no right or wrong answer to the questions; we are interested in your real experiences.

Everything you tell us will be anonymized for the purposes of our research.

Do you have any questions to start with?

No? Great. Here we go.

1. PC posture (max 5 minutes).
   - Are you interested in the topic of posture and hand position when working on a PC?
   - Describe what your work environment looks like (at home or in the office).
   - Describe the places where you often work (desk, sofa, bed, at a coffee house, outside, ...)
   - What kind of desk or chair do you have?
   - How should one sit? Do you follow this? Why yes / why not?
2. Risks associated with poor hand position (max. 5 minutes).
   - How often (after what time) do you take a break from working with the mouse?

- Do you know how long this time should be to avoid health risks?
- (If you do not follow it yourself) Why do you not follow it yourself?
- Do you know or care about the risks associated with poor hand position when working on a computer for long periods of time?
- What is the correct hand position when working on a PC? Do you follow it? Why yes / why no?
- Do you use a mouse or touchpad more often? Why?
- Describe what accessories or alternative ways of controlling the PC you use (mouse pad, splint, touch-pad, vertical mouse, touch screen, ...)

3. Discomfort or pain when working on the PC for long periods of time(max. 5 minutes).

    - Describe your discomfort or pain when working on a PC.
    - What is working on a PC for long periods of time like for you? After what length of time does your arm/back/something else start to hurt?
    - What do you do to prevent/prevent discomfort and pain?
    - Do you know other ways to prevent it that you haven't tried? Why haven't you tried them?

4. Follow-up questions.

    - Have you been diagnosed with carpal tunnel syndrome?
    - When were you diagnosed?

Debriefing (5 minutes)

Thank you very much for the interview. Do you have any questions or feedback for me at the end? Your responses are only for our research purposes only and will be anonymized. Now I can tell you more about our project. We are developing a smart mouse pad to help prevent carpal tunnel syndrome. We're currently working on refining the prototype. Would you be interested in testing the mouse pad with us when we have the prototype ready? Finally, I will ask you if you have friends/acquaintances who also have problems with wrist pain when working on a PC and would be willing to participate in our research. Thanks again, and goodbye.

Appendix B

Screens

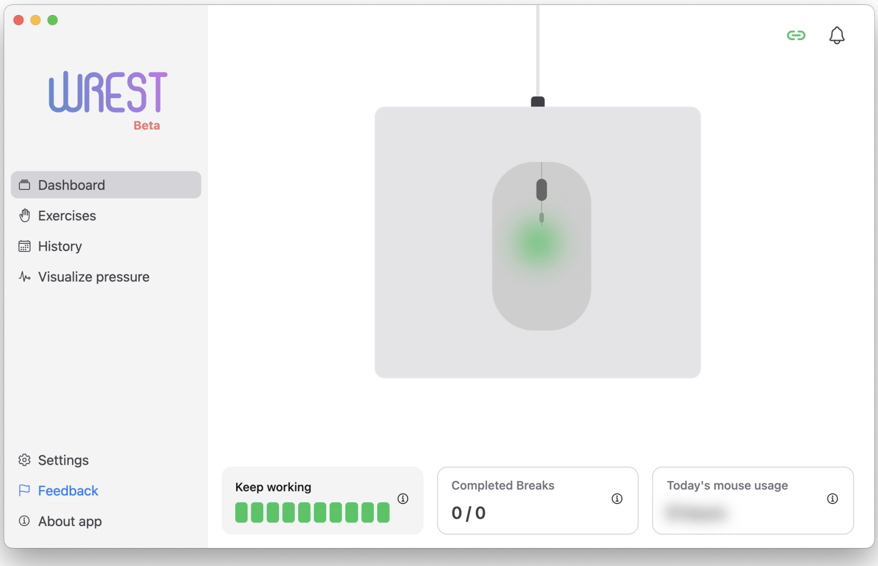


Figure B.1: Final screen design for the application dashboard (light theme)

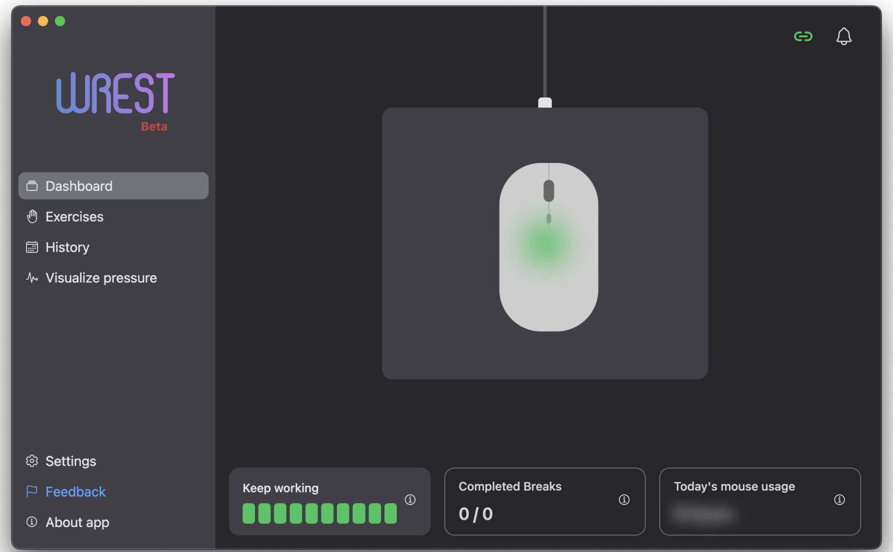


Figure B.2: Final screen design for the application dashboard (dark theme)

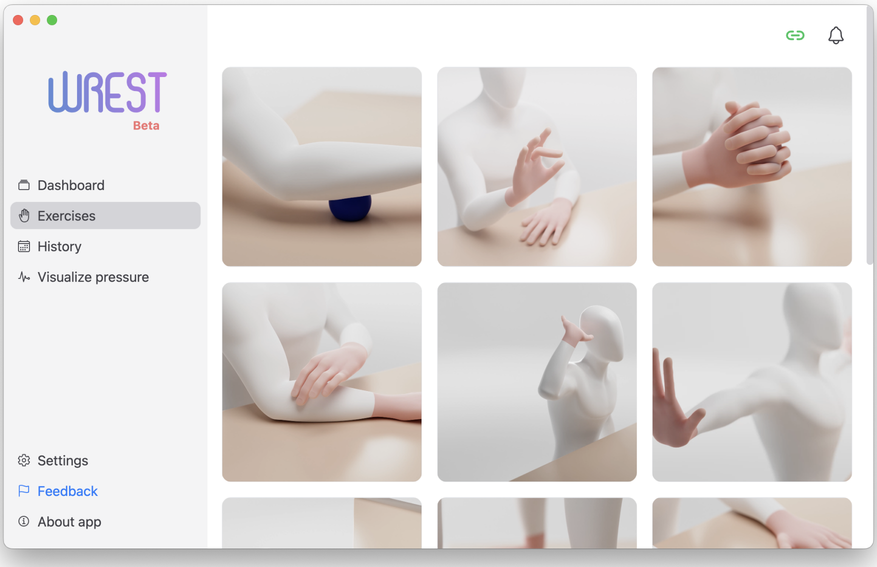


Figure B.3: Final screen design for the Exercises screen

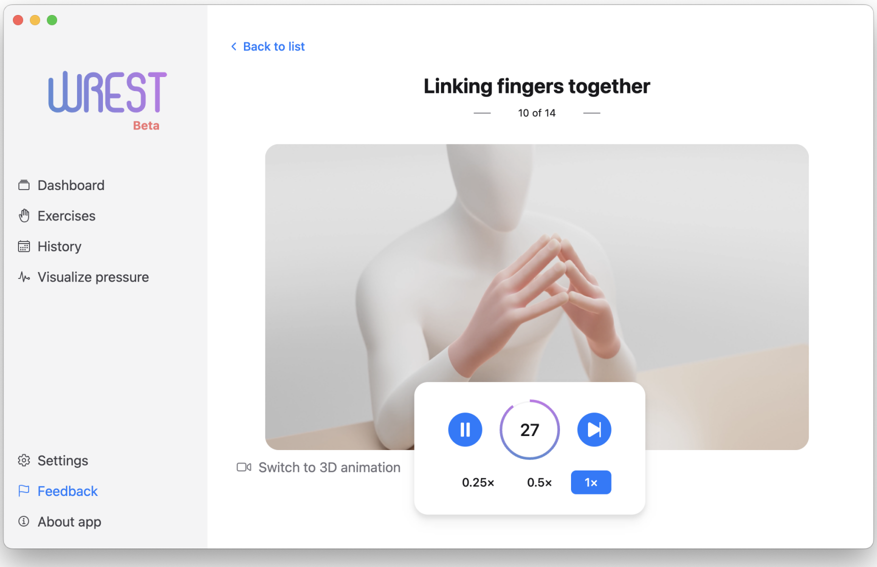


Figure B.4: Final screen design for the Exercise Details screen

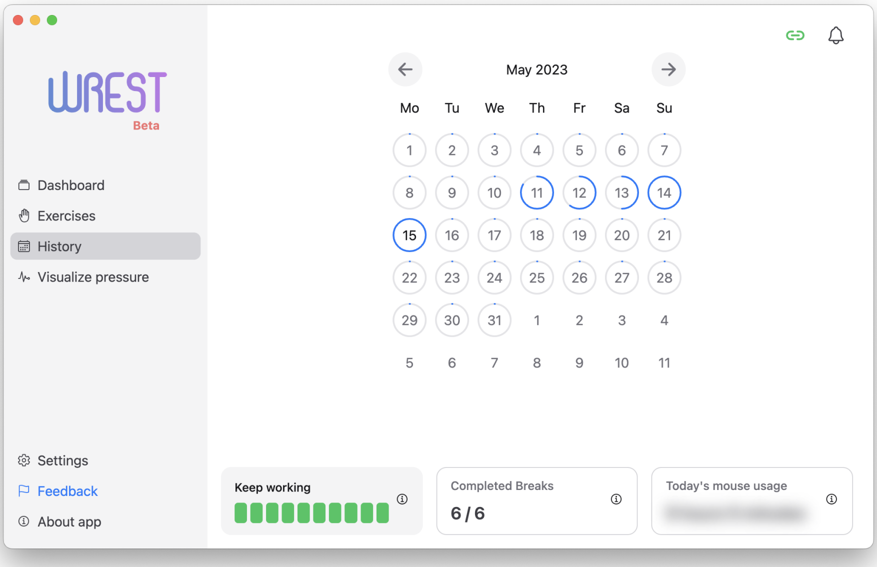


Figure B.5: Final screen design for the History screen

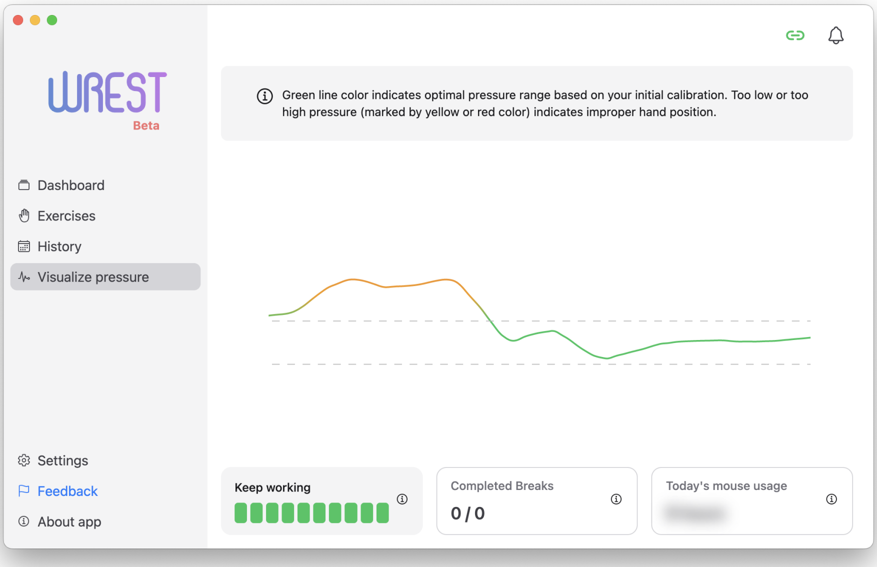


Figure B.6: Final screen design for the Visualize pressure screen

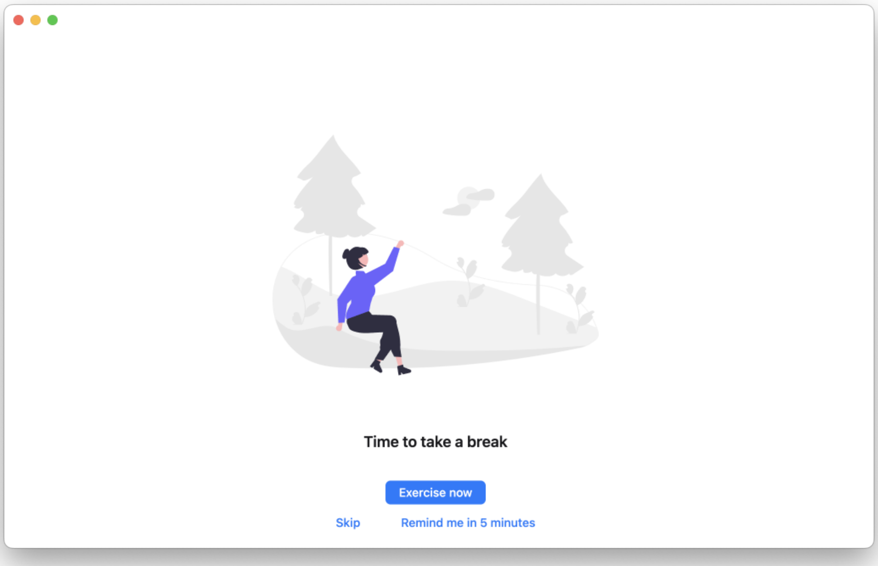


Figure B.7: Final screen design for the Break notification screen

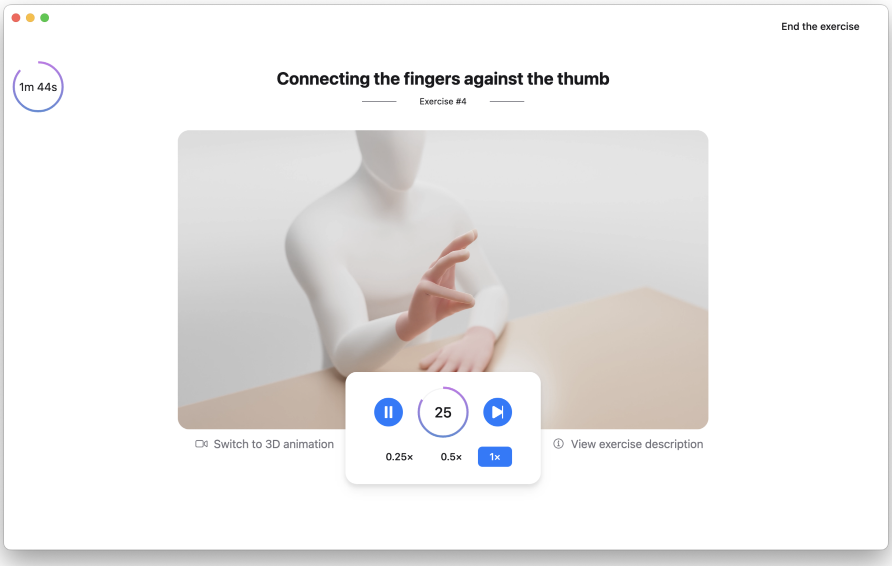


Figure B.8: Final screen design for the Exercise walkthrough screen

Appendix C

Flows

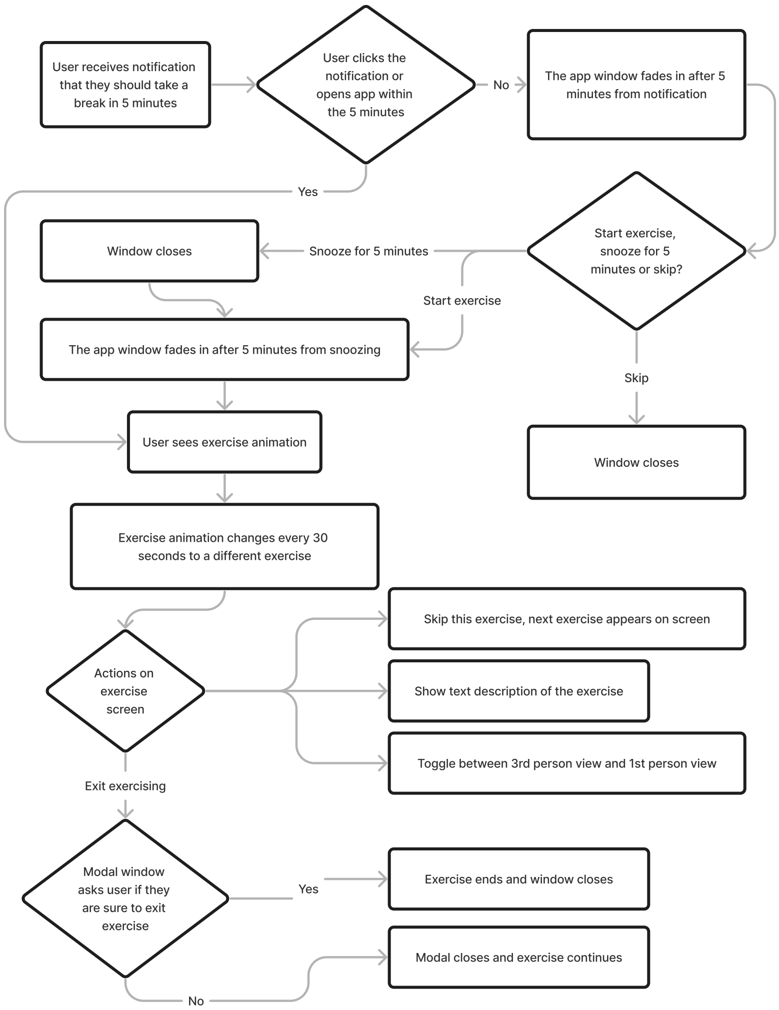


Figure C.1: Exercise flow diagram

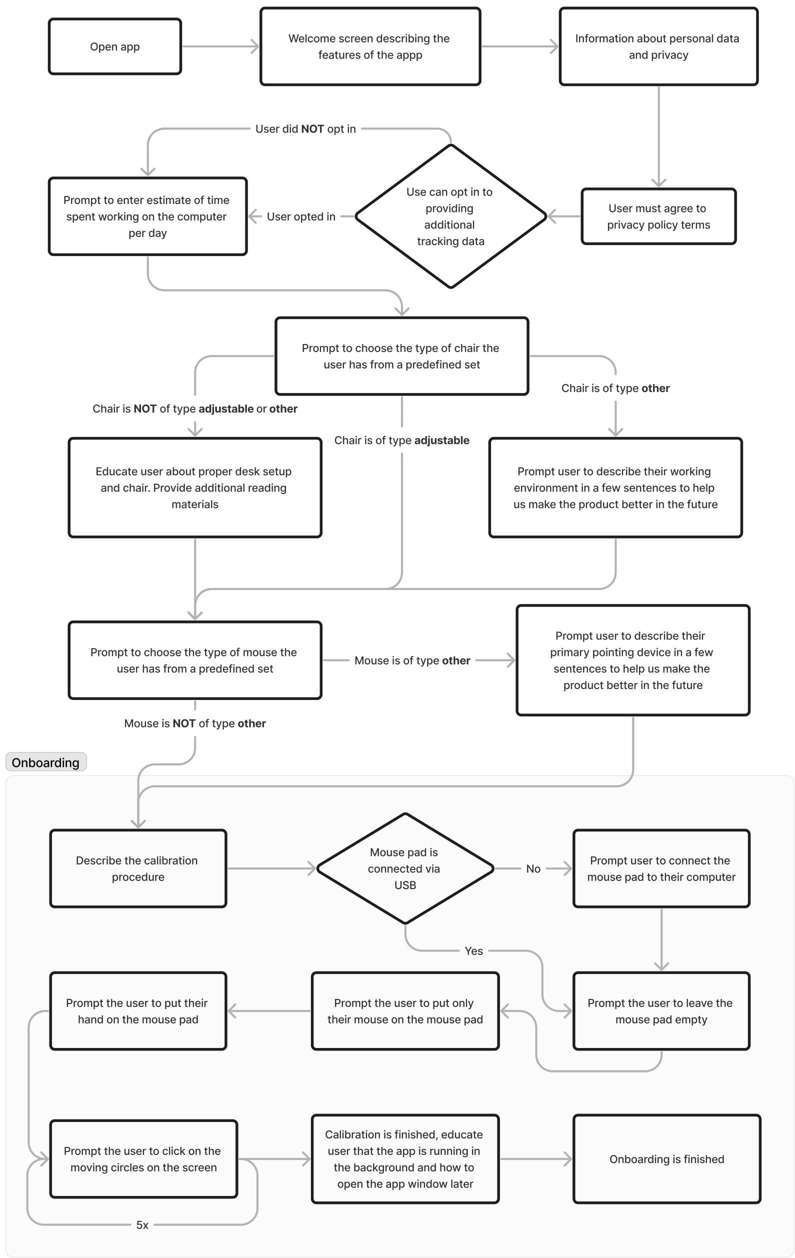


Figure C.2: Onboarding flow diagram

Appendix D

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