Improving Comfort for Transtibial Socket Users

Master Thesis by
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Master Thesis

Improving Transtibial Socket Comfort Using Wearable Vibration Technology:
Research and exploration of improving comfort in the transtibial socket, resulting in the direction of rehabilitation and vibration technology.

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Summary

This report presents the complete design journey of developing a more comfortable prosthetic socket, by looking further than traditional factors like pressure distribution and volume fluctuation. Instead, it explores a rehabilitation-focused approach: integrating vibration therapy to assist residual limb recovery and improve comfort throughout the day.

The process began with in-depth *User research*, exploring the background and physical demands of lower limb prosthetics, pressure-sensitive areas, and real-life challenges faced by users. Insights from Hoogstraat Orthopedie and research on the lifestyle of amputees were translated into a user scenario of Stacy. This scenario highlighted recurring pain points, particularly end-of-day fatigue and residual limb discomfort. These were often triggered by factors such as physical activity and weather conditions. Building on these findings, and following additional research into existing technologies for transtibial amputees, the *Exploration and Conceptualization* phase revealed that the area in recovery support is an opportunity which has not been explored yet. Ideation and journey mapping led it to a more focused direction: incorporating focal vibration therapy as a tool for muscle relaxation and improved circulation for pain reduction.

In the *Concept Validation* phase, vibration therapy was evaluated through scientific literature and product analysis. Research on optimal frequency, amplitude, and usage duration helped shape the technical parameters of the design. Research on current market products helped position the concept as both affordable and novel. To define the intended user experience, moodboards were created, leading to key characteristics the product should have. These characteristics are gentle, caring, helpful, and dependable, in order to offer relief in a calm and accessible way. The *Motor Selection and Placement* translated these goals into practical decisions. After reviewing various vibration motors, voice coil actuators were selected for their precision and suitability. Placement was decided through focal vibration therapy, pressure mapping, and anatomical research. The chosen locations are on the gastrocnemius medial head, soleus, peroneus longus, tibialis anterior muscle.

In Translating Research into Design, all insights were brought together in a simplified 3D-printed prototype. While not yet suitable for practical use, the prototype demonstrates component layout and wire routing. It serves as a starting point for future testing, supporting targeted vibration while maintaining socket comfort and flexibility. A BOM showed the further details of the concept, including the weight

and affordability. The final concept design illustrates how the product could be implemented in a future context, bringing together the essential elements of its intended function.

This project shows how rethinking conventional approaches to prosthetic design can lead to meaningful improvements in user comfort. By combining user research, anatomical insight, and technical design, the project takes a broader perspective of comfort: one that considers not just how a prosthesis fits, but how it feels throughout the day. Hopefully, this direction encourages further progress toward more thoughtful, comfortable and user-centered prosthetic care.

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Introduction

Prosthetic limbs play an important role in enhancing the mobility and quality of life for amputees. However, they present several challenges, such as skin problems caused by volume change, pressure points, shear forces and increased temperature (Paterno et al., 2018). On top of that, muscle fatigue is a significant issue for lower limb amputees who wear prosthetic limbs for prolonged periods (Shamsuddin et al., 2023). Understanding the complexities of prosthetic use is necessary for developing solutions that can improve the user experience.

This project aims to improve the day-to-day comfort of lower limb (transtibial) prosthetic users from low-income backgrounds by exploring existing research and gaining insight into the problems they commonly face. The goal is to use this understanding to guide the development of affordable, user-centered design ideas that enhance comfort and accessibility.

The report begins with *User Research*, outlining the physical and practical challenges of prosthetic limb use through anatomy insights, an user scenario, and a prosthetist visit. These findings emphasize the need for solutions that improve both comfort and daily usability. The *Exploration and Conceptualization* chapter follows, detailing the idea-generation process and identifying recovery support as a promising focus for reducing fatigue and end-of-day discomfort. In *Concept Validation*, the project draws from scientific literature and product analysis to define relevant parameters. It outlines the best usage patterns and proposes a design that supports relief and relaxation through physical vibration, form and experience. *Motor Selection and Placement* then investigates the most suitable type of vibration motor and determines the optimal positioning on the residual limb to maximize effectiveness. Finally, *Translating Research into Design* turns these insights into a product concept. It presents a physical prototype with component details, a summary of the final design's functionality, and future recommendations.

1 User Research

This chapter explores the facts and challenges related to lower limb amputees. It covers the basics of prosthetic limb components, including details such as weight, structure, and pressure-sensitive areas, as well as the required care and maintenance. Day-to-day challenges are examined through a user scenario, and additional real-world insights were gathered during a visit to a prosthetist.

For definitions of common prosthetic terms used in this chapter, refer to Appendix A.

1.1 Facts and Maintenance

1.1.1 The lower limb and Prosthetic

A prosthesis consists of a socket, pylon and prosthetic foot (see Figure 1). A gel liner is used to improve comfortability and reduce friction between the residual limb and the socket during motion. Different thicknesses of socks can be used after putting on the gel liner, to adjust to the volume of the socket. Lastly, the prosthetic foot has to provide stability to the whole prosthetic.

A natural leg weighs roughly 1/6 of a person's overall body weight. For below-knee amputees, the average weight of a prosthetic limb is around 1.8 kg (Comprehensive Prosthetics & Orthotics, 2021). Based on a prosthetist from Hoogstraat Orthopedie, the lighter the prosthesis, the more comfortable it will be during dynamic movement.

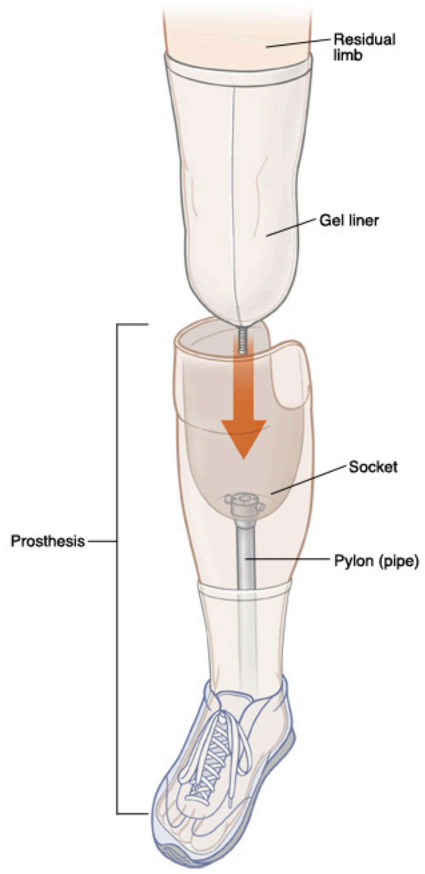

Figure 1: Prosthetic overview (Tyra, 2021)

1.1.2 Pressure Sensitive and Tolerant areas

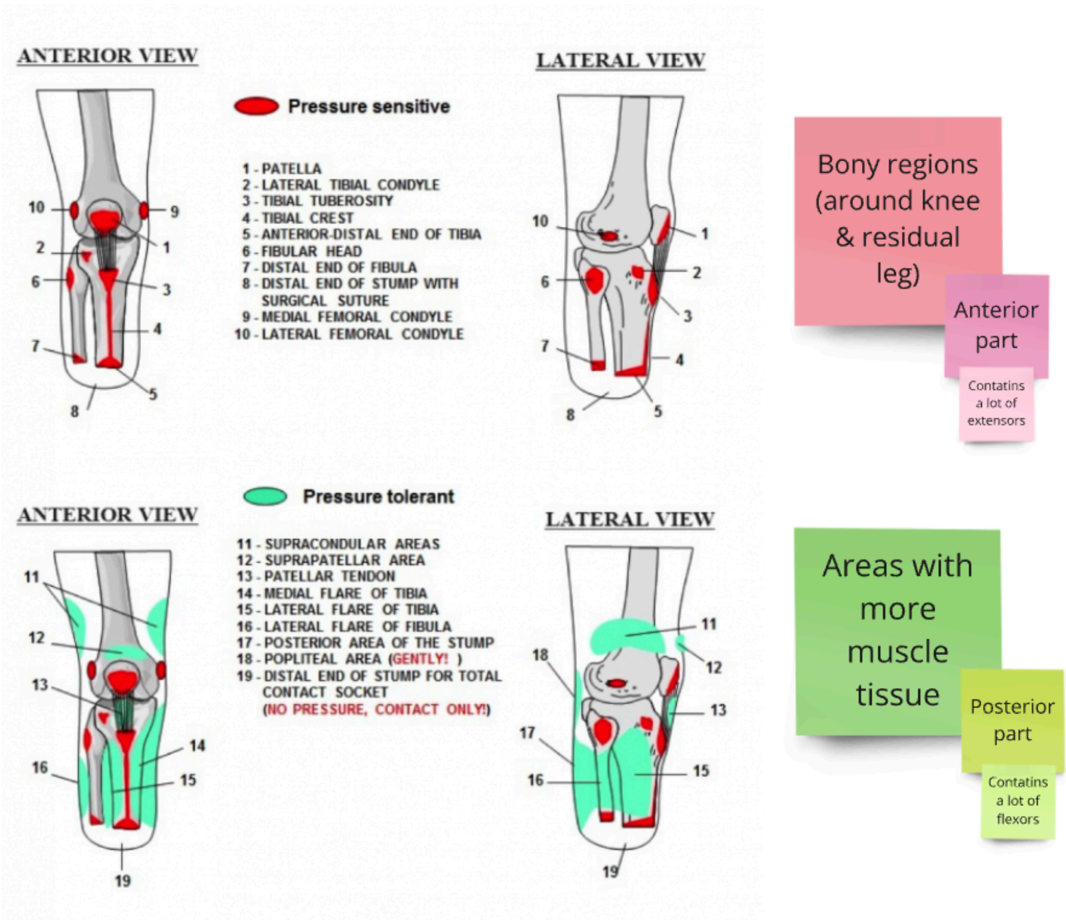

Figure 2: Pressure sensitive and tolerant areas in residual leg with transtibial amputation (Physiopedia, 2011)

The residual limb contains areas that differ in their ability to tolerate pressure, depending on underlying anatomical structures (see Figure 2). **Pressure-sensitive areas** include primarily bony regions such as the distal tibia and fibula, which are prone to discomfort or injury under load. Areas surrounding these bony regions, though slightly more resilient, still require protection to avoid discomfort or injury. In contrast, **pressure-tolerant areas** are composed mainly of muscular tissue. These are located primarily in the posterior region of the limb, such as the flexor muscle group, which can safely bear more weight.

1.1.3 Care and Maintenance

The following care guidelines are essential for maintaining the prosthetic socket, liner, socks, and residual limb (De Hoogstraat Orthopedietechniek, 2024):

- **Socket**: Clean the socket daily using lukewarm water and pH-neutral soap or 70% alcohol. After cleaning, rinse thoroughly and ensure the socket is completely dry before use.
- **Liner**: Wash the liner every day with lukewarm water and pH-neutral soap. After washing, rinse well and dry it thoroughly before use.
- **Sock**: Use fresh socks every day. Wash them at a maximum temperature of 40°C using neutral washing powder and avoid using fabric softener.
- **Residual Limb**: Promote blood circulation in the residual limb by massaging, brushing, or rubbing it with a rough towel. Alternating baths, where the water temperature switches between hot and cold, can also help improve circulation. For pressure spots, apply a hydrocolloid bandage.
- **Preventing Skin Conditions**: Skin conditions can result from factors such as socket fit, sweat, limb shape, and the overall care of the residual limb. Regular checks of the residual limb and socket fit are crucial for preventing these issues.

1.2 Residual limb pain and Other challenges

Residual limb pain is a common challenge for lower limb amputees and frequently starts right after the postoperative period. It can include irritation, infection, and phantom limb sensations (Hoffman, 2012), and is often described as a sharp, throbbing, or burning sensation that results from causes such as surgical trauma, neuroma formation, or underlying disease like infection or nerve pain. Each of these causes requires a tailored solution, such as medical treatment, surgical revision, or lifestyle changes. For neuroma-related pain specifically, vibration therapy has shown promise as a non-medical management strategy (Amputee Coalition, 2025).

Beyond these underlying causes, lower limb amputees also frequently experience discomfort and fatigue at the end of the day due to the increased physical effort required when walking with a prosthetic limb. This is particularly true for unilateral amputees, who often expend more energy during mobility than individuals with both lower limbs intact. Over the course of a day, this increased effort can result in soreness, tiredness, and general discomfort (Wright et al., 2008). This discomfort may also affect other parts of the body, particularly the intact limb, due to compensatory movements and biomechanical imbalances caused by the prosthesis (Fey et al., 2012; Wentink et al., 2013). Göktepe et al. (2010) further support this, linking extended prosthetic use to pain outcomes tied to both energy consumption and prosthetic fit and function. The design of the prosthesis plays a significant role, as poor fit or misalignment can increase pressure and shear forces, leading to pain during walking and other activities (Pitkin, 1997). In addition, effective muscle feedback during movement is important for maintaining stability. Without proper training or support, users may develop an unbalanced gait, further contributing to discomfort (Melcer et al., 2011).

The quality of the prosthetic foot also influences comfort. Elements such as stiffness and shock absorption affect energy return, and poor performance in these areas can result in greater muscle and joint pain in both the residual and intact limbs (Fey et al., 2012; Alaranta et al., 1994). On top of this, residual limb volume changes are a common issue for many users. Research shows that both increases and decreases in fluid volume can occur, even in mature residual limbs (Sanders & Fatone, 2011). These fluctuations are influenced by activity level, posture changes, and temporary conditions such as swelling from exertion (Sanders et al., 2018; Hamzah et al., 2022). Volume can vary throughout the day, depending on factors like temperature, physical activity, and how often the prosthesis is removed and reapplied (Sanders et al., 2012; Youngblood et al., 2019). To adapt to these changes and maintain comfort, users often adjust socket fit using socks of varying thickness (Swartzendruber et al., 2013). While self-adjusting sockets may become a future solution, current limitations around cost and added weight still pose challenges.

While self-adjusting sockets may offer a promising solution to managing daily limb volume fluctuations, current limitations such as added cost and weight make them less accessible for many users. In the meantime, addressing discomfort requires a broader and more accessible approach. Notably, stress and tension are known to intensify pain perception. Research indicates that up to 50% of pain can be alleviated through relaxation techniques alone (Amputee Coalition, 2025), highlighting the value of gentle, non-invasive strategies to support daily recovery and stress management.

Additional key findings related to volume change, pressure, comfort, and gait can be found in Appendix B.

1.3 Hoogstraat Orthopedie Insights

A visit to a prosthetist in Hoogstraat Orthopedie was conducted to gain insights into the making and fitting of lower limb prostheses in a real-world setting. The making of the instant socket can be found in Figure 3 below. During the visit, observations were made, and insights were gathered from the prosthetist regarding the challenges and nuances of prosthetic design and user experience. This includes key observations and an overview of suspension systems, which are registered in Appendix C and D.

From these observations, several takeaways are identified:

- **The creation of a socket is typically a static process.** Is it possible to design a socket in a more dynamic way? Would that be more comfortable for the user in dynamic situations?
- **The process of creating a fitting and comfortable socket is largely based on the intuition and experience of the prosthetist.** Is it possible to make the process less reliant on intuition and more systematic, following a clear, step-by-step methodology? Such a method would need to balance structure with flexibility to account for each user's unique anatomy, needs, and dynamic requirements. Achieving this balance could lead to more consistent results while still addressing the individuality of each user case.
- Physical check-ups are typically scheduled a year after the creation of a new socket as a standard appointment, or a month after the socket's creation if the patient reports any problems. In the meantime, patients can call if they experience issues. However, **some may fail to notice minor skin problems**, such as swelling, which could turn into more serious complications if not addressed in the early stages. Could a new approach be developed to help patients or prosthetists detect and address such issues sooner, thereby preventing larger problems? For example, with real-time monitoring and sensors?
- **All adjustments are made by prosthetists, which can delay comfort and fit when the residual leg undergoes change.** Is it possible to give the user more freedom to make adjustments for these changes? Or implement an automatic system which reduces these changes?
- **Aesthetics are seen as an accessory, separate from functionality.** Is it possible to combine aesthetics and functionality in a way that enhances both the appearance and comfort of the prosthetic?"

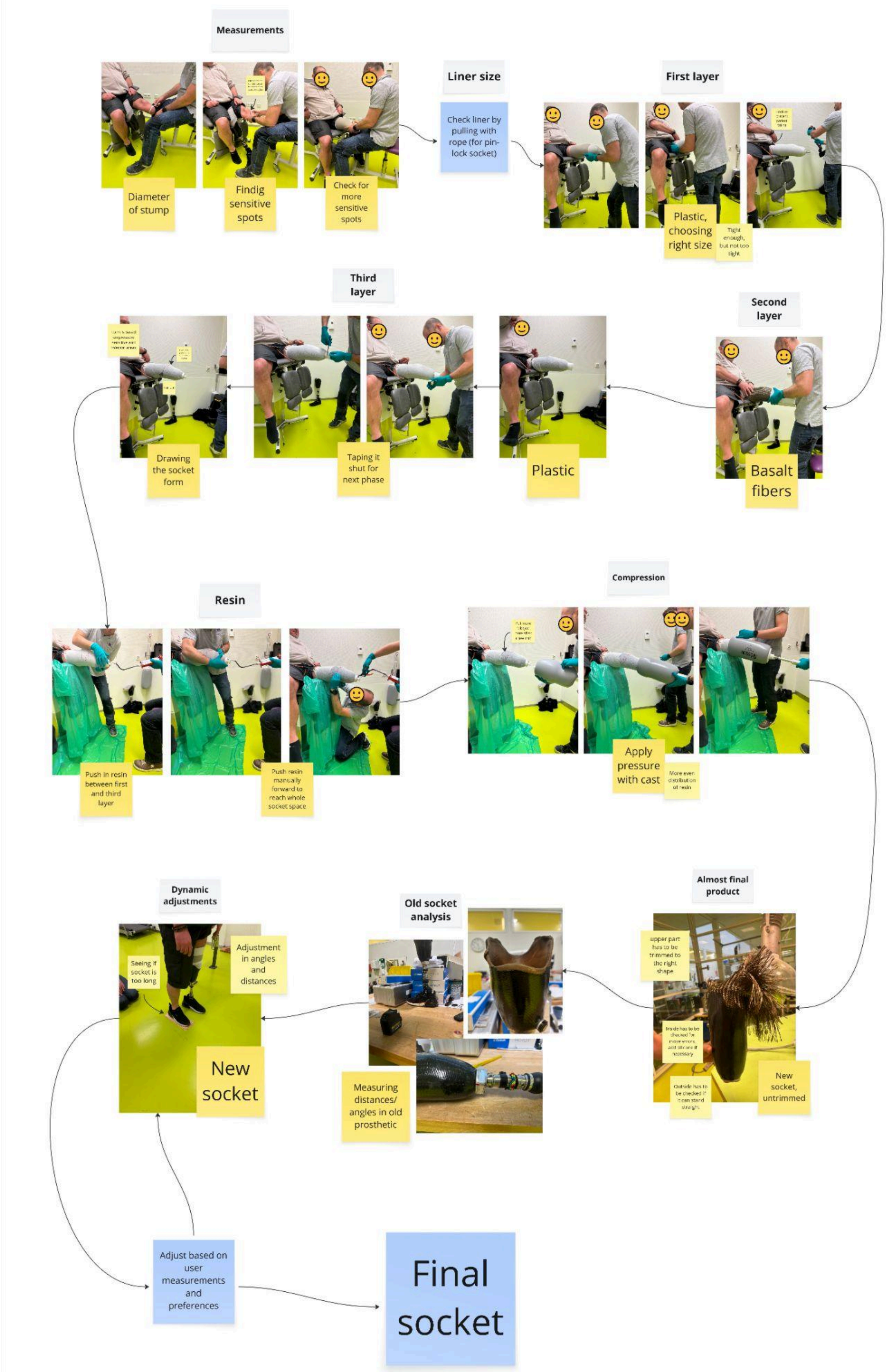

Figure 3: Making of the instant socket at Hoogstraat Orthopedie

1.4 User scenario

Understanding the daily experiences of individuals living with limb loss is essential for identifying the challenges they face and developing solutions to improve their quality of life. Below, an example of a day in the life of a below-knee prosthesis user is presented. This scenario highlights the practical challenges and coping strategies employed throughout the day. Inspiration from the user scenario is based on real life cases documented in Appendix E.

1.4.1 Day in the Life of Stacy

Morning

Stacy is a 32 year old transtibial amputee. She had to amputate her limb due to trauma, one of the most common causes of limb loss (Molina, 2019). Stacy begins her day calmly. She uses her iWalk crutch (Figure 4) to move around the house and prepares her breakfast. After breakfast, she spends some time doing embroidery in front of the TV. It's a quiet and focused activity that helps her ease into the day. After some time, she heads to the bathroom to shower. A non-slip mat is in place to reduce the risk of falling and a built-in seat is used for ease and comfort. After drying off, Stacy applies a silicone lotion to her residual limb to minimize friction when putting on her liner. She also wears a pair of modified leggings, where one leg is cut to accommodate her prosthesis. She then dons her prosthesis. Today she chooses to use vacuum suspension prosthesis instead of a shuttle-lock, as she plans to have an active day.

Figure 4: iWalk crutch (Probrace, 2025)

Afternoon

The weather is sunny but chilly. After having lunch with a friend, Stacy is now driving to a nearby lake now for a walk. Before starting the car, she doffs her prosthesis, as she only uses her intact leg to drive and finds this more comfortable. This is only possible because she is wearing her modified leggings. If she had chosen a regular pair of jeans, she would have had to keep the prosthesis on and tuck it under her other leg. While driving, she enjoys the warmth of the seat heater on her lower back, something she finds soothing because she often experiences discomfort in that area from wearing a prosthetic. Once arrived at the park, she takes a peaceful walk with planned breaks on the park benches. By late afternoon, snow begins to fall. Stacy decides to return to the car before the paths get too slippery for her prosthesis to walk on. The sudden drop in temperature also triggers an increase in phantom pain, making the walk back to her car more challenging.

Evening
Once back home, Stacy feels tired, but still prepares dinner and ends up having a quiet evening reading a novel. She notices that her residual limb is experiencing more pain than usual, likely due to the active day and the change of weather. After doffing her prosthesis, she cleans her liner using baby shampoo for her sensitive skin. She then decides to sleep on the couch. This allows her to elevate her residual limb and stay closer to the kitchen, where she needs to get ice for relief. Just before going to sleep she puts on her shrinker sock to help manage the volume fluctuation overnight, making it easier to put her residual limb into her socket the next morning.

1.4.2 Key Observations

- The user follows a calm and structured morning routine, which helps her transition into the day at her own pace. Physical activity such as taking a walk is also taken at her own pace to manage energy levels.
- Modifications to clothing can make everyday activities like walking or removing the prosthesis mid-day easier and more comfortable.
- Tools such as a non-slip mat and built-in shower seat are used to support safety and comfort during daily hygiene routines
- Daily donning and doffing routines include applying silicone lotion for reducing friction on the residual limb and washing the liner at the end of the day.
- Prosthetics are generally only used when the user starts the day, mainly when leaving the house. Before that the user opted for a crutch.
- The choice of prosthesis (e.g. vacuum suspension or shuttle-lock) is influenced by the activity level of the day.
- External factors like temperature and surface conditions directly impact mobility, and phantom limb pain.
- Comfort features in the environment, such as car seat heaters and benches, help manage secondary discomfort from prosthesis use.
- At-home recovery strategies, such as icing and elevation, are necessary after a hard day with the prosthesis.

- Independence is a strong value. Despite the fatigue and pain, the user continues to care for herself by having a structured morning routine, engaging with friends outside, taking a walk, and dedicating time to creative hobbies.

Conclusion

This chapter examined key anatomical and mechanical aspects of lower limb prosthetic users. A foundational understanding of pressure-sensitive and pressure-tolerant areas of the residual limb is essential to ensure comfort, prevent injury, and support effective prosthetic function. In addition to anatomical concerns, proper care of prosthetic components and residual limb is essential to maintaining limb health, and overall functionality.

Aside from technical and anatomical problems, amputees must also deal with comfort and adjustment issues. These challenges are often intensified by factors such as prosthetic pain and physical demands of wearing a prosthesis. A visit to a prosthetist in Hoogstraat Orthopedie, provided valuable insight into how these issues are addressed in practice. Observations of the fitting and adjustment process emphasized the importance of personalisation, but also highlighted the need for innovation in areas such as fit, monitoring and a more systematic approach. These highlights are discussed further in the next chapter *Exploration and Conceptualization*. Additionally, insights from the user scenario show how prosthesis users often make personal adaptations in their routines and environments to maintain comfort and autonomy. This reinforces the importance of user-centred design that considers not only function but also daily lived experience.

Taken together, the integration of anatomical knowledge, prosthetic design, maintenance practices, and real-world application illustrates the complexity of lower-limb prosthetic use. A holistic, user-centered strategy is still required in both clinical and research settings to improve mobility outcomes and quality of life for individuals with limb loss.

2 Exploration and Conceptualization

This chapter explores the development of new ideas to improve comfort for lower limb prosthetic users, beginning with technical research into pressure-sensitive areas and limb volume changes. After identifying the limitations of current sensor technologies and socket designs, a series of ideas were created. These were organized into clusters, informed by user insights and preliminary findings. Using tools like selection matrices and the Ansoff Matrix, the ideas were evaluated for feasibility and novelty and then grouped into clusters. Deeper investigation into the feasibility of these ideas led to the identification of Recovery as a promising concept, which addresses muscle relief and long-term comfort. This direction, supported by a revised journey map, offers a novel and adaptive approach to improving comfort for lower limb prosthetic users, and provides a structured starting point for the next phase of the design process.

2.1 Preliminary Research

As part of the preliminary research for this chapter, potential solutions to improve comfort for lower limb amputees were explored, with a focus on pressure-sensitive areas and residual limb volume changes. This research included a review of existing adjustable socket designs (Appendix F) as well as various sensors capable of detecting pressure and/or volume fluctuations (Appendix G). Within the sensor research, pilot tests were conducted using force-sensitive resistors (FSRs) and piezoelectric sensors to evaluate their performance and in conditions similar to those within a prosthetic socket. These informal tests, carried out in a non-laboratory setting, revealed that both sensor types exhibited unreliable performance, especially under curved or compressed conditions commonly found inside a socket. The supporting data and analysis can be found in Appendix H.

While additional sensing technologies (Appendix G) appeared promising, the decision was made to explore alternative methods beyond sensor-based solutions. This shift aimed to broaden the approach for improving user comfort in prosthetic design.

2.2 Ideation

The outcomes of this preliminary research phase contributed to a broader understanding of key challenges. However, the ideas in the takeaways list in chapter *1.3 Hoogstraat Orthopedie Insights* offered a different perspective, providing deeper insight into the user experience itself. Based on this set of concluded insights and the knowledge from the preliminary research, a series of ideation sketches were created through brainstorming (Appendix I). To evaluate and organize the ideas, a set of selection matrices was created (Appendix J). These tools helped to narrow down the range of ideas by identifying those that struck a balance between novelty and feasibility. The aim was to find a “sweet spot” which was not overly speculative but allows exploration into future development. These sketches placed within the matrices were further analyzed and put into thematic clusters. These clusters influenced the creation of the first version of a journey map, which visualizes an improved user experience with the prosthetic based on the research findings. The first version of the journey map, along with descriptions of all clusters, is shown in Figure 5. Further details of the Journey map will be explained in chapter *2.4 Revised Journey Map.*

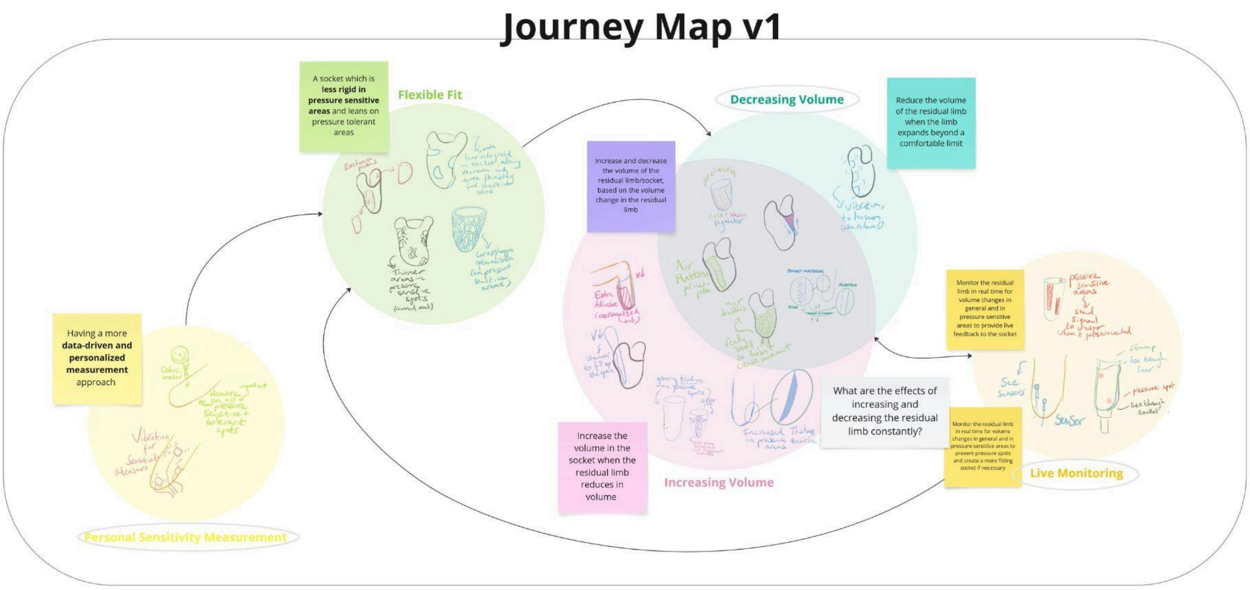

Figure 5: First version of the journey map with description

Within the journey map, only one focus area was selected for further exploration, based on several factors and time constraints. One key consideration was compatibility with the vacuum suspension system (see Appendix D). This suspension system requires a sealed environment to maintain negative pressure, making it less suitable for the ideas in **Flexible Fit**. Additionally, the residual limb tends to increase in volume rather than decrease when using a vacuum suspension system (Sanders, et al., 2011; Street, 2006), which makes **Increasing Volume** cluster less suitable. The **Personal Sensitivity Measurement** ideas were excluded because an effective solution already exists: a 14-actuator ring developed by MIT, which measures around the limb with multiple points to generate a 3D sensitivity map (TED, 2014). Finally, the **Live Monitoring** cluster was also eliminated due to time constraints. As a result, **Decreasing Volume** was selected as the best option for the next phase.

2.3 Exploratory Research and Final Direction

Figure 6: a. Multi-material 3D-printed socket and b. Pressure-Distributing socket

Following the initial selection of 'Decreasing Volume' as the most suitable direction, additional research was conducted to explore various ideas and technologies that could support this concept. These included:

- **AMI Surgery**: A surgical technique where nerves within the residual limb are connected to an external **bionic prosthesis**. Artificial electrodes are then placed on each AMI muscle to allow control and sensory feedback. (Bloomberg Originals, 2019; TED, 2018)
- **Sensitivity Measurement Technology**: The 14-actuator circle, developed by MIT, is a device that wraps around the residual limb to measure multiple parts

and creates a 3D map of sensitivity spots. This method gathers detailed information about pressure tolerance at different locations, which can be used to inform the design of a more personalized and comfortable prosthetic socket (TED, 2014). An example of such an application is the **multi-material 3D-printed socket**, which can be seen in Figure 6a (TED, 2014a).

- **Pressure-Distributing Socket**: A socket that distributes pressure more evenly across the residual limb, by using different kinds of materials and external components, preventing discomfort and improving fit. This socket can be seen in Figure 6b (Sengeh, 2012).
- **Temperature regulating liner**: the temperature-regulating liner by Outlast (2025), increases thermal comfort by helping the user maintain a consistent skin temperature and reduce perspiration-related discomfort.

These findings were mapped onto an Ansoff Matrix within **Existing Products - Existing Markets**, to assess their relationship to the existing prosthetics market (see Figure 7). This helped determine which solutions were already established and which had the potential for innovation.

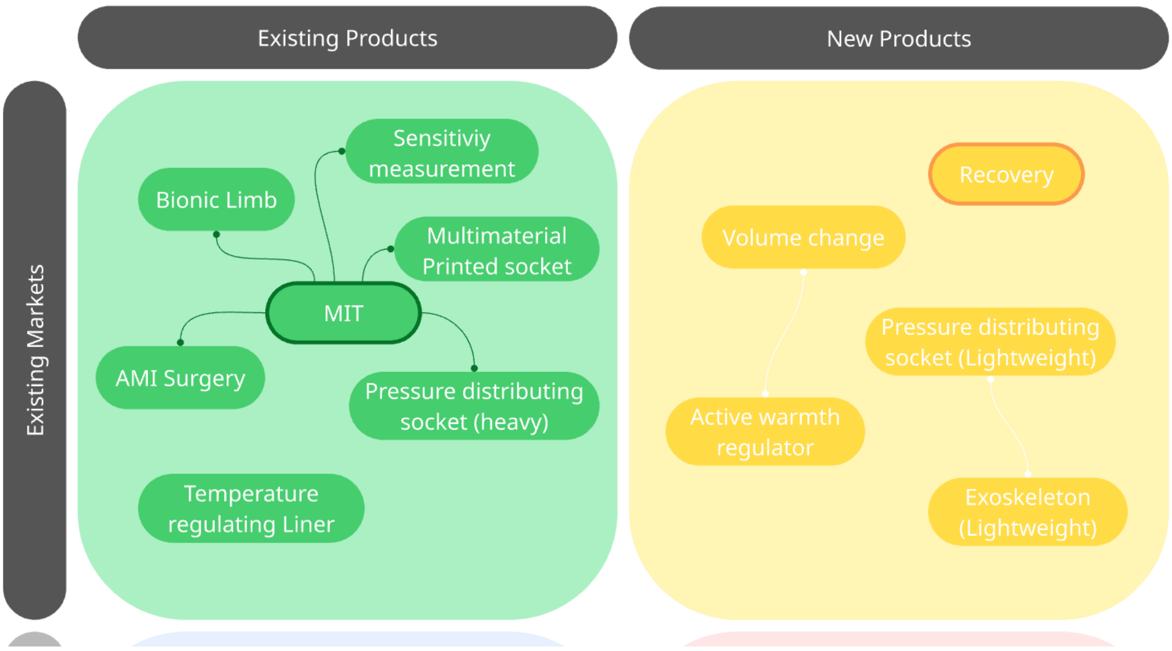

Figure 7: Ansoff Matrix: Overview of existing and new products in the same market

The *Decreasing Volume* cluster from the 2.2 Ideation phase was revisited, and further exploration was conducted to evaluate and refine the ideas (see Appendix K). This process generated new or more detailed product concepts that align with the **New Products - Existing Markets** category of the Ansoff Matrix (see Figure 7). These ideas focus on developing novel solutions within an already established market. Most relate to volume change or pressure, areas which have already seen exploration. Some concepts are closely aligned with existing products. Although these directions have value, they offer limited potential for differentiation or new user impact within the scope of this project. Additionally, the findings in *1.4 User Scenario* highlight the challenges users face at the end of the day. As a result, **Recovery** was selected as the most promising concept due to its limited exploration in the current market and its potential to address the identified user challenges. A list of requirements (Appendix L) was established to guide the final idea decision. One key requirement, that the product should not exceed the size of a standard socket, ultimately led to the selection of the concept *Recovery by Vibration* (see Figure 8). A concept which applies vibration therapy to the residual limb to support recovery and improve comfort.

Figure 8: Recovery by Vibration, The final idea direction

2.4 Revised Journey Map

Based on these new ideas, a revised journey map was developed (see Figure 9), with a more detailed version available in Appendix M. The clusters **Personal Sensitivity Measurement**, **Increasing Limb Volume**, and **(Live) Monitoring** remain unchanged, while the Exoskeleton idea (see Appendix K) has been added to the **Flexible Fit** cluster. Additionally, **Pressure Distribution** was included in the title to provide more context. The idea in **Decreasing Limb Volume** has been moved to the new cluster, **Improved Recovery**, which also includes the same Exoskeleton idea in Flexible Fit.

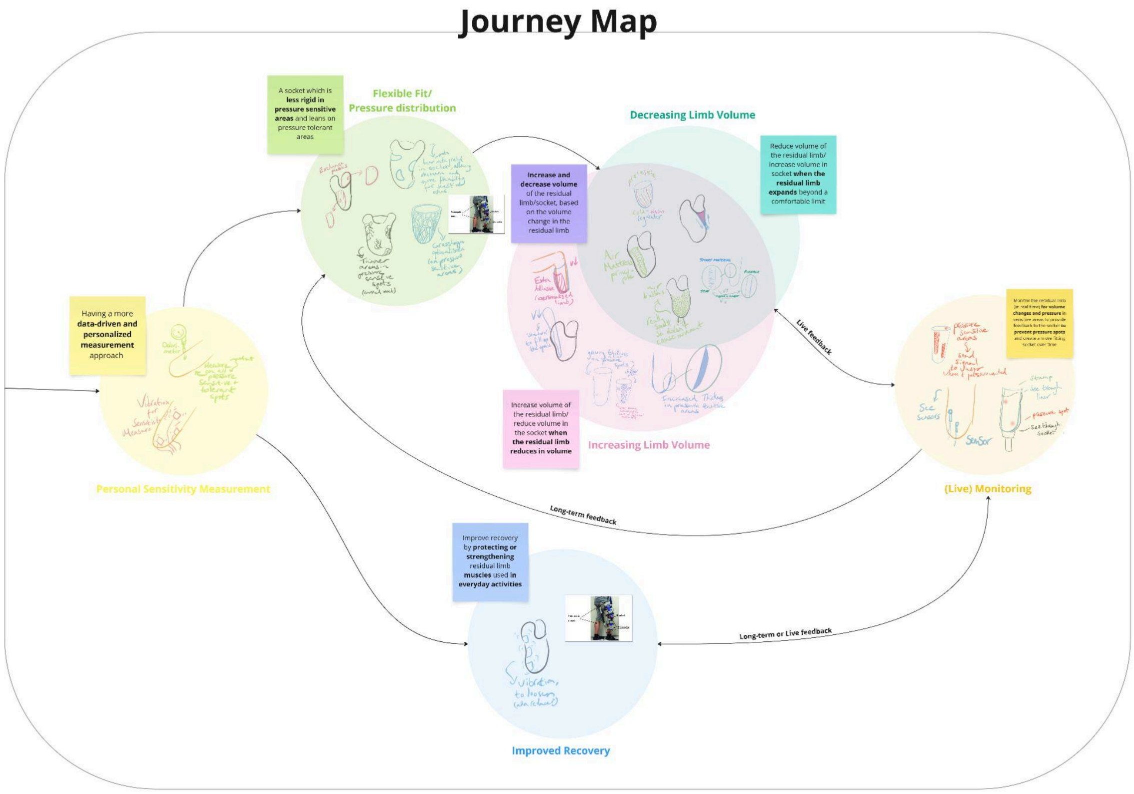

Figure 9: Revised Journey Map

The journey map begins with **Personal Sensitivity Measurement**, where the user's lower limb is measured in a data-driven way, providing a more precise mapping of pressure-sensitive and pressure-tolerant points, compared to traditional, intuitive methods. Once this data is collected, a custom socket is created that focuses on reducing rigidity in pressure-sensitive areas, while providing more support in pressure-tolerant areas. This makes the socket more flexible and offers an **even pressure distribution** for the lower limb.

As the user wears the prosthesis, the socket has the capability to **adjust the volume**—either increasing or decreasing based on **live feedback**, allowing the prosthetic to better fit the residual limb and enhancing comfort. In addition to 'live' feedback, a 'long-term' feedback option is available, where data is saved and analyzed over time to improve the socket fit, contributing to a more comfortable user experience.

Finally, the Improved Recovery cluster utilizes data from **(Live) Monitoring** or **Personal Sensitivity Measurement** to relieve pressure from the muscles throughout the day or at the end of the day. This helps in promoting muscle recovery and overall comfort during prolonged use.

Conclusion

This chapter brought together research, ideation, and analysis to define a direction for improving prosthetic comfort. Starting with technical exploration and existing prosthesis, the process moved from broad brainstorming to a refined set of ideas. Tools like selection matrices and the Ansoff Matrix helped structure the thinking and identify gaps in the current market. Among the ideas, the Recovery element stood out as both innovative and underexplored, making it the best choice for further development. Additionally, the journey map was updated to reflect how various innovations, ranging from pressure distribution to dynamic fit adjustments, can contribute to a more comfortable and responsive prosthetic experience. Together, these insights have shaped a clearer direction for the project, with a focus on the Recovery element.

3 Concept validation

This chapter explores the Recovery by Vibration concept, building on insights from scientific research, perceived product qualities, and analysis of existing products. Drawing from literature on vibration and heat therapy, the chapter outlines the therapeutic parameters most suitable for lower limb amputees. In addition, it defines the recommended timing of use to align with user routines and comfort needs. Finally, important design aspects like form, material, and temperature communicate the product's intended emotional and sensory experience, with the goal of providing a gentle, supportive, and restorative experience that is distinct from the prosthesis itself.

3.1 Vibration for Recovery Research

Vibration therapy is increasingly recognized as an effective method for muscle recovery, particularly in reducing muscle soreness and enhancing recovery following exercise. Several studies support the use of vibration therapy, both local and whole-body. According to research on delayed onset muscular soreness (DOMS), therapeutic vibration can considerably reduce pain, improve range of motion, and enhance kinesthetic awareness, strength, and blood flow (McLagan, 2025; Piotrowska et al., 2021; Physiopedia, 2025). In addition, vibration therapy is linked to changes in biochemical markers that reflect recovery. For instance, reductions in inflammatory biomarkers such as interleukin-6 and histamine have been observed, indicating a lower immune response, reduced swelling, and more efficient muscle repair (Lupowitz, 2022). It also shows potential in the healing of hard-to-heal wounds and management of neuropathy, expanding its relevance beyond muscle soreness reduction and recovery following exercise (Haba et al., 2024; Saragih et al., 2024).

3.1.1 Approaches within Vibration Therapy

Focal muscle vibration (FMV) is a targeted approach, which delivers low-amplitude and high-frequency stimulation to specific muscles. It has shown long-lasting benefits, including improved circulation, muscle mass gain, enhanced motor control, and reduction in joint and back pain (Tahir et al., 2022).

Whole-body vibration (WBV), on the other hand, involves standing, sitting or laying down on a platform that transmits vibrations through the entire body. (Edward & Laskowski, 2024). This technique stimulates large muscle groups simultaneously and is often used to promote muscle activation, improve proprioception, and enhance blood flow. Low-frequency WBV has also shown promising results in aiding recovery, reducing pain sensitivity, and improving muscle performance post-exercise (Akehurst et al., 2021; Piotrowska, 2021), without the harmful effects seen in high-frequency occupational vibrations (Kerschan-Schindl et al., 2001).

While the benefits of WBV generally improve with increased frequency and amplitude, careful tailoring of vibration parameters is needed to avoid side effects like head acceleration (Al Masud et al., 2022). In this context, focal vibration is more suitable due to its targeted approach.

3.1.2 Optimal Frequency, Amplitude, and Duration

Studies suggest that the most effective vibration frequencies for recovery range between 20 and 50 Hz for vibration therapy in general (Akehurst et al., 2021; Lapole & Pérot, 2010; Lupowitz, 2022; Raastad & Hallén, 2000). Reported vibration amplitudes typically fall between 0.1 and 0.5 mm, and session durations of 15 to 30 minutes are considered optimal for recovery (Akehurst et al., 2021; Piotrowska et al., 2021).

In the context of focal vibration therapy, both frequency and amplitude ranges are larger. However, shorter session durations of approximately 10 minutes are often recommended for focal applications (Myovolt Store, 2025; Human Locomotion, 2025). Tahir et al. (2022) categorize vibration frequencies into three ranges:

- **Low frequency** (30–50 Hz): Relaxation and treatment of delayed-onset muscle soreness (DOMS)
- **Medium frequency** (80–120 Hz): Proprioceptive improvements and treating pain
- **High frequency** (120–300 Hz): Strengthening of muscle fibers

Capobianco (2024) gives a similar result, noting that higher frequencies (100 to 250 Hz), are most effective for pain relief and muscle activation due to enhanced blood flow, while lower frequencies promote relaxation and reduce post-exercise soreness.

In a broader review of 56 studies, the optimal frequency range for focal vibration therapy appears to fall between 60 and 120 Hz with amplitudes up to 1 mm (Figure

10). This range has been shown to aid in muscle repair and supports the potential of focal vibration therapy as a method to improve outcomes in individuals with limb amputation (Penasso et al, 2023).

However, the effectiveness of vibration transmission is not determined by motor output alone. Thicker and softer interface materials, such as a liner, tend to dampen or filter out high-frequency vibrations. As a result, lower-frequency vibrations are more likely to transmit effectively through these materials, although achieving this may require a larger or more powerful vibration motor (Precision Microdrives, 2021a).

Based on these results, a frequency range of 30 to 120 Hz and an amplitude range of 0.01 to 1 mm are selected. Both low and medium frequencies are chosen to create a balance between relaxation and muscle recovery, while maintaining feasibility when a liner is involved. To achieve sustained benefits, vibration therapy should be incorporated 2 to 3 times per week, for 10 minutes per session, as part of a regular recovery regimen. However, the specific timing and parameters may need to be adjusted depending on individual fitness levels, recovery needs, and athletic goals. While most applications are applied post-exercise, pre-exercise sessions have also shown promise (McLagan et al., 2025; Piotrowska et al., 2021).

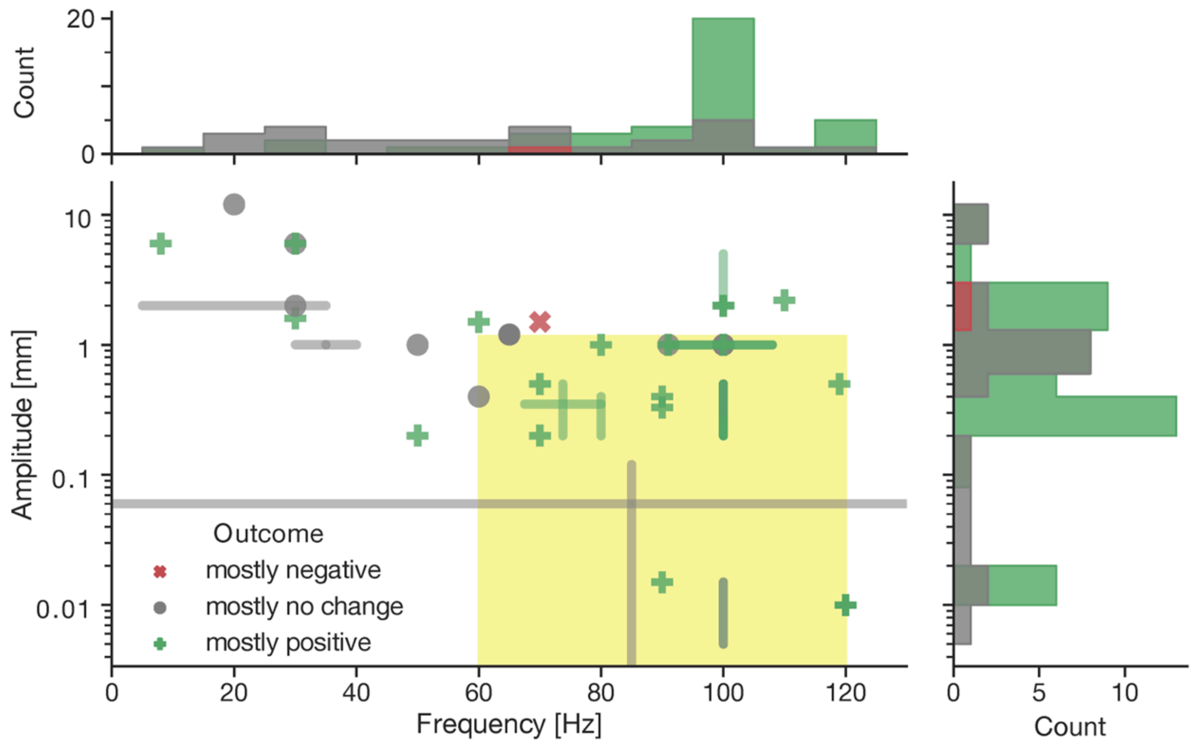

Figure 10: Optimal frequency and amplitude range for focal vibration therapy (Penasso et al, 2023)

3.1.3 Vibration vs. Massage

While (focal) vibration therapy is not shown to be more effective than massage or stretching in reducing muscle soreness (Fuller et al., 2015), it offers advantages in terms of portability, autonomy, and broader therapeutic applications. Because vibration motors are typically smaller and flatter than those used in massage devices, the resulting products can be more compact, lightweight, and wearable, giving users the freedom to apply treatment independently and in any suitable setting. Vibration therapy has also been shown to improve postural stability in transtibial limb amputees (Rusaw et al., 2012). This shows that vibration therapy can aid both muscle recovery and proprioceptive function, which is especially valuable for individuals with lower limb loss. In contrast, while vibration has also shown promising effects on hard-to-heal wounds and neuropathic symptoms (Haba et al., 2024; Saragih et al., 2024), massage interventions have not shown similar results. One study, for example, reported no evidence of healing progress associated with massage (Isworo, 2021).

3.2 Existing Products and Specifications

3.2.1 Limitations in Current Products

Despite the growing scientific support for vibration therapy, the number of commercially available vibration-specific recovery products remains relatively limited. The majority of devices currently on the market are massage-based, including massage chairs and massage guns (Figure 11a). Wearable vibration systems, such as Myovolt (Figure 11b), are less common. These products vary significantly in form, function, and user experience, which influences their applicability in daily recovery and rehabilitation contexts. Unlike vibration therapy devices, electrical muscle stimulation (EMS) induces muscle contractions using electrical impulses and can be uncomfortable due to the intensity of stimulation. Improper use of EMS may also pose health risks, which is why it is not included in further research (Pulse Device, 2025).

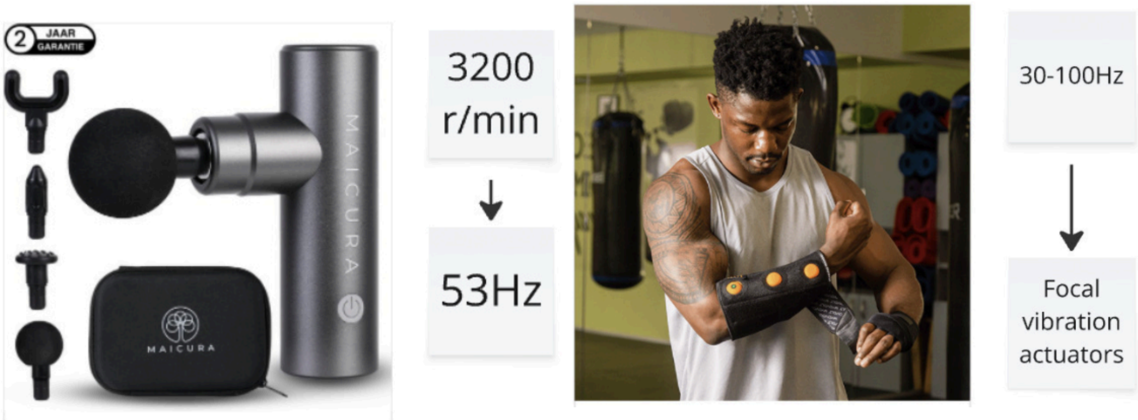

Fig 11: a. Massage Gun (Maicura, 2025), b. Myovolt wearable (Myovolt Store, 2025)

Massage guns are a massage device with vibration and are widely available on the market. However, there is a risk of applying excessive pressure on muscles because they require self-application. This can also increase the chances of improper use. Excessive force may aggravate sensitive tissues or lead to discomfort. Especially in users with residual limbs, where pressure-sensitive areas are more common. In contrast, wearable devices like Myovolt deliver targeted focal vibration without requiring the user to manually apply pressure. Because the device is worn on the body and secured with straps, the intensity remains consistent and gentler, promoting comfort and usability. This approach is particularly beneficial for individuals with limited mobility or those seeking passive recovery solutions during the day. Notably, the frequency range reported by Myovolt aligns with findings from *3.1 Vibration for Recovery Research*: it has been reported to deliver vibration in the range of 30-100 Hz.

3.2.2 Temperature

Temperature therapy has been used to support muscle recovery, particularly following physical activity. Research shows that both cold and heat applications are effective in reducing muscle damage after exercise (Petrofsky et al., 2015). However, while cold therapy offers clear benefits, its integration into a compact, wearable product presents significant technical challenges. For this reason, heat therapy is prioritized in the current concept development.

Local heat application has been shown to enhance blood flow, reduce muscle stiffness, and improve overall tissue elasticity. The temperature range for local heat therapy typically lies between 38°C and 43°C (McLagan, 2025), and this can be applied for 15–20 minutes at a time (Kumar, 2024). However, sessions should not exceed 20 minutes (Department of Health, 2021), as prolonged exposure can result in inflammation or injury. The muscle tissues also need gradual warming to benefit fully from the heat therapy (Trentacosta, 2021). Heat can be applied 2–3 times per day (Department of Health, 2021). with at least one hour of rest between sessions (Kumar, 2024).

Further research supports that raising muscle temperature to around 40°C leads to favorable effects on muscle recovery (McGorm et al., 2018). Notably, McGorm et al. also found that applying heat more than 16 hours before exercise may result in better outcomes than heating immediately beforehand. This may relate to the role of heat shock proteins (HSPs)—a family of proteins that respond to physiological stress and assist in cellular repair (Hu et al., 2022). These proteins tend to increase significantly approximately 24 hours after heat exposure, suggesting that heat may trigger longer-lasting adaptive responses beneficial to muscle performance and repair (McGorm et al., 2018).

These findings align with the functionality of commercial systems like Myovolt, which operates within the 38°C to 40°C range for muscle performance applications. For sub-acute or chronic injury recovery, a slightly higher range of 40–45°C applied over 15–20 minutes is recommended for better rehabilitation purposes (Myovolt Store, 2025a).

3.3 Desired Perception and Experience

In the design of prosthetic products, the user's perception and emotional experience are just as important as functionality. The way a product looks, feels, and behaves directly influences how users relate to it, influencing a user's sense of self. This includes how they want to be perceived by others. The context of use also helps define the product's tone and purpose. In this section, product characteristics and timing of use will be explored, with an emphasis on the characteristics.

3.3.1 Characteristics

Characteristics have been brainstormed from a designer's perspective to get a better understanding of how lower limb users may perceive their prosthesis (see Figure 12). Positive characteristics identified include sturdy, reliable, and loyal. These are qualities that align with the user's desire for independence and belonging in daily life. However, negative impressions also emerged. The prosthesis is often seen as counterintuitive, largely due to a visual and tactile disconnect: while the upper part has an organic form, the lower part appears rigid and mechanical. This contrast in form, combined with cold, futuristic materials, contributes to an impression of stiffness and discomfort. Despite its intention to mimic a human limb, the prosthesis can feel impersonal or unnatural.

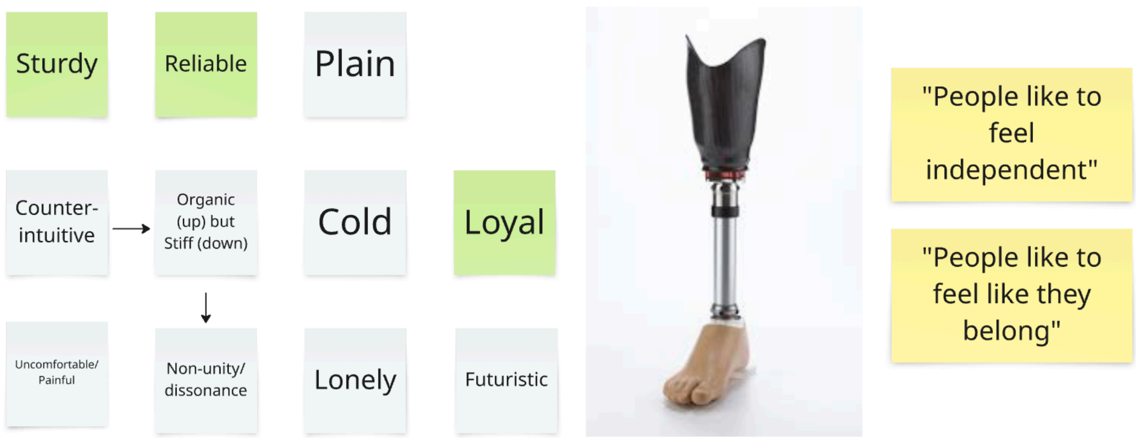

Figure 12: Characteristics of a prosthetic limb

The existing characteristics provided a base for exploring features of the Recovery by Vibration concept. However, the concept serves a completely different function: aiding in muscle recovery rather than providing a means to walk. Several mood boards were created to explore and communicate this shift.

Figure 13: Moodboard Calm and Peaceful

In Figure 13, the intention is to evoke a sense of calm and peace, a moment of relief the user looks forward to at the end of a long day. The goal was to position the product as part of a relaxing routine at the end of the day, similar to a massage or wellness device. Common elements in the moodboard are soft, organic forms and natural colour palettes, conveying freshness and slow, soothing movement.

Figure 14: Moodboard Kind & Caring

Figure 14 expresses kindness and care. The intention was to make the product feel emotionally supportive, as if offering a gesture of affection after a long day of coping with socket-related pain. This is visually communicated through handmade aesthetics: objects that look imperfect but one-of-a-kind. Forms are rounded and embracing, with cheerful yet balanced colours. The materials suggest warmth, flexibility, and a softness that feels welcoming.

Figure 15: Moodboard Gentle, Helpful and Reliable

In Figure 15, the moodboard introduces the characteristics of gentleness, helpfulness, and reliability. These were expressed through long, rounded shapes and soft pastel tones. It also features some harder elements, such as in the material or colour. This suggests reliability, without compromising the aspect of comfort. The sensation accompanying these charisteristics is a low vibration, portraying the gentleness, and a structure that is soft yet strong enough to be supportive.

Bringing together the insights from all moodboards, the Recovery by Vibration concept is designed to offer a softer and more supportive experience than the prosthesis. The goal is to evoke a feeling of care, relief and recovery at the end of the day, without losing the feeling of reliability. Based on the findings, the product should express the following qualities:

- **Colour**: Muted yet colourful, using soft pastel tones combined with harder and darker elements to signal comfort and reliability.
- **Form**: Rounded, organic, and embracing to evoke kindness and support.
- **Material**: Soft and flexible, while maintaining enough structure to feel stable and reliable.
- **Tactile Experience**: Low, gradual vibrations in waves, to support relaxation and recovery
- **Temperature:** Warm, offering a sense of kindness and comfort.

Intended Character: Gentle, caring, helpful, and dependable, offering comfort from home in a relaxing way.

For this project, the experience will be mainly incorporated in the tactile feel of vibration, as it is the key sensory element.

3.3.2 Timing of use

Timing of use is an important consideration in the design of prosthetic-related products, as it influences both user experience and effectiveness. It is decided that the Recovery by Vibration concept is intended primarily for use at the end of the day, when discomfort and fatigue from prosthetic wear are most commonly reported (Wright et al., 2008). However, research also suggests that vibration therapy may be beneficial when applied at the beginning of the day to help prepare the body for activity (McLagan et al., 2025; Piotrowska et al., 2021). Based on findings in chapter 3.1 Vibration for Recovery and 3.2 Existing Products and Specifications, a recommended usage schedule would involve approximately 15 minutes of vibration therapy both in the morning and evening. Heat therapy is included to provide additional relief. These moments of relief, between donning and doffing, could further support comfort and recovery during ambulation without compromising usability.

Conclusion

The evidence presented highlights the various benefits of vibration and heat therapy for muscle recovery, stress reduction, and pain management. Such outcomes are especially relevant for lower limb amputees, who often experience daily fatigue and socket-related discomfort. Vibration therapy has been shown to improve circulation, proprioception, and postural control, while also offering potential in wound healing and neuropathic pain relief. Similarly, heat therapy can enhance tissue elasticity and muscle repair when applied within safe temperature and time ranges.

Based on these insights, the Recovery by Vibration concept should incorporate low-amplitude vibration of 0.1-1 mm, within a frequency of 30–120 Hz, applied for around 15 minutes per session based on the average focal vibration and heat therapy time. Ideally, vibration therapy would be used in the morning to prepare the body for activity and in the evening to promote relaxation. Additional sessions during the day are also possible, depending on individual needs. Gentle heat can be optionally combined in the 38–43°C range to support relaxation and recovery. However, if only one session per day is feasible, the evening session would be the most beneficial. To complement its physical benefits, the concept should also deliver a comforting emotional experience. This includes rounded, organic forms and soft but flexible materials can help create a sense of relaxation and support. In frequency and amplitude, this can be achieved by gradually increasing and decreasing the parameters in a wave-like way. This positions the product not just as a recovery device, but also as a moment of care and relief in the user's daily life.

4 Motor Selection and Placement

In this chapter, there will be a closer look taken at the focal vibration therapy part. This includes selecting the most suitable vibration motors for focal vibration therapy within the prosthetic socket. This selection is based on desktop research, with one motor type tested beforehand. The optimal placement of the motors on the residual limb is also explored by identifying the most relevant muscles.

4.1 Selection of Most Suitable Vibration Motor

4.1.1 Testing Linear Resonant Actuators

Linear resonant actuators (LRAs), a type of vibration motors, were selected at first because they are a compact and low-cost actuator capable of producing targeted vibration, making it suitable for this application. To assess feasibility, a basic test setup was created using an Arduino UNO. Wires were soldered to the LRAs to ensure a stable connection throughout the testing process. A library is used to change the frequency (LearnElectronics, 2017). Figure 16 shows the set-up of the LRA with the Arduino Uno. The arduino code for the LRAs testing in this part can be found in Appendix N.

During testing, it was found that the vibration motor maintained a relatively consistent frequency, even when the frequency was altered. This observation is in line with Cao (2025), who informs that the optimal performance in frequency is set to the range of 170-180 Hz. Any changes outside this range do not reliably alter the output frequency. However, the vibration intensity varied when adjusting the duty cycle. The Amplitude could not be controlled independently with the LRA alone. Based on calculations, the default amplitude is approximately 50 (see Appendix N).

To enable more refined haptic feedback, the LRA can be paired with an Adafruit DRV2605L Haptic Motor Controller (see Figure 17). The basic, real-time, and complex codes and effects can be found by including the Adafruit_DRV2605.h library in Arduino. While this expands the range of programmable feedback modes, it also increases overall cost. On top of that, there is currently no evidence that these enhanced haptic effects provide the same therapeutic benefits as vibration therapy.

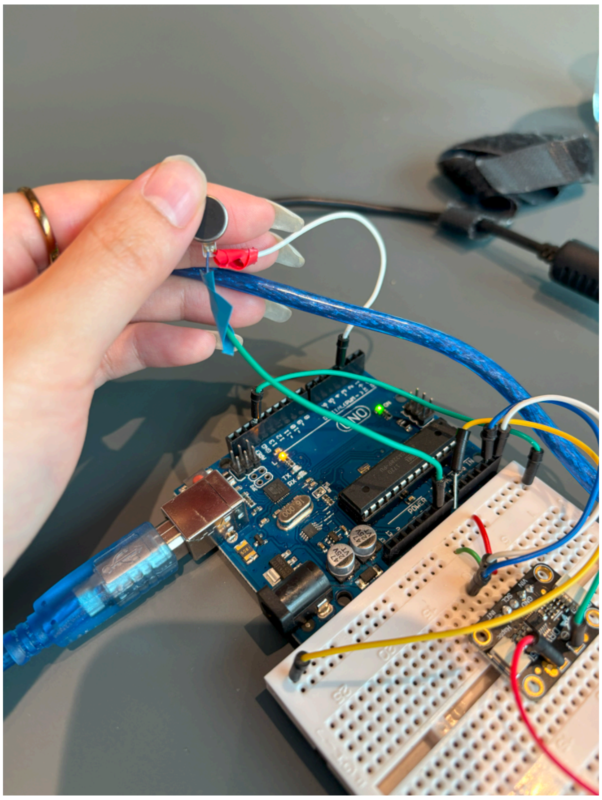

Figure 16: LRA Set-up

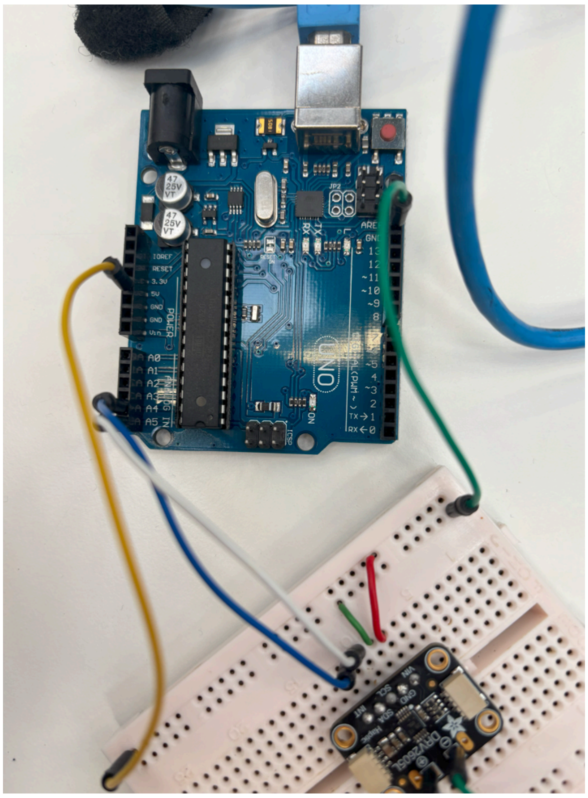

Figure 17: DRV2605L Set-up

Due to time constraints, more extensive testing of different vibration motors could not be conducted within the scope of this project. As a result, only desk research was carried out to identify the most suitable vibration motor in section *4.1.2 Selection of Vibration Motors*. However, for prototyping the LRAs will still be used to demonstrate the general functionality and feasibility of the concept.

4.1.2 Selection of Vibration Motors

The table below (Table 1) presents an overview of the main actuator types, focusing on the key areas: frequency range, amplitude, depth of vibration, and performance. This table is created to compare and determine the most suitable option for use in focal vibration therapy.

Type	**Frequency Range**	**Amplitude**	**Depth of Vibration**	**Performance/ Accuracy**
Voice Coil Actuator (VCA)	Wide, 1 to 500 Hz	Adjustable, 0.05-67mm	Deep	Excellent
Eccentric Rotating Mass (ERM) Motor	Increases linearly with applied voltage, from 1 Hz up to 300 Hz	Coupled with frequency	Deep	Moderate
Piezoelectric Actuator	Very broad, up to 50KHz	Dependent on the type, due to high range	Shallow to Deep, dependent on the type	Excellent
LRA	Fixed, 170-180 Hz	Adjustable	Shallow	Good

Table 1: Different types of Vibration motors, comparing Frequency range, Amplitude, Depth of Vibration and Performance/Accuracy. (Bala, 2023; Cao, 2025; H2W Technologies, 2018; Newport, n.d.; Schumate, 2016)

The **Voice Coil Actuator (VCA)** was determined to be the best choice for further idea development based on a comparison of the most important characteristics: frequency range, amplitude, depth of vibration and performance.

- **ERM and LRA motors**: are more affordable and readily available for quick prototyping, but their restricted frequency and amplitude control makes them less suitable for applications that require precision, such as in focal vibration therapy.

- **Piezoelectric actuators**: range in a wide variety and provide excellent precision. However, their fragility reduces the feasibility for inside the prosthetic socket (Liu et al., 2020).

4.2 Placement of vibration motors on the Residual Limb

Focal vibration therapy typically involves wrapping and fastening a vibration device around the targeted muscle, ensuring minimal to no movement. The stabilization is required for isometric contractions,in which the muscle remains at a constant length and joint movement is restricted. During vibration, it is required for the user to be in a stretching position for certain muscle groups. Figure 18 shows examples of these stretching positions while the vibration device is applied on certain muscle groups. Once positioned, the isometric contractions can be performed to relax the muscles. (Human Locomotion, 2025).

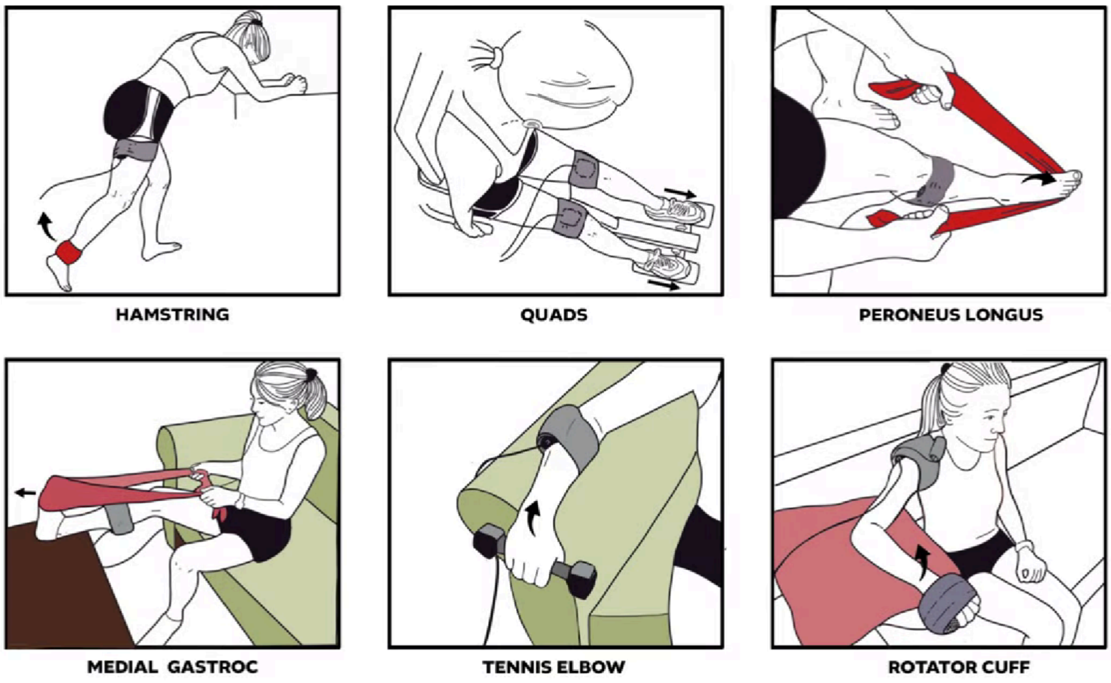

Figure 18: Positioning of the vibration device with possible stretching

Unfortunately, no research has been found on focal vibration to the residual limbs of transtibial amputees. Therefore, the following section will explore the placement of vibration therapy on relevant muscle groups.

4.2.1 Elimination of Muscles

- **Muscles above the knee**: such as core muscles, quadriceps and hamstrings, play a big role in stability and walking with a prosthesis for transtibial socket users. (Zepeda, 2024). It is also found that these users walk using a higher residual limb biceps femoris instead of intact biceps femoris. (El Ghailassi, 2024). However, these muscles cannot be targeted for vibration therapy inside the lower limb socket.
- **Runner's Knee**: Patellofemoral pain syndrome is characterized by anterior knee pain resulting from repetitive stress in the knee joint. Besides running, it can also affect individuals engaging in activities that involve frequent knee flexion, such as walking, squatting, or climbing stairs (Linderbaum, 2016). However, transtibial socket users show a reduced knee flexion during gait due to gait compensation strategies, and the absence of a biological ankle and foot.

While upper limb muscles are suitable for vibration therapy, they are not compatible with the design wishes for the transtibial socket (see Appendix L). Therefore it falls outside the scope of this project. However, future research could explore vibration integration for upper-limb prostheses or wearables. Similarly, runner's knee is less relevant in this context, as transtibial users exhibit reduced knee flexion during gait.

4.2.2 Relevant Lower Limb Muscles

According to ASEC (2017), the muscles affected by a transtibial amputation are distributed across the four major anatomical compartments (Figure 19) of the lower limb:

- **Anterior Compartment**: Anterior Tibialis (AT), Extensor Hallucis Longus (EHL), and Extensor Digitorum Longus (EDL)
- **Deep Posterior Compartment**: Posterior Tibialis (PT), Flexor Hallucis Longus (FHL), and Flexor Digitorum Longus (FDL)
- **Lateral Compartment**: Peroneus Longus (PL) and Peroneal Brevis (PB)
- **Superficial Posterior Compartment**: Soleus, Gastrocnemius

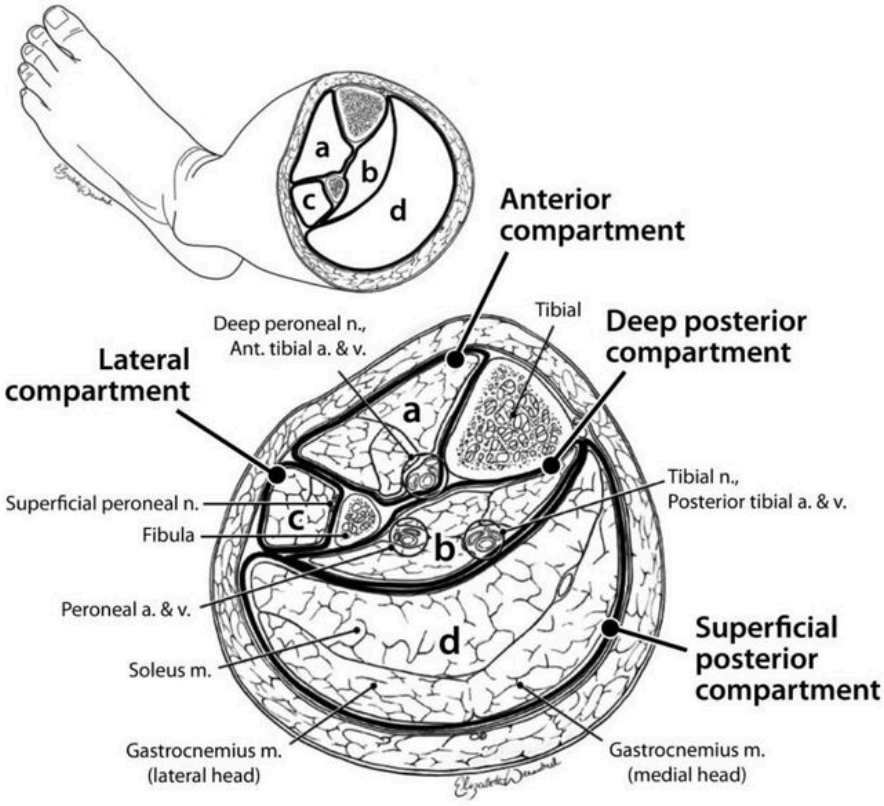

Figure 19: Four anatomic compartments of the lower limb in Transtibial amputees (Van Wyck, 2016)

Finite element modeling by Sampaio de Oliveira & Uchida (2025) shows that out of these muscles, which muscle contractions influence pressure distribution within the lower limb socket (Figure 20). Five high pressure zones were identified. (Figure 21):

- **Popliteal Fossa**: Experiences most pressure during heel strike.
- **Patellar Tendon**: Exhibits the highest pressure at toe-off, likely due to its function in force transfer.
- **Tibial Tuberosity**: Displays moderate pressure, yet remains clinically significant due to its prominence and sensitivity.
- **Fibular Head & Residuum Tip**: Experience significant pressure, especially during mid-stance and toe-off.

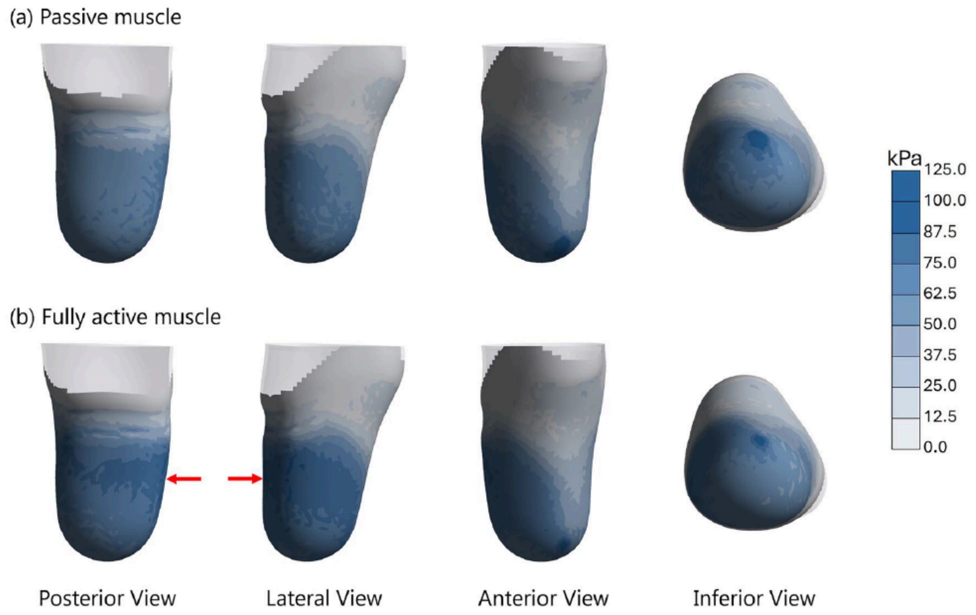

Figure 20: Map of predicted socket pressure in the residual limb (Sampaio de Oliveira & Uchida, 2025)

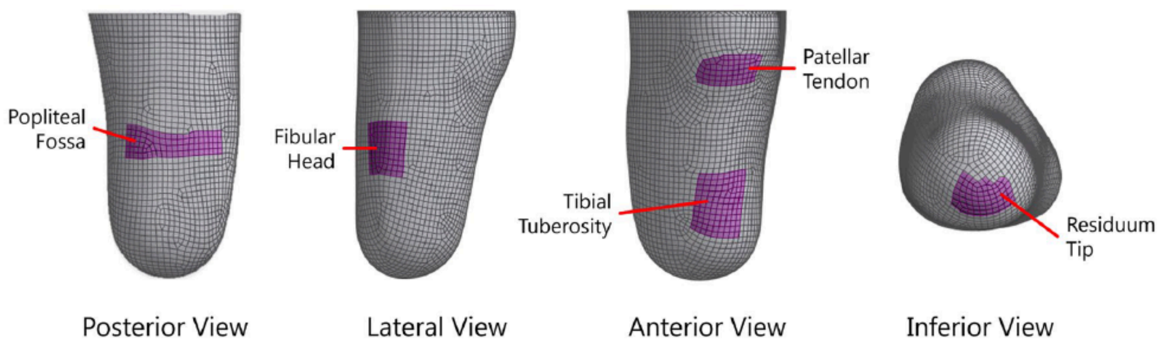

Figure 21: The highest predicted pressure zones (Sampaio de Oliveira & Uchida, 2025)

4.2.3 Most Suitable Muscles for Vibration Therapy

Based on the anatomical findings and pressure distribution presented in this chapter, the following muscles have been selected as the most suitable targets for focal vibration therapy.

- Gastrocnemius Medial Head
- Soleus
- Peroneus Longus
- Tibialis Anterior

This selection is based on the location and their use in existing focal vibration applications, which can be found in Appendix O. Figure 22 shows the placement of each vibration motor within the prosthetic socket, based on the selected muscles. During the vibration therapy, stretching of the residual limb may be necessary for all three muscles, except the tibialis anterior. However, due to limited existing research on how these muscle groups respond to vibration therapy in residual limbs, further investigation is needed.

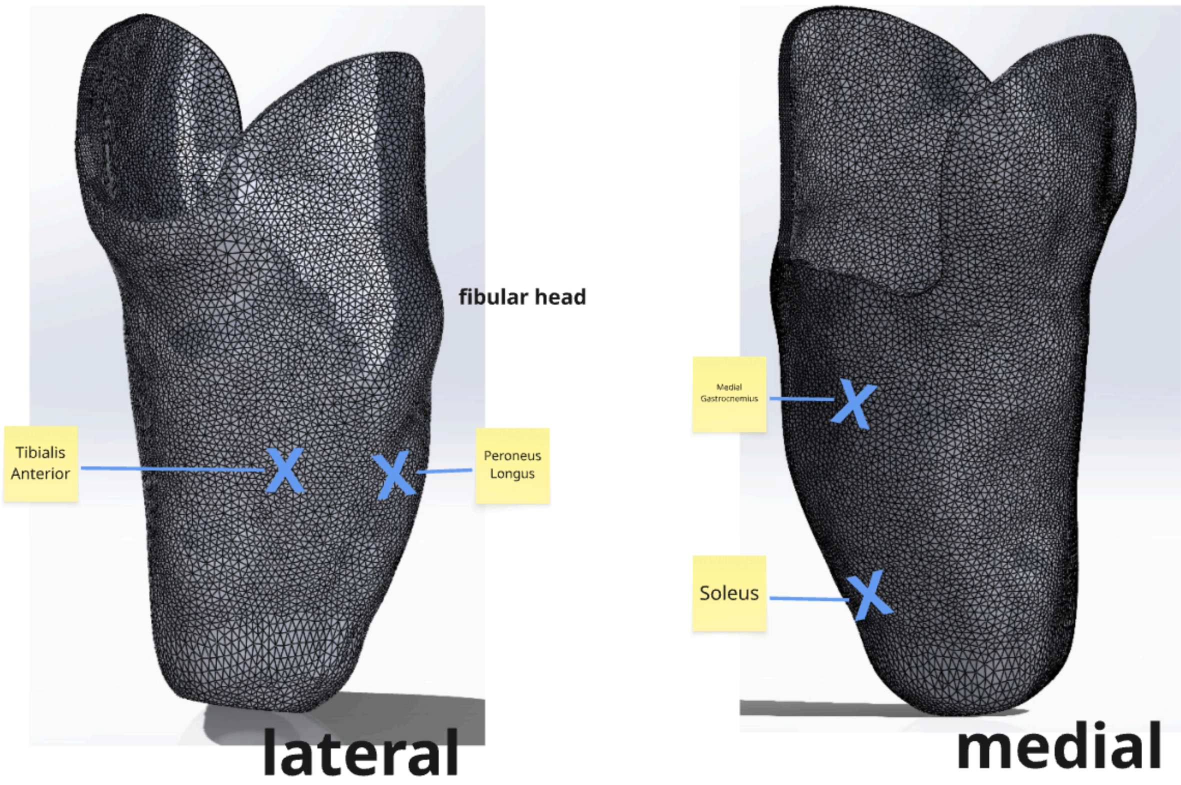

Figure 22: Placement of the vibration motors on target muscles within the socket

Conclusion

This chapter highlights the most suitable vibration motors and their optimal placement for focal vibration therapy within a transtibial prosthetic socket. Through testing and comparison, the Voice Coil Actuator (VCA) was selected based on its most fitting parameters. Relevant residual limb muscles were also analyzed, leading to the selection of four key target areas for motor placement. These insights are an important part in the concept design, and are carried forward into the next chapter *Translating Research into Design*.

5 Translating Research into Design

In this chapter, a physical prototype is developed to illustrate the initial test setup. Required components and estimated costs are gathered to provide an approximate sales price and to compare the weight of the design with that of a traditional socket. Finally, all findings are brought together to create a final design concept, which serves as a basis for future research.

5.1 Prototyping

5.1.1 3D-Modeling and Printing

A simplified version of the socket is created in Solidworks, incorporating four Voice Coil Actuators (VCAs) positioned over the Gastrocnemius Medial Head, Soleus, Peroneus Longus, and Tibialis Anterior muscles to support focal vibration therapy. The circular cavities indicate spaces for the vibration motor placement, while the rectangular openings help the routing of wires to the exterior of the socket (Figure 23). Positioning the wiring externally minimizes interference with socket comfort and allows for easier extension or adjustment during testing procedures. The entire socket is 3D-printed using the UltiMaker S5. Both the SolidWorks and 3D-printed socket are presented in Figure 24. Additional pictures of the Solidworks model are shown in Appendix P.

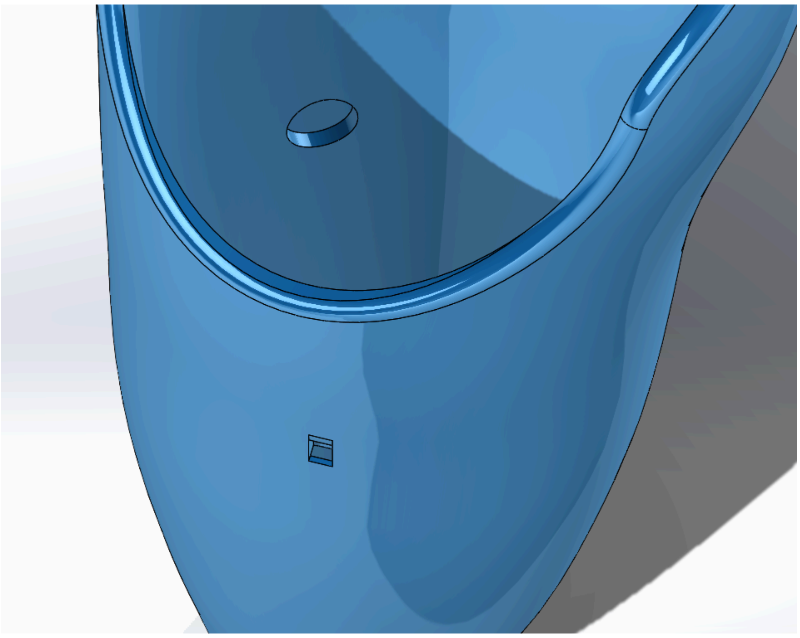

Figure 23: Circular and rectangular cavities for the vibration motor and wires

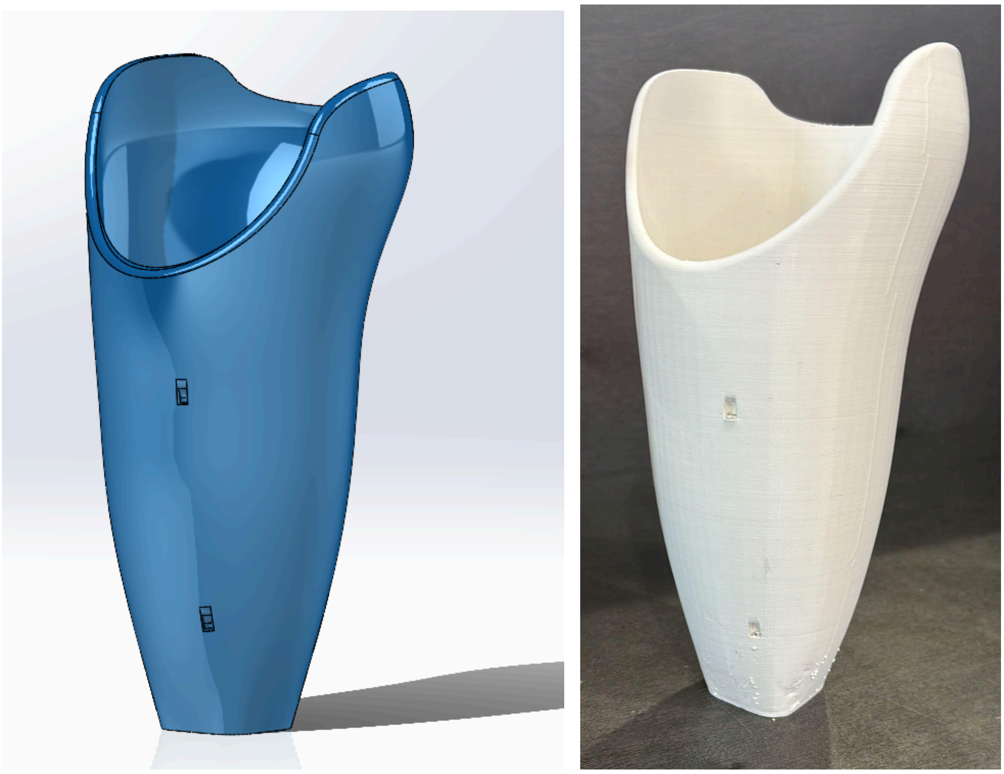

Figure 24: SolidWorks socket (left) and 3D-printed socket (right)

Figure 25: Support inside the vibration motor and wire holes

However, the removal of the internal printed support structures were unsuccessful (see Figure 25). This led to printing the socket horizontally in two parts. This can be seen in Figure 26. The two halves are sanded with sandpaper for a smoother texture and put together with epoxy glue (see Figure 27).

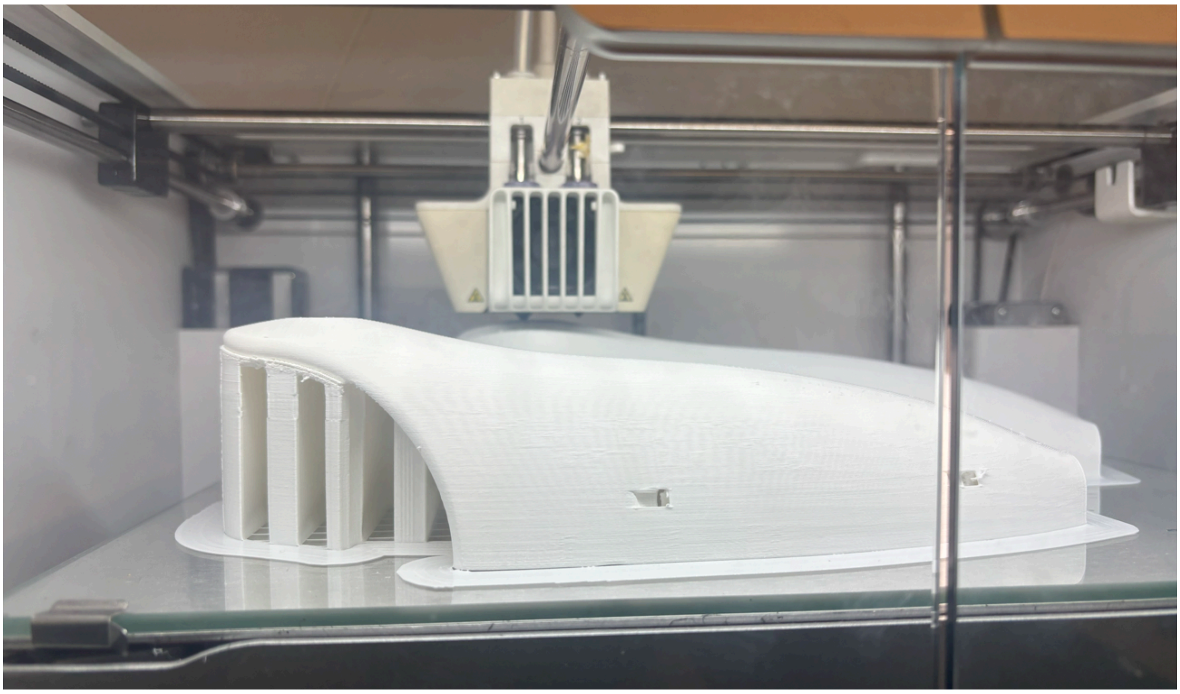

Figure 26: Two parts of the socket printed horizontally

Figure 27: Two halves of the 3D-printed socket put together with epoxy glue

5.1.2 Finishing the Model and Integrating Vibration Motors

The prototype is sprayed with MoTip Primer for a smoother finish (Figure 28), and the vibration motors were integrated (see Figure 29). The vibration motors were also integrated in a split socket, which can be seen in Figure 30.

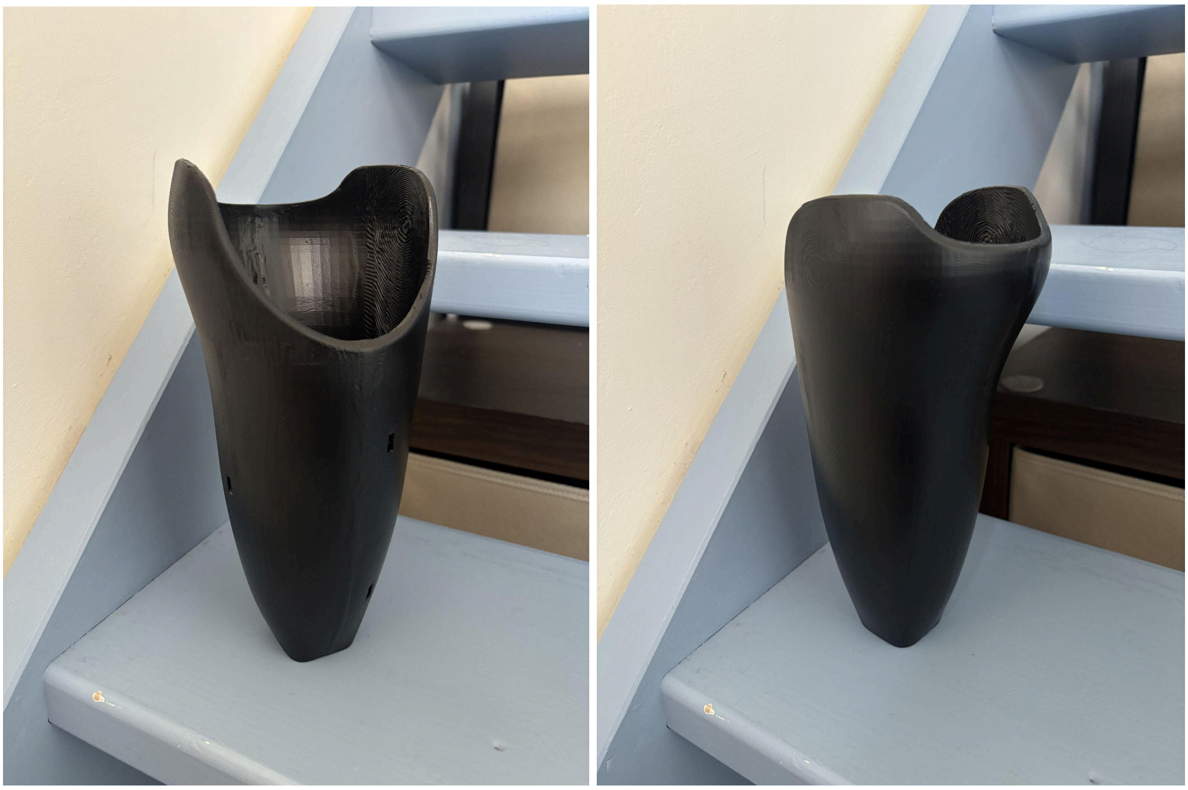

Figure 28: Socket sprayed with MoTip Primer

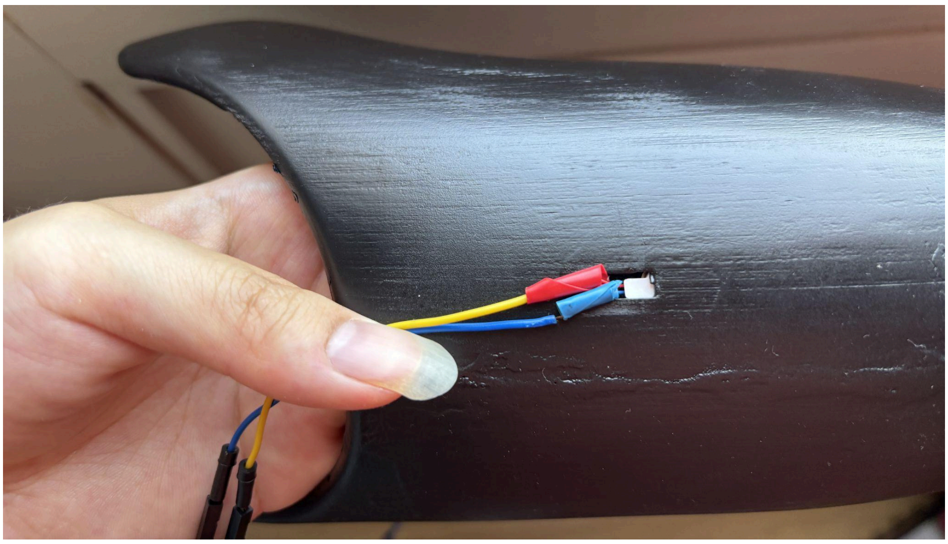

Figure 29: Vibration motor in socket

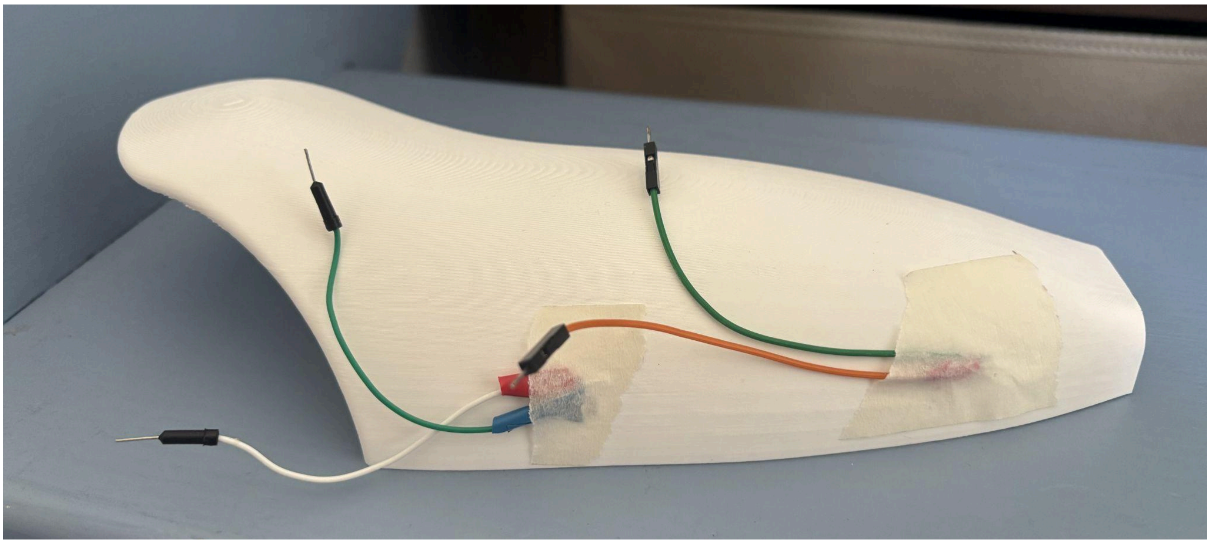

Figure 30: Sensors in the one part of the socket

Testing revealed that when the vibration motors are attached directly to the socket wall, the socket vibrates. However, the inner side of the vibration motor where the liner would be located, does not. To solve this, a small gap or “air pocket” between the socket wall and the vibration motor is recommended to improve vibration transmission to the inner side. For example, the vibration motor can be held in position using L-shaped silicone supports. This keeps the motor in position but still allows movement for vibration to the inner side (see Figure 31).

During integration and testing, several wires broke due to movement and fragility of the pre-attached wires on the vibration motors. For future testing, it is advised to secure and protect the wires with glue immediately after positioning them within the socket. Additionally, taping the external wires is recommended to minimize movement and reduce the risk of wire damage.

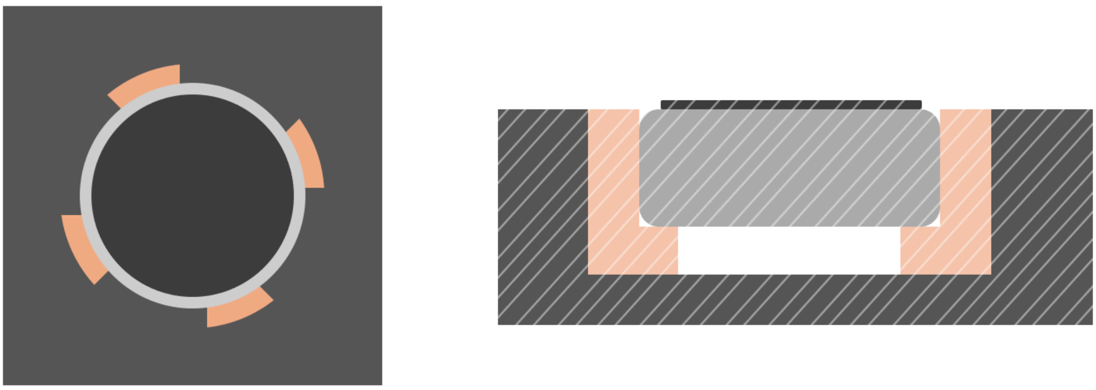

Figure 31: Top view and Section view of a vibration motor in L-shaped supports.

5.2 Concept Details and Evaluation

5.2.1 Bill of Materials

The Bill of Materials (BOM) (see Table 2) shows all components used in the prototype, along with their estimated cost and weight. This information helps evaluate whether the total weight remains comfortable for daily use and whether the cost aligns with the goal of creating an affordable, inclusive solution. All component sources and references are listed in Appendix Q.

Component	**Weight [g]**	**Unit Cost [€]**	**Quantity**	**Total Weight [g]**	**Total Cost [€]**
3D-printed Socket	660	17.50	1	660	17.50
Voice Coil Actuator	13	36	4	52	144
Silicone	0.3	0.01	4	1.2	0.04
Copper Wire	-	0.005	8	-	0.04
PCB	75	5	1	75	5
Battery	80	17	1	80	17
Button	0.7	0.60	1	0.7	0.60
Total				868.9	184.18

Table 2: Bill of Materials for the Concept Design

5.2.2 Battery Capacity and Usage

Based on the calculated usage time, a 2000 mAh battery would already be sufficient for one day of use, covering approximately 4-5 sessions. However, additional components may consume extra power, and it is generally recommended not to use a battery at full capacity. Taking this into account, the realistic capacity would support around 3-4 sessions. To extend usage and reduce the need for daily charging, a 4000 mAh battery is chosen. This provides approximately 2.5 hours of continuous use, which is enough for at least 8 sessions. The calculations can be found in Appendix R.

Currently, the system is activated with a single button that turns on all motors simultaneously. A remote or app can be introduced in the future to enable different vibration zones and patterns independently. However, the latter does come with additional costs. Publishing an app on the Google Play Store requires a one-time fee of €25 (Inspiring Apps, 2023), while the Apple Store-app requires an annual developer fee of €99 (Apple Inc., 2025).

5.2.3 Affordability and weight

Traditional lower limb prostheses are typically in the price range from €2,500 to €8,500 (Durett's Orthotics & Prosthetics, 2024), with an average weight of around 1.8 kg (Comprehensive Prosthetics & Orthotics, 2021). A carbon fibre socket alone would be around 500 grams (Owen & DesJardins, 2020).

In comparison, a 3D-printed socket costs only €85 including all materials, and the estimated sales price of the entire prosthesis with this socket is €145 (van der Stelt et al., 2023). Although more affordable, the current 3D-printed socket weighs 869 grams, which is significantly heavier than a carbon fibre socket. The integrated vibration system contributes around 209 grams to this weight. Hence, while the 3D-printed design offers a large cost reduction, further iteration is needed to reduce the current weight. Exploring alternative materials or printing techniques could help improve the weight, thus comfort, and bring the socket's weight closer to one of the conventional carbon fibre models.

5.3 Conclusion: Final Concept Design

Based on the research and exploration conducted throughout this thesis, the final concept design is a relaxation and recovery device, where focal vibration therapy is applied within a transtibial prosthetic socket. This concept has Voice Coil Actuators (VCA) integrated into the socket, allowing the user to receive therapeutic vibration sessions as part of their daily routine. Both at the beginning of the day to help prepare the body for activity, and at the end of the day to support recovery and relaxation. Figure 32 shows how the VCAs are integrated into the final version of the Recovery by Vibration socket, which also includes a pouch for the battery and pcb.

Figure 32: VCAs in Final version

5.3.1 Focal vibration Session

Each session is designed to last approximately 15 minutes and aims to minimize residual limb pain, enhance proprioception, lessen delayed onset muscle soreness (DOMS), and encourage muscle relaxation. Heating pads may be turned on during the session to increase the therapeutic effect, maintaining a temperature between 38 and 43°C. The vibration pattern consists of waves ranging from 30 to 120 Hz, with an amplitude between 0.01 mm and 0.1 mm. The session begins at 30 Hz and increases by 5 Hz every half a second until reaching 120 Hz, before gradually decreasing in the same steps back to 30 Hz. The amplitude increases and decreases 0.01 mm per 10 Hz. The increase and decrease goes simultaneously with the frequency. This ascending and descending wave cycle is repeated for the duration of the 15-minute session, providing a dynamic and relaxing pattern. The Arduino code for this pattern can be found in Appendix S.

To ensure effective delivery of the focal vibration, motor placement must be tailored to each individual's residual limb. The target locations are based on the insights gathered in earlier chapters, where the targeted muscle areas experience significant pressure during gait and are relevant for focal vibration therapy. These muscles include: the gastrocnemius medial head, soleus, peroneus longus and tibialis Anterior

5.3.2 Future recommendations

The concept offers a starting point for future exploration into redefining comfort for transtibial prosthetic users, through the use of focal vibration therapy. Further research should focus on fully integrating the vibration motors into the socket - or preferably the prosthetic liner - to enhance comfort, usability, and the transmission of vibration. Additional testing is also needed to evaluate whether the selected vibration intensities and wave pattern durations are optimal, and how adjustments could improve therapeutic effects.

Furthermore, the concept takes the user experience into account by incorporating the intended product character into the vibration sessions. However, the form and aesthetics of the product still require further exploration. To convey the remaining characteristics, such as kind and helpful, muted yet colorful tones should be combined with darker and harder elements. This shows both comfort and reliability in the product. The overall form would be soft, rounded, and organic, so it feels kind and supportive. The selection of the materials are chosen for their softness and flexibility, balancing it with enough rigidity to provide a sense of security and stability. This can offer a better experience, where users can enjoy and trust the product as part of their daily well-being.

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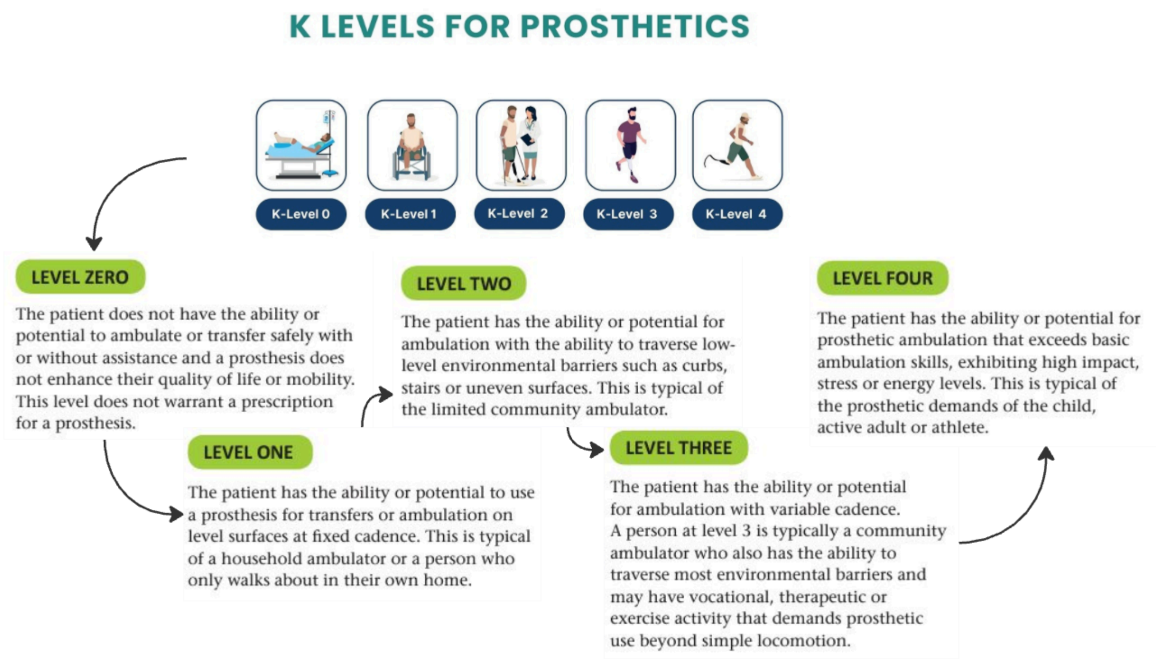
Appendix

A. Common terms

- **Rotation**: The twisting of the socket against the leg during the stance phase of the gait. Rotation forces can be reduced by designing a proper socket shape, together with the right suspension system. (Ottobock, 2024).
- **Shear**: Occurs when the residual limb moves in and out of the socket during the swing phase of gait, leading to skin tension or "pistoning."Shear forces can be controlled by the appropriate liner material and suspension mechanism. (Ottobock, 2024).
- **Proprioception**: The awareness of the position and movement of body parts. In a healthy limb,sensory nerves in muscles and tendons tell the brain where your knee, ankle, and toes are, as well as if they are flexing or wiggling. This can be achieved by choosing a suspension system which provides the most secure connection between the socket and residual leg. (Ottobock, 2024).
- **K levels (Activity levels)**: classify a prosthetic user's mobility potential, guiding prosthetic selection. Figure below gives an overview of these levels.



Activity levels, adapted from Zepeda (2023) and Inmotion (2013).

B. Volume change, pressure, comfort and gait Research

This section summarizes the key findings from research papers in four categories: volume change, pressure and shear, comfort and fit, and gait. These factors are important in prosthetic design, as they can ensure a secure fit and minimize discomfort in the user's daily life. Findings of transfemoral prosthesis are also taken into account, due to similarities in challenges and design. Besides that, there is limited research on transtibial sockets alone.

Volume change

- After amputation, the most volume stabilization happens in the following year. However, this stabilization is influenced by lifestyle, weight and activity level. (Kahle, 2016). These big volume fluctuations are one of the biggest challenges faced in rehabilitation. (Lanahan et al., 2023). However, after this period the residual limb will still have gradual changes over time mainly caused by the weight factor and maturing of the limb. (Seo et al., 2021). (Sanders & Fatone, 2011).
- Volume fluctuations also happen throughout the day and are managed by interchanging socks with different thicknesses throughout the day (Carrigan et al., 2016) (Lanahan et al., 2023).
- Current socket technology does not account for volume fluctuations (Kahle, 2016) and are unable to provide users and prosthetists with user data about the socket fit change over time. (Roy et al., 2020).
- The frequent replacement of sockets is difficult due to the time and money spent creating a socket. That is why accessories, such as socks or pads, are used to fill up the extra space inside the socket as a long and short term solution. (Seo et al., 2021). However, using these accessories does not bring back the interface pressure to its former level. The change in the residual leg is non-uniform and can vary in volume and shape. (Carrigan et al., 2016).
- Multiple studies have shown that doffing during resting periods have positive effects on volume fluctuation in shuttle-lock suspension sockets, resulting in less volume lost. (Lanahan et al., 2023).
- Residual limbs reduce in volume in the no-vacuum or suction suspension, but increase in a with-vacuum condition. (Sanders, et al., 2011) (Street, 2006)
- Vacuum and suction sockets improve volume control and the overall limb health more than the other sockets. (Safari & Meier, 2015)

- The distal part of the residual leg has the greatest volume reduction (Wilson et al., 1987), while not wearing the prosthetic consistently can cause an increase in volume in the distal part of the residual leg (Vigo company).
- Newly amputated limbs typically shrink in size, form, and volume. Preventing falls during the acute and intermediate stages of amputation rehabilitation should be a priority in limiting negative effects (Kahle, 2016).
- A volume increase of 3-5% is enough to create difficulties in donning and discomfort for the user (Paternò et al., 2018).
- Depending on the suspension type and socket size, the daily volume fluctuations can range from -11% to +7% or more. In vacuum assisted suction (of -78kPa) it is an increase around 3.7% after a 30 minute walk, while in non-vacuum suspensions the decrease is around -6.5%. (Paternò et al., 2018)
    - This increase is also visible with a liner: when there is a liner used the increase is 3.5%, compared to a 5.8% in the absence of a liner.
- Speed of volume changes: around 0.10–0.12 mL/min during standing and 0.20–0.30 mL/min after motion. (Paternò et al., 2018)

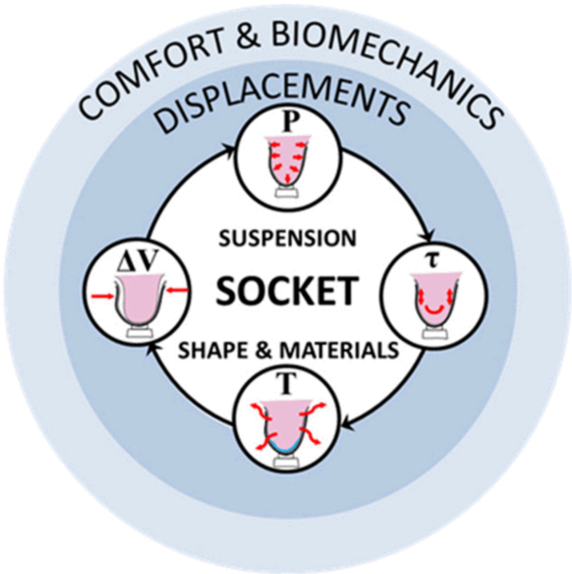
Pressure and shear

- 59% of lower limb amputees have problems with the socket fit. This could lead to skin irritations in 41% of the amputees. The main issues are concentrated pressure points and shear forces inside the socket. This could lead to less energy use throughout the day. (Chatterjee et al., 2016).
- In vacuum systems it is found that peak pressures are decreased during walking, compared to other suspension symptoms.
- Long-term and unevenly applied high pressures to the skin can result in pressure ulcers, sensitive skin, irritations, and partial or total vascular occlusions. These spots can change the metabolic rate and blood flow, resulting in an increase in temperature and sweat. (Paternò et al., 2018)
- Stresses on the residual limb depend on strength and lifestyle. (Paternò et al., 2018)

Comfortability and fit

- Proper prosthetic socket fit is crucial for optimal function, comfort, and skin health in residual limbs. (Carrigan et al., 2016). When there is an air gap in the vacuum suspension or an improper fit in the socket, there is a chance of skin disorders such as blisters due to movement inside the socket (Ferraro, 2011). (Seo et al., 2021). As a result, the effectiveness of a lower limb prosthesis is mainly determined by its capacity to reduce residual limb in-socket movement while preserving residuum health. (Roy et al., 2020)

- Poor fit can cause skin ulcers and infection, which can lead to revision amputation. (Kahle, 2016). Revisioned surgery is performed to improve the function, comfort, or look of the residual limb. (AOFE Clinics, 2024).
- Liners are widely used because of their skin adherence probabilities, forming a protective barrier against abrasion. It also helps in pressure distribution. Rolling silicone or other elastomer-based liners on the residual limb also provides a more effective cushioning effect. However, it does increase perspiration, which reduces cleanliness and can cause skin infections. (Paternò et al., 2018).
    - <u>Silicone elastomer liners:</u> Have a higher stiffness in tension, which provide a better suspension and minimize displacement between the socket and the residual limb. They are preferable for softer residual limbs.
    - <u>Urethane liners</u>: Avoids skin breakdown because it has a high friction coefficient, due to the material being a better skin adhesion.
- The main cause for failure of amputee prostheses is the user dissatisfaction caused by inadequate socket fit and comfort. (Kahle, 2016). A low satisfaction level from users in their prostheses are caused by problems with the socket. This includes poor comfort, reduced biomechanical functionality and impaired control. These are caused by factors such as interfacial pressure, volume change, shear stress and temperature, but also the shape and materials. (see Figure below). On top of that, skin lesions develop in 63-82% of lower limb amputees, resulting in a prosthesis abandonment rate of approximately 25-57%.

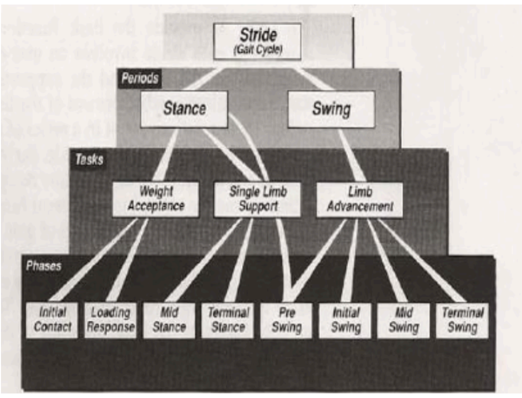


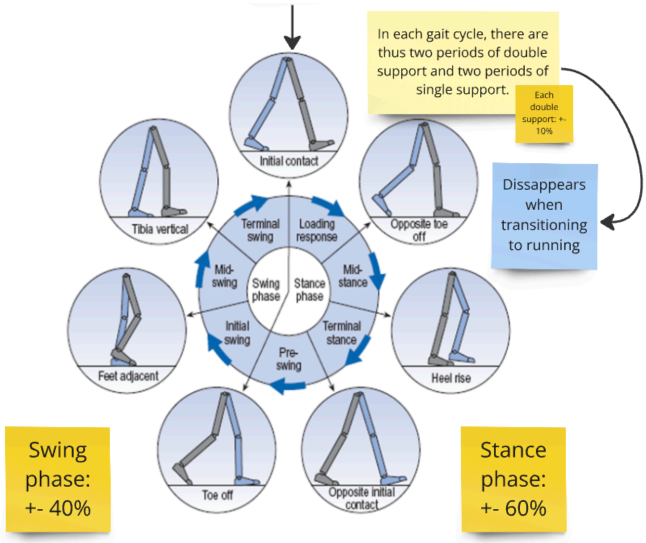
Problems within socket caused by displacements (Paterno et al., 2018)

- Current techniques are limited. Instead of a strict systemic approach based on quantitative data, prosthetists have to rely on subjective verbal feedback from the user and their own experience in visual clues. (Roy et al., 2020). (Paternò et al., 2018).
- Socket comfort is achieved by a proper gait and a natural transfer motion of the residual limb with the prosthetic. (Roy et al., 2020)
- Interchanging socks throughout the day to maintain the right fit can be difficult, time consuming or even impractical in certain cases, including situations where there are concerns about social acceptability. Because it requires the user to doff their prosthetic. (Lanahan et al., 2023).
- According to the gate control theory, pain felt by amputees can be decreased by applying physical stimuli, such as pressure. (Sanders & Fatone, 2011).
- The right socket design, suspension system, prosthesis components and prosthesis alignment help against biochemical problems caused by amputation. (Paternò et al., 2018)
- The efficacy of a suspension system is evaluated by measuring the relative displacements between the stump and the socket (pistoning) This can be measured by radiography, ultrasound, computerized tomography, standardized photographs and motion analysis systems based on markers. Reduced pistoning avoids ‘milking’, which is an excessive elongation of distal tissues. (Paternò et al., 2018).
- TSB sockets with seal-in liner provides the least pistoning (around 2.5mm), especially compared with PTB sockets (16 mm) (Paternò et al., 2018)

- Magnetic-lock suspensions are easier to don and doff, but create a larger pistoning effect
- Slippage occurs when the friction coefficient between the skin and the socket or liner, or between the liner and socket, are too low. When the friction coefficient is too high, it causes high shear stresses. When these high stresses are between the limb and socket, it can lead to tissue reformation and an increase in the risk of injuries. It also can cause tissue distortion during donning, doffing and ambulation. On top of that, it could lead to skin breakdown. (Paternò et al., 2018)

Gait

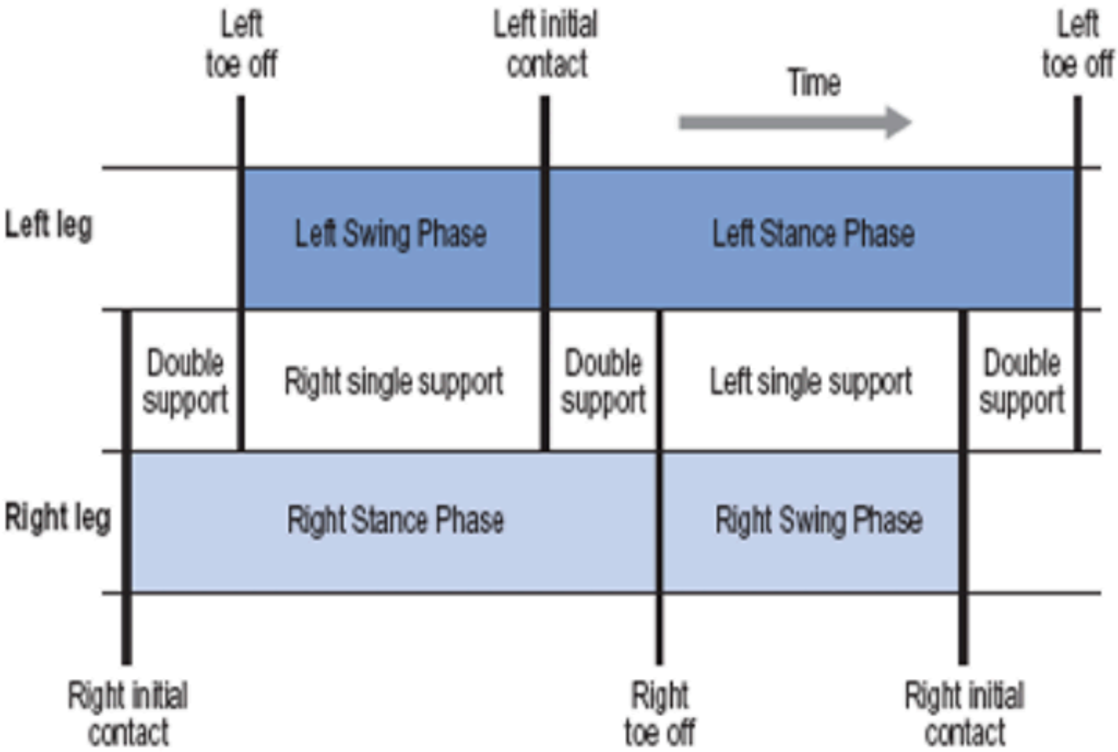




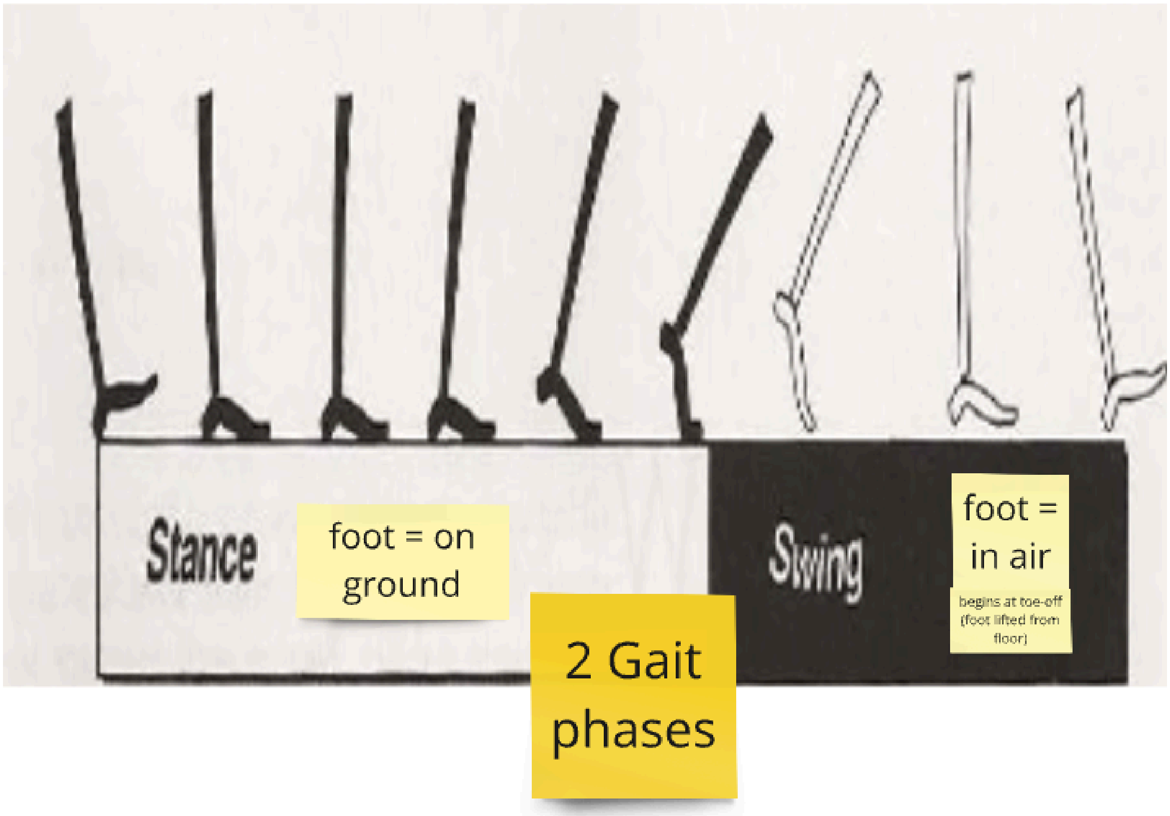
(Kharb et al., 2011) *Adjusted from Kharb et al. (2011)*

- During a gait cycle, one limb provides support while the other moves forward to establish a new support position. The limbs then switch roles. (Kharb et al., 2011)
- Stride length = The distance between the placement of the same foot, which is two step lengths
- Cadence [steps/min] = the number of steps per minute
  - Cycle time [s] = 120/cadence
  - Speed [m/s] = stride length [m] / cycle time [s]

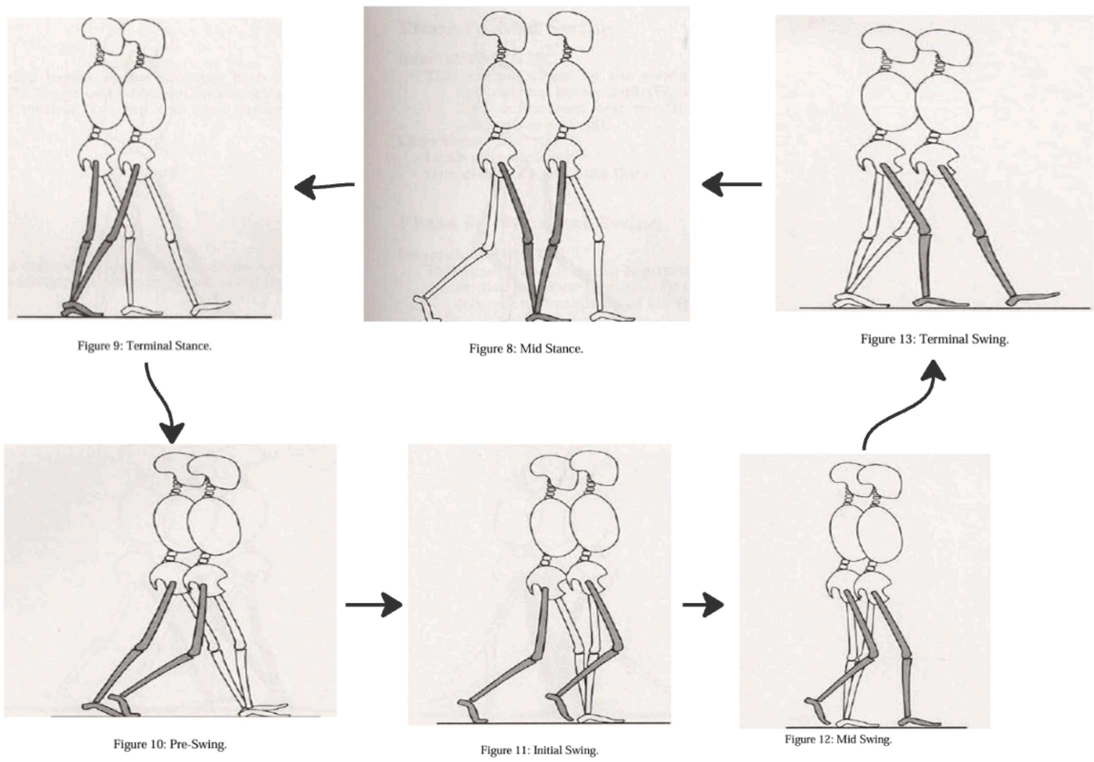
- When a person has a 'bad foot,' the stance phase is shorter on the affected foot, while the swing phase is shorter on the 'good foot.' This reduces the overall step length. A short step length on one side typically indicates issues with single support on the opposite side. (Kharb et al., 2011)



- Vacuum and suction sockets aid in a better gait symmetry. (Safari & Meier, 2015).
- Walking speed increased in vacuum suspension, due to more Activity Balance Confidence and reduced distraction in the gait cycle (Ferraro, 2011).
- 49.2% of transtibial prosthesis users have reported a fear of falling, whereas 52.4% of lower limb amputees have reported falling incidents. In these incidents, 40.4% end up with injuries (Paternò et al., 2018)
- Inadequate prosthetic components can raise metabolic expense, incorrectly stimulate muscles and a decrease of gait symmetry (Paternò et al., 2018)
- The lower limb experiences high stresses during gait (Paternò et al., 2018)
- Each person's gait is unique, to the extent that it can be used to recognize an individual. (Kharb et al., 2011)



Stance and Swing phase visualised,adapted from Kharb, et al. (2011)

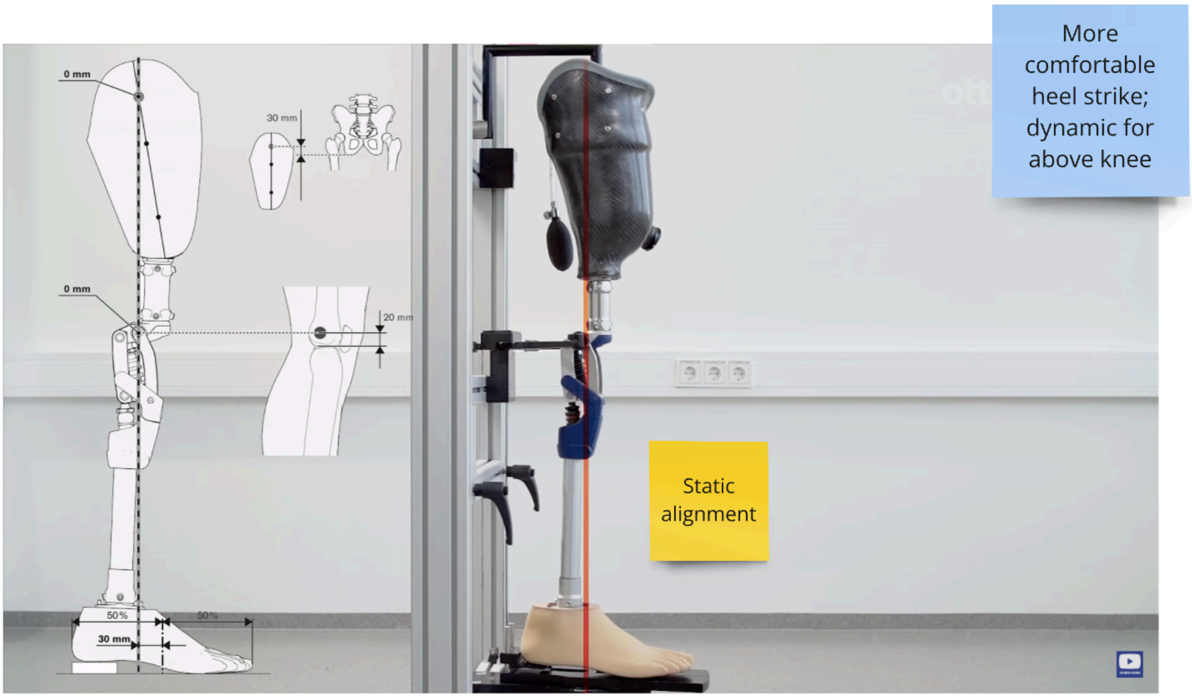


Gait cycle terms and visualisation,adapted from Kharb, et al. (2011)

C. Key observations

- The ‘plotjes’ (small oval silicone pads) are used to prevent sensitive areas from pain by giving it more room in the socket
- The socket is shaped by preventing pressure on sensitive areas and putting more pressure on non-sensitive areas.
- Liners which are thicker in the front and thinner in the back exist to give more support to sensitive areas.
- A tight socket feels comfortable for the user.
- The making of a socket is always static. This could be done by several methods, including casting with water or using an air bubble. Once the socket is made, adjustments are made based on the user’s gait, primarily by modifying angles and length. Sometimes it is necessary to create more space for unexpected sensitive spots in the socket. However, the static way of socket making can lead to problems in dynamic situations.
- There are no specific rules for making a socket more fitting and comfortable. The prosthetist adjusts the socket based on their experience and feedback from the user.
- Both pistoning and rotation can cause skin problems.
- Adjustments and changes to the socket are made based on the user’s activity level. For instance when someone declines in activity level, a shuttle-lock socket might be recommended.
- Users usually have multiple sockets for different purposes. For example one for swimming and one for the daily routine. However, the socket shape itself is still the same.
- In Hoogstraat Orthopedie, they mainly use shuttle-lock and vacuum systems. The suction socket is seen as the vacuum system with less benefits.
- Within four hours this ‘instant socket’ is made, adjusted to the user’s gait and preferences, and ready to be worn home.
- The socket is preferred to be as light as possible.
- Optionally, users can personalize the aesthetics of the socket by selecting a colored pattern.
- A follow-up check is conducted by phone after one month. If no further problems have surfaced, no appointment for further adjustments have to be made. After a year, the user is scheduled for an in-person check-up and any necessary adjustments. In the meantime, users can't contact the prosthetist if they experience any discomfort or problems.
- Two out of three patients were unaware that they had developed a minor skin issue, such as swelling, caused by a prosthetic that no longer fit properly.

- Proper alignment of a prosthetic limb is crucial for user comfort and functionality because it ensures that the components are properly positioned in relation to the user's residual limb and body posture. Each person's gait is unique, determined by their body mechanics and residual limb shape, making alignment a very personalized process.
- A well-aligned prosthetic minimizes pressure points, improves stability, supports a natural walking pattern, and reduces the risk of secondary issues such as joint or back pain. Regular adjustments may be required over time to accommodate changes in the user's gait or limb shape, to ensure comfort and efficiency.



Alignment of prosthetic (Ottobock, 2016)

D. Overview of suspensions systems

Based on information provided by Hoogstraat Orthopedie and personal research, Table A has been created to present the three most commonly used suspension systems: vacuum, shuttle-lock, and suction. Additionally, Table B offers a detailed comparison of these systems, evaluating important factors affecting user experience,

Type	Sub-type	How does it work?	+ HO*	- HO*
Vacuum		Consists of a sealing sleeve and exhaust valve, to remove air and keep a regulated pressure level within the socket	High proprioception and performance	Uses a sealing sleeve that can get in the way during activities. Not suitable for people with a shorter residual leg.*
	Passive	Removes air only during donning.	Effective in keeping the pressure constant in the socket.	
	Active	Removes air during gait in stance phase.	Very effective to keep the pressure constant in the socket	More expensive than the other sockets
Shuttle-Lock		Consists of a pin at the end of the liner. The pin is inserted into a shuttle lock at the bottom of the socket to keep the residual limb inside the socket.	Easy donning and doffing. No extra sleeve needed. Good proprioception and performance	Not suitable for people with a higher activity level
Suction		Consists of a sealing sleeve and one-way valve. Removes air in stance phase.	Effective in keeping the pressure constant	It's a lesser version than the vacuum socket. Uses a

			in the socket.	sealing sleeve that can get in the way sometimes. Not suitable for people with a shorter residual leg.*

Table A: Explanation of suspension types and pros and cons of each based on Hoogstraat Orthopedie visit

	Vacuum	Shuttle-Lock	Suction
Activity level	All, but best for 2-4	1 and 2	All
Comfort	The least movement inside the socket. Requires a total-surface-bearin g socket, which already makes it more comfortable due to the pressure relief caused by evenly distributed pressure.	Movement and rubbing in the socket due less control of forces inside the socket.This can cause the most skin conditions.	Requires a total-surface-bearin g socket, which already makes it more comfortable due to the pressure relief caused by evenly distributed pressure. However, it can experience too much suction which results in a lower comfort.
Convenience	Donning: Roll on liner and prosthetic sock before sliding into socket. Rub lotion on the leg above liner to prevent dragging on the skin. Roll up the sealing sleeve to	Easiest for donning and doffing, but need to add socks 3 to 4 times a day due to change in volume.	Donning: Roll on liner and prosthetic sock before sliding into socket. Rub lotion on the leg above liner to prevent dragging on the skin. Roll up the sealing sleeve to

	seal the liner. No need to modify throughout the day, only when necessary.		seal the liner. No need to modify throughout the day, only when necessary.
Limb Health	Most healthy, because it regulates the volume change and increases hydration and blood flow to heal open wounds.	Constrict blood vessels, which reduces leg volume causing movement in the socket. Movement can cause skin conditions.	Constrict blood vessels, which reduces leg volume causing movement in the socket. Movement can cause skin conditions.
Performance	Best out of all. There is maximum confidence and control. This results in a more symmetrical gait while using less energy.	Lack of control and security for people in activity level 3 and 4, but meet the needs of people in level 1 and 2.	In between vacuum and shuttle-lock, because it lacks the high pressure and movement within the socket.
Proprioception	The sense of control is almost like having the leg back, because of the high air pressure within the socket.	Lowest level, because of the most movement inside the limb.	In between vacuum and shuttle-lock, because it lacks the high air pressure and allows some movement within the socket.

Table B: Comparison of vacuum, shuttle-lock and suction suspension with important factors (Ottobock, 2024)

Based on table A and B, the **vacuum suspension** is the best suspension for lower limb amputees across most activity levels (2-4), despite the inconvenience of the extra sleeve. It promotes hydration and blood flow, aiding in the healing of open wounds. In addition, it helps regulate volume changes in your leg, preventing tissue shrinkage or expansion during the day. This results in a consistent fit by maintaining size retention. The high air pressure and even pressure distribution enhance

proprioception, resulting in a strong sense of control, increased comfort, and minimal rubbing or pistoning.
For users with lower activity levels, the **shuttle-lock** socket is a good alternative. Especially when the person is less mobile, the easy donning and doffing brings more convenience to the daily routing.
For a residual limb which is too short for vacuum (or suction) suspension, a **combination of both vacuum and shuttle-lock** can be used to rip the benefits of both suspension systems.

E. User Scenario Research

F. Adjustable sockets

Adjustable sockets are a way to accommodate the difference sizes and shapes of residual limbs. They provide greater flexibility and efficiency by eliminating the need to change socks during volume fluctuations throughout the day. In this section the findings of existing adjustable sockets have been put into two categories: manual and automatic sockets. Manual prosthetic sockets require users or prosthetists to make adjustments manually, such as adding socks or adjusting the socket to accommodate changes in the residual limb. In contrast, automatic prosthetic sockets use technologies such as sensors or adjustable components to adapt the fit in real time. Responding to limb volume changes without the need for manual intervention. This classification highlights the adaptability and versatility of the sockets rather than focusing on their specific applications for the lower or upper limbs. The details of the socket are illustrated in the figures. Additional explanations, including any unique selling points, are provided in the accompanying text.

Manual sockets

Connect TF
(SRT Prosthetics & Orthotics, 2021)
(Össur Academy, 2022)

The screw holes are adjusted only occasionally and are used for personalized modifications, such as adapting the prosthetic to the current length and circumference of the residual limb.

Revofit
(Click Medical, 2016)

Open-source tutorials are available, providing guidance for prosthetists in designing custom prosthetic sockets.

Socket-less Socket
(Martin Bionics Innovations, 2024)

This socket claims to build limb muscles by providing room for movement and flexibility.

Infinite socket TF
(Infinite Socket TF | LIM Innovations, 2017)

The Infinite Socket TF is designed with a modular frame and carbon fiber struts, allowing prosthetists to quickly adapt the socket to accommodate bodily changes. The adjustable components provide both patients and clinicians with the ability to fine-tune the fit for improved comfort and control. To enhance usability, the flexible brim can be tightened for added stability during walking or loosened for greater comfort while sitting.

Infinite socket TT-S
(The World's Most Adjustable Socket I LIM Innovations®, 2017)

- Distal and proximal volume management
- Knee flexion optimization
- Move without irritation of the socket
- Reduces skin problems, by having rigid and flexible surfaces
- Vibration dampening technology
- Lightweight
- Weight limit of 145 kg
- Cover for personalisation

Scandinavian flexible socket
(Pritham, 1989)

- Adjustability by flexibility
- Ensures proper load disstribution
- The flexibility can lead to material stress, causing cracks and reducing durability over time

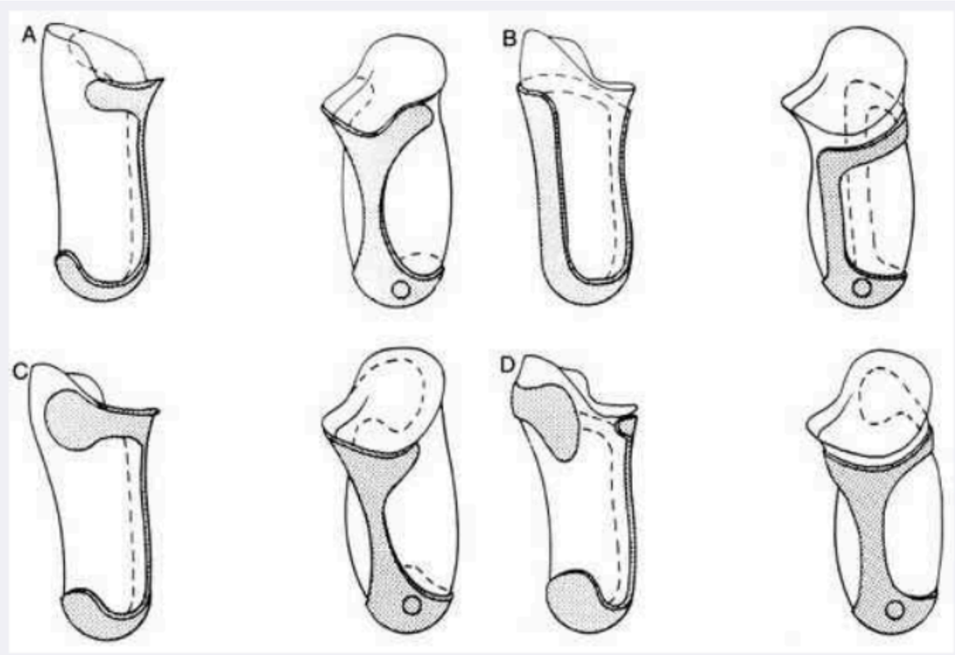
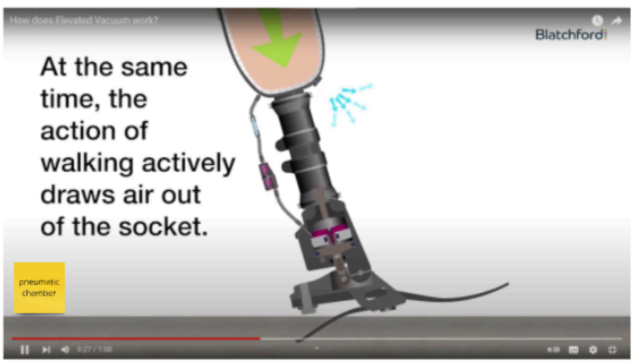


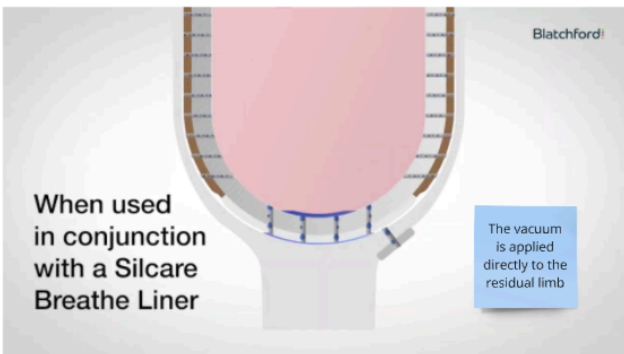
Figure: Scandinavian Flexible Socket (SFS) variations, combining flexible liners and rigid frames for comfort and support.(Pritham, 1989).

Automatic sockets

Elevated vacuum with Silcare breathe liner
(Blatchford Institute, 2024).

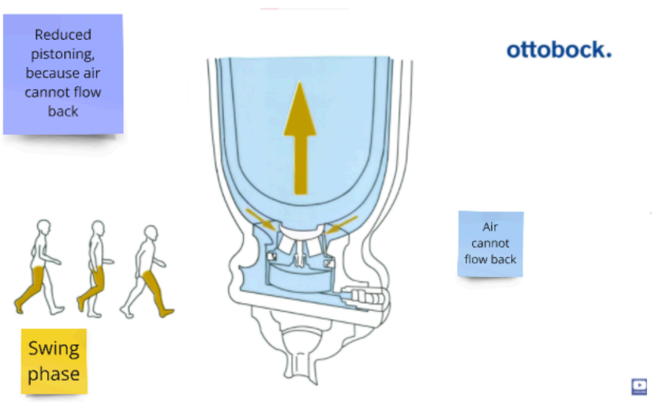
- Constant vacuum level within the prosthetic socket
- Improves suspension and reduces limb movement

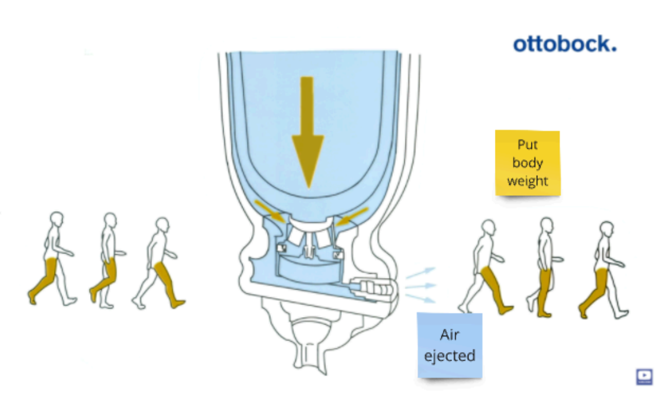




Dynamic vacuum system

- Adjusts vacuum in real-time, based on limb volume changes and user movement
- Responsive and flexible fit for user

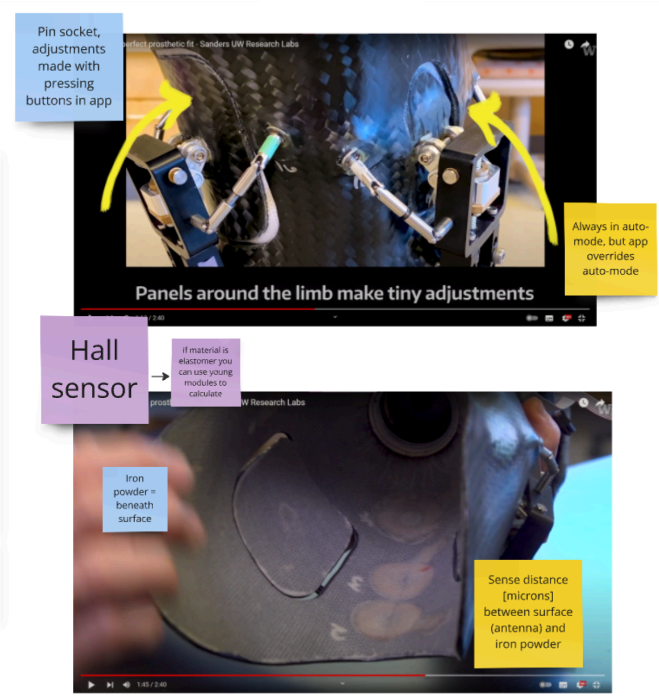




Sanders UW Research Lab

(University of Washington, 2022)

Accuracy is not mentioned.



Conclusion

The research on adjustable sockets supports the importance of putting pressure on pressure-tolerant, muscular regions while minimizing contact with pressure-sensitive, bony areas to ensure user comfort and safety. However, while such designs improve fit and reduce discomfort, they may result in reduced proprioception compared to more secure systems, such as the dynamic vacuum system. Even though the dynamic vacuum systems offer the best proprioception, due to their ability to maintain a secure and consistent connection between the residual limb and the socket, the high cost makes it less accessible to many users.

On the other hand, ongoing improvements, such as Sanders UW research lab, show ongoing advancements in making prosthetics more adaptable and user-friendly. While these innovations indicate progress, the "perfect socket", one that balances comfort, proprioception, affordability, and adjustability, has yet to be fully realized

G. Sensors

Based on the findings in the previous chapters, sensors are a possible solution due to their ability to measure volume changes and pressure spots. These are addressing key challenges for transtibial amputees. This appendix outlines the requirements and wishes for sensor integration, focusing on accuracy and adaptability. Furthermore, an overview of available sensors which are able to monitor pressure and/or volume are given in a table to compare and select the most fitting sensors for further research and testing.

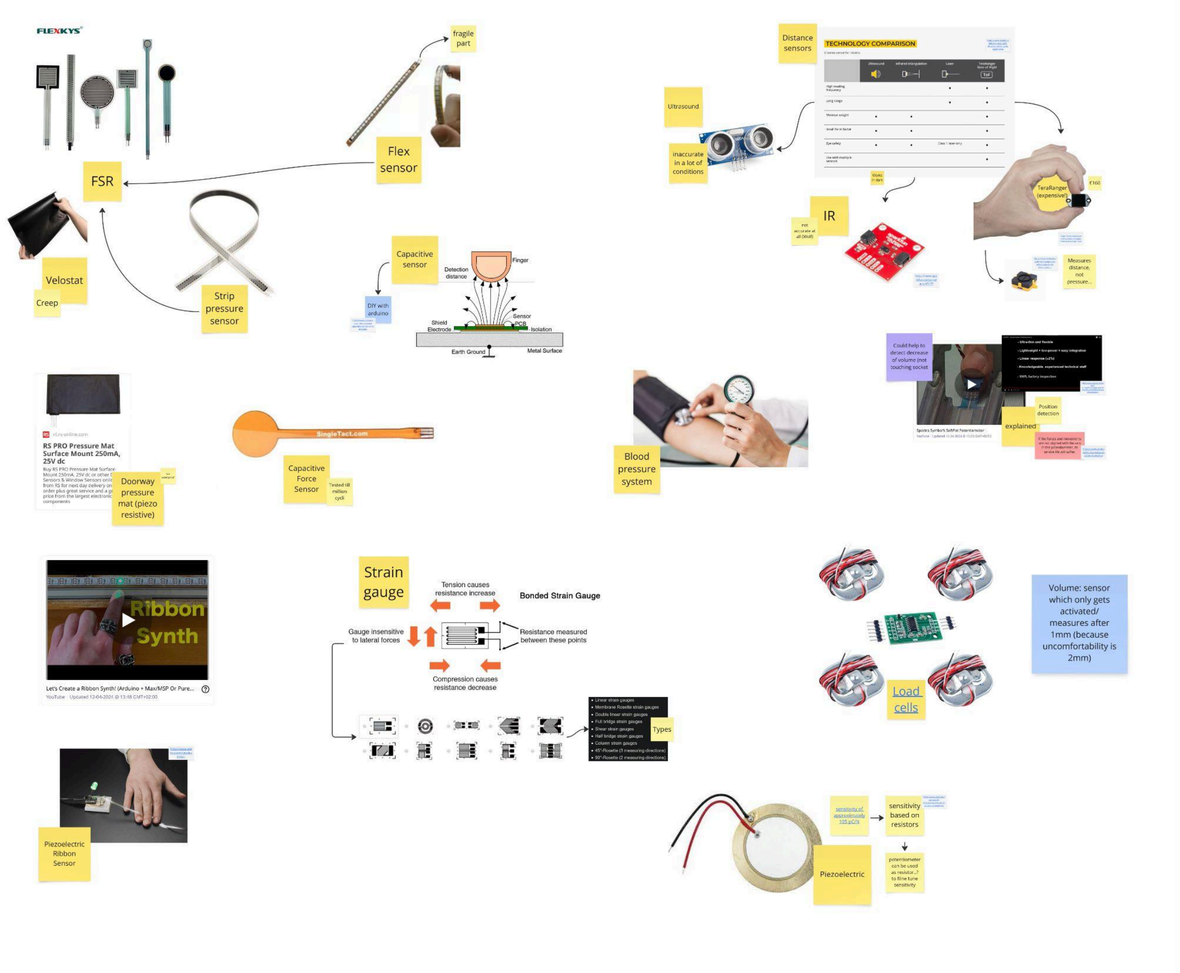
Requirements and Wishes

Requirements

- The sensors should be able to detect volume change
- The width of the sensors must be smaller than radius of stump
- The length of the sensors must be smaller than the height of the stump
- When the sensors are integrated in the socket, it should feel as comfortable as the socket without sensors
- The sensors should be able to withstand peak pressure of 800N (approximate jumping force of 90kg person) (Physics Netowork, 2024)
- The sensors should be able to detect peak pressure of 300N (approximate peak pressure of 90kg person running) (Nebula Physio and Wellbeing Ltd, 2024)
- The sensors should be accurate in the range of 1 mm, based on uncomfortability starting at 2 mm volume change in leg
- The sensors should be able to detect dynamic change; change of force during walking and running
- All sensors should weigh less than 80 g together.
- The sensors should be durable and resistant to breakage.
- The sensors with prosthetic should be within the price range of a traditional prosthetic,
- The sensors must withstand temperatures from -5 to 50 °C when exposed to environmental conditions. This range is based on existing prosthetics (Henson, 2023), combined with the lowest temperature recorded in the Netherlands (Wedia, n.d.), which is slightly lower than the European average, and the highest temperature recorded in Europe (WMO, 2024).

Wishes

- Thickness has to be the same thickness as the socket, which is around 5 mm, or less than the thickness of the socket.
- The sensors can detect pressure and pressure change as accurate as possible in static and dynamic position
- The sensors have to be as aesthetically pleasing or more than the original socket
- The sensors fit in the socket
- The sensors are as affordable as possible
- The sensors are as light as possible
- The sensors can maintain functional when bent
- The sensors can withstand the coldest temperatures in Europe (-60 °C) (Mappr, 2021).



Overview of all considered sensors

To create the overview table, only the most representative and readily available examples of pressure sensors were included, prioritizing relevance and practicality. The figure with overview of all considered sensors includes all sensors that were considered during the selection process.
On top of that, the requirement size and weight of the sensors are already taken into account before creating the table. The selected sensors focus on measuring pressure and/or distance, as these parameters are necessary to measure pressure and/or volume in lower limb prosthetic sockets.

The sensors and sensor details, which do not fit in the requirements, are highlighted in red. The sensor details which do not fit in the wishes are highlighted in yellow. The sensors highlighted in green are the most suitable sensors.

Sensor	**Measures**	**Size [mm]**	**Weight per sensor [g]**	**Force [N]**	**+**	**-**
Piezoresistive sensor (FSR, FlexiForce,)	Pressure	D = 14 L = 116 T = <1		440		Found in pilot sensor test: inaccurate when bent
Flex sensor (short)	Pressure	L = 60 W = 6		25 – 100 KΩ		Prone to breakage
Velostat	Pressure	L = 280* W = 280* T = 0.1	19	<500 ohm.cm		Creep
Capacitive sensor	Pressure and Distance			20g-6kg		
Capacitive Force sensor (SingleTact)	Pressure	D = 15 T = 0.30	0.23 (electronics = 1.6)	450 +Max F = 300% FSR		Temperature sensitivity < 0.2%/° C
Piezoelectric sensor	Pressure	D = 20 T =				Found in pilot sensor test: Sensitive to perspiration,

						Prone to breakage when bent
Piezoelectric Ribbon sensor	Pressure	L = 600* W = 8 T =		** 15±30 % nF with capacity of 120 Hz	Flexible, designed as sleep sensors underneath mattress	
Load sensor	Distance	L= 40 W = 40 T = 20	10	500 (50 kg)		Creep after 1 min
Ultrasound	Distance	L = 45 W = 20 H = 15				Not as accurate as it says, especially in dark spaces. Range: 2-450 cm
Infrared	Distance	L = 40 W = 18 H = 12				Range: 4-30 cm
TeraRanger	Distance	L = 42 W = 30 H = 13	9			Range: 0.03 - 3.3m
SoftPot Potentio-meter	Placement	L = 100*	15		Water and dust tight	

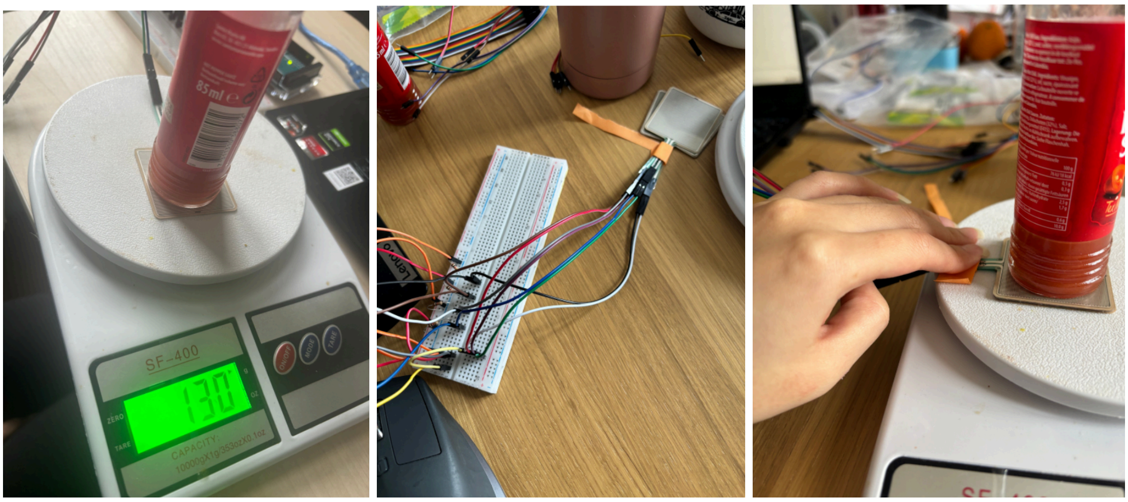
Table: Overview of sensors with details

H. Pilot sensor tests

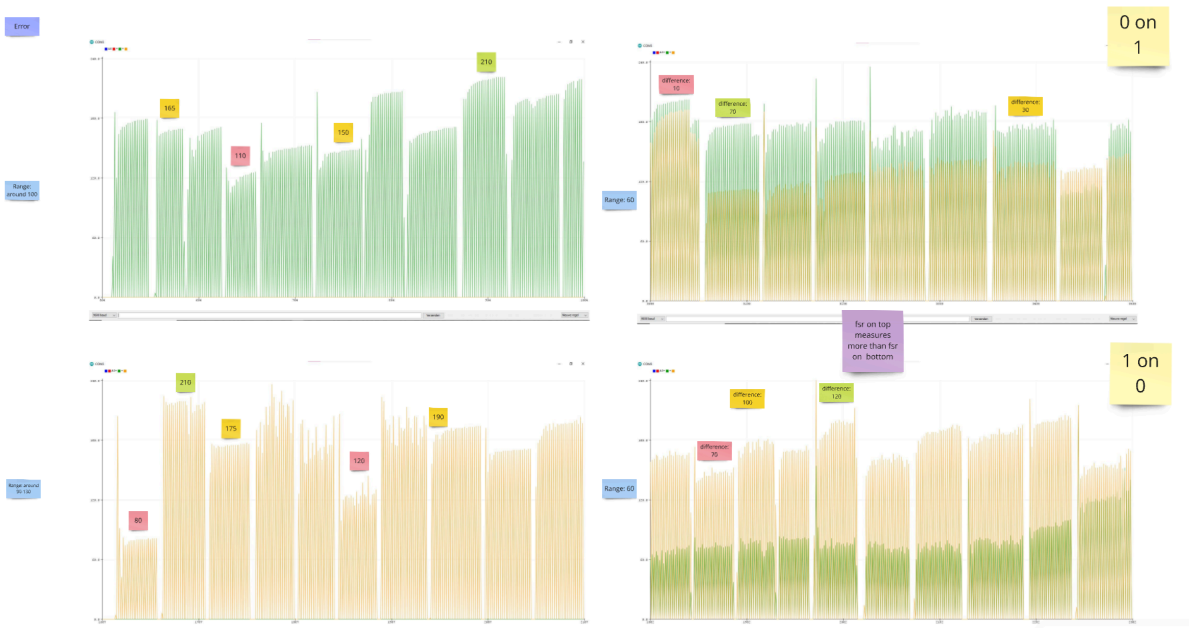
These tests are conducted prior to lab experiments to assess feasibility before initiating the actual experiments.Three tests have been conducted with one to four Force Sensitive Resistors (FSRs) in square shape and a piezoelectric sensor.

Square FSRs Static (130 gram)

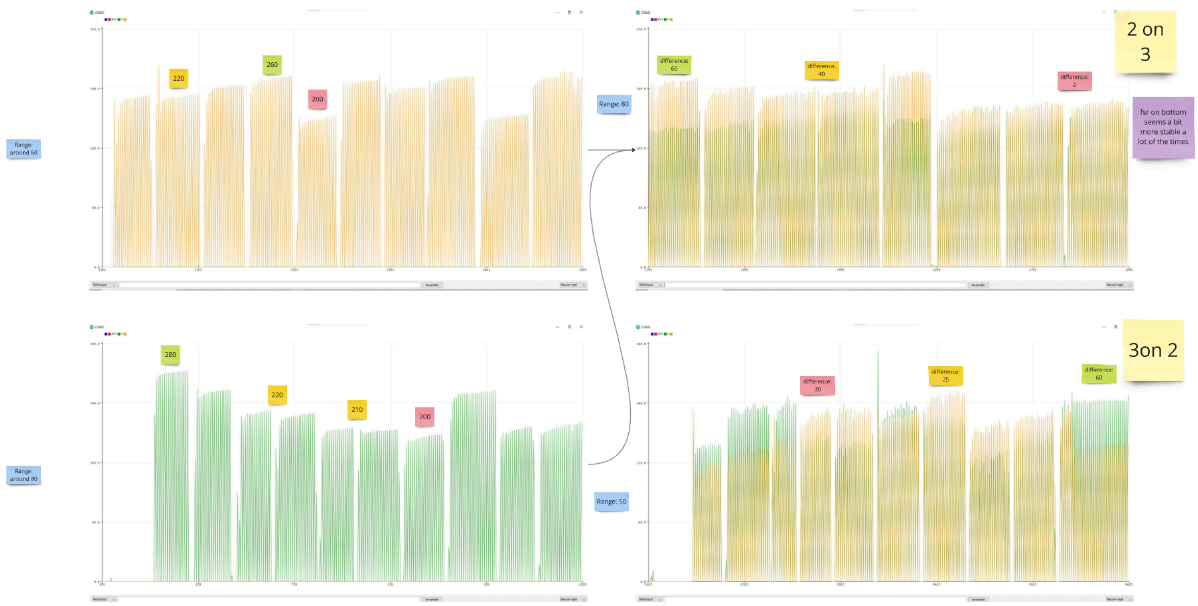
Four FSRs (FSR 0 - 4) from Flexiforce were tested with a weight of 130 grams, with the results plotted using the Arduino serial plotter.



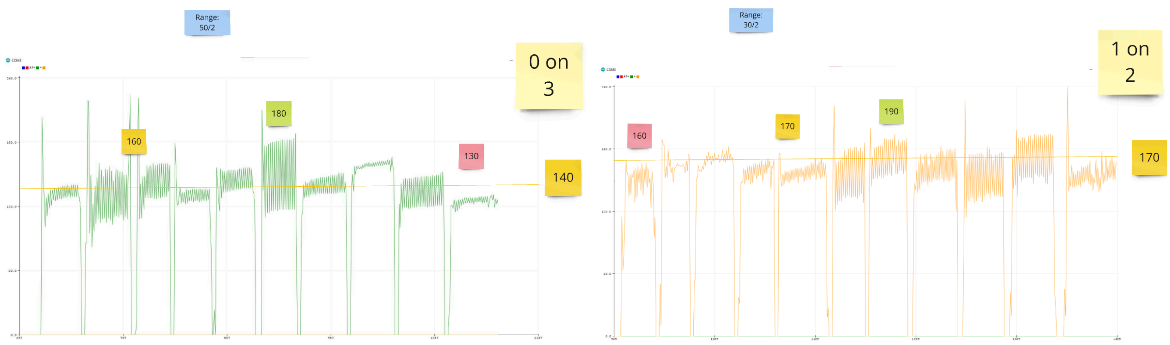
Square FSRs test set-up (130g)

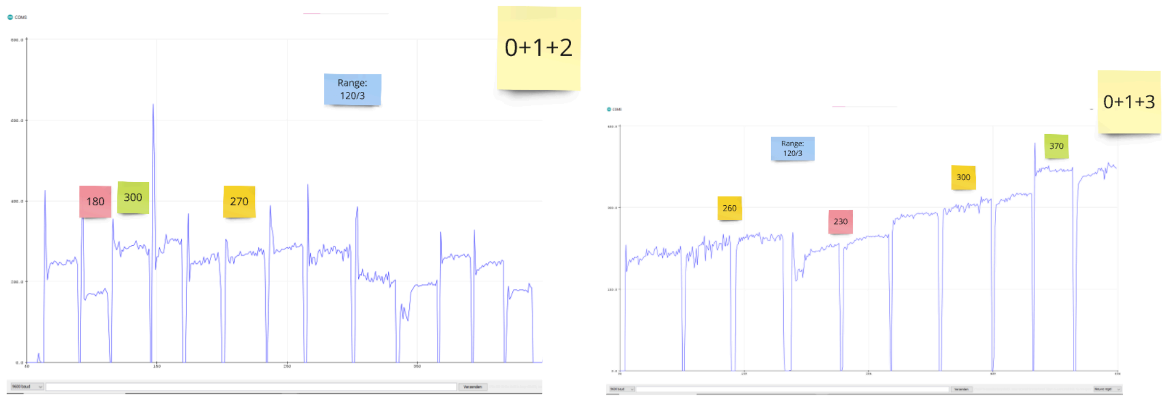


From upper left to bottom right: FSR 0, FSR 0 on 1, FSR1 and FSR 1 on 0

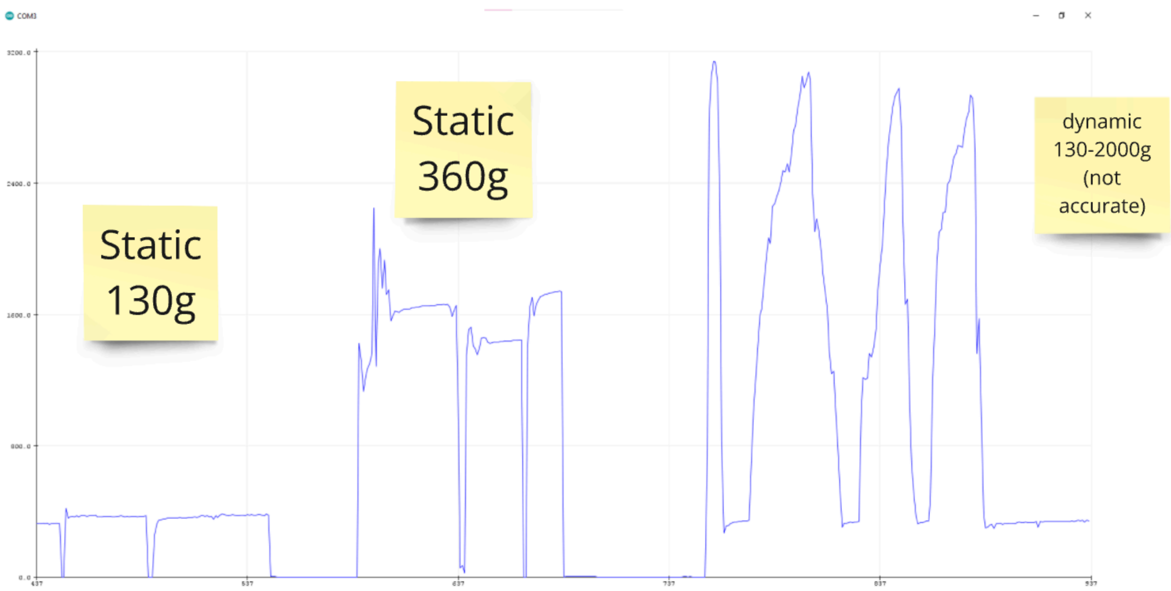


From upper left to bottom right: FSR 2, FSR 2 on 3, FSR3 and FSR 3 on 2





Various FSRs stacked



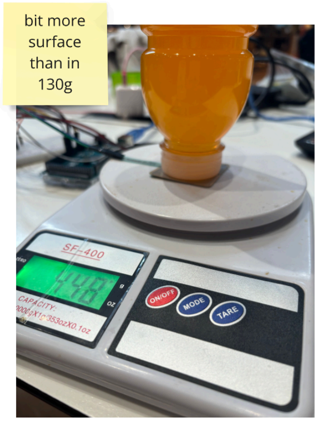
Single FSR on multiple weights.

Based on the above figures the following conclusions can be drawn:

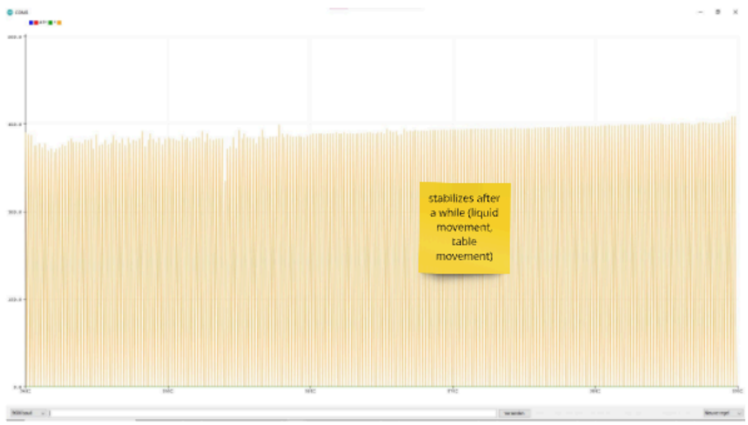
- For small loads (around 130g) this type of FSR is not very accurate. The difference between the smallest and highest measured loads can be as much as twice the value of the highest load.
- In almost all cases, when two sensors are stacked on top of each other, the lower sensor registers a lower value than the sensor above it. In some instances, the measurement from the top sensor can be up to 1.5 times higher than that of the bottom sensor.
- When multiple sensors are stacked, the measurement range per sensor decreases when it is divided by the amount of sensors, compared to a single sensor. This is likely because the lower sensors detect less force. However, the error range still fluctuates between 50-80 grams, in comparison to the individual sensors which are 60-130 grams.
- Under dynamic weight loads, the sensor measurements appear to fluctuate

Square FSRs Static (450 gram)

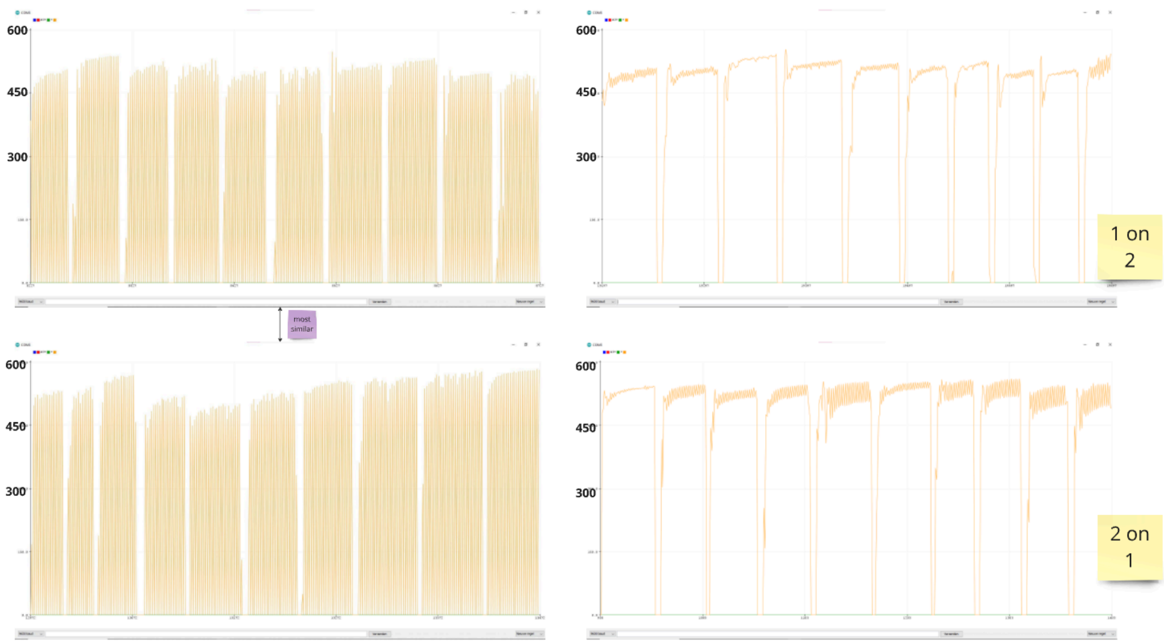
Four FSRs (FSR 0 to 4) from FlexiForce were tested using a weight of approximately 450 grams, with the results below plotted using the Arduino serial plotter.



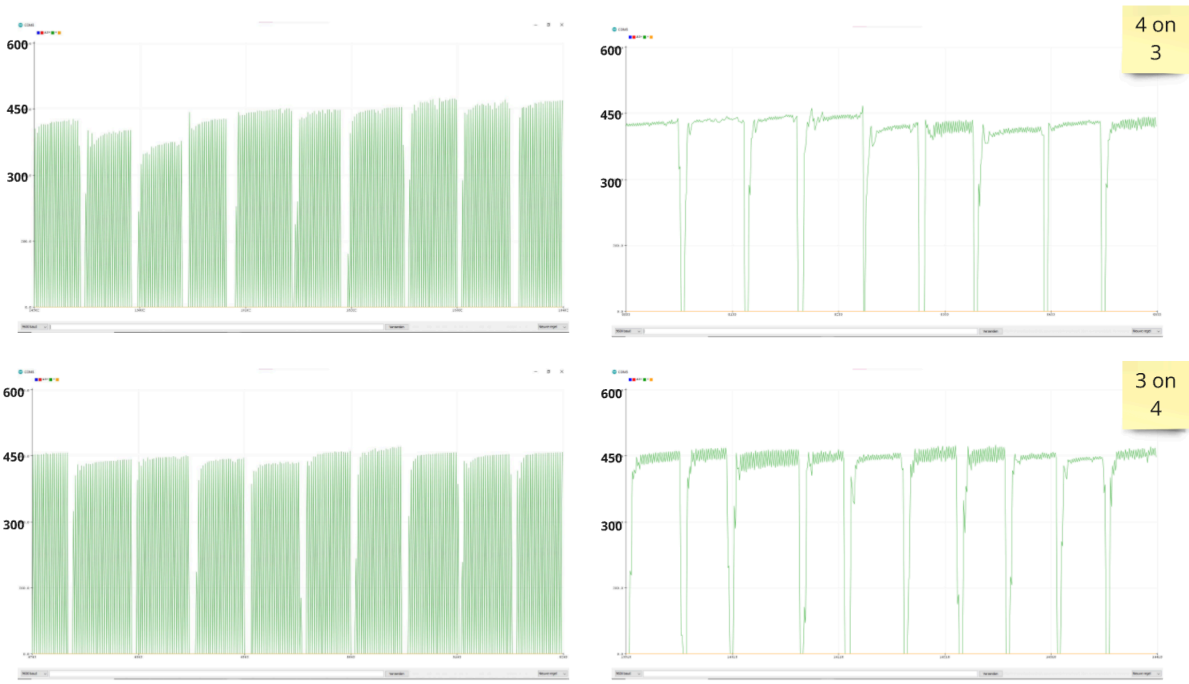
Experimental set-up



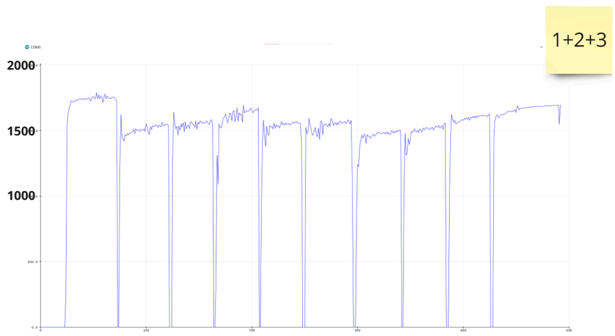
Stabilization of sensor with weight



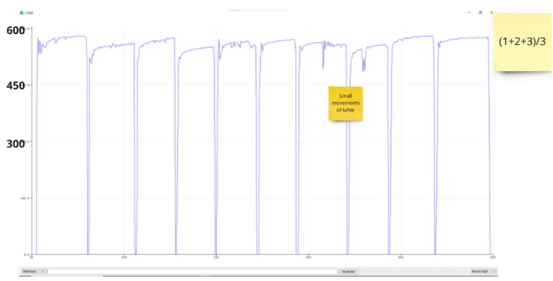
From upper left to bottom right: FSR 1, FSR 1 on 2, FSR 2 and FSR 2 on 1



From upper left to bottom right: FSR 3, FSR 4 on 3, FSR 4 and FSR 3 on 4



FSR 1, 2 and 3 stacked

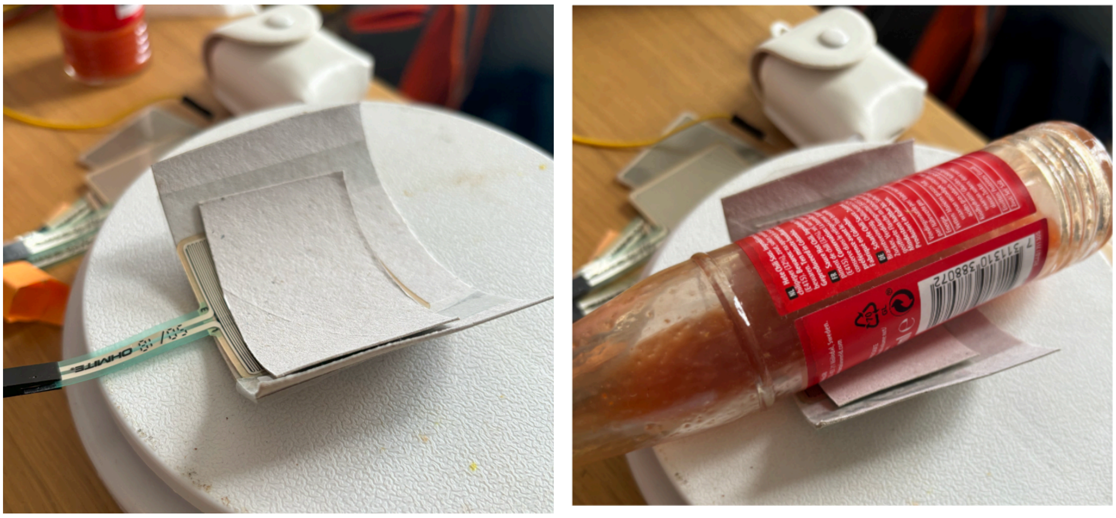


FSR 1, 2 and 3 stacked and divided

- These results show a similar range of differences and fluctuations between the smallest and highest measured load as in the static 130 grams FSRs test. However, the differences in this test are relatively less significant because of a higher applied load.
- When the sensor detecting a higher load is placed at the bottom (e.g. FSR 2 and FSR 3), it detects a lower load, which evens out with the lower numbered sensor on top (see FSRs 1 on 2 and 4 on 3)
- The FSRs are highly sensitive to small movements. For instance, minor movements (such as shifts in the table) can cause differences of approximately 80 grams.

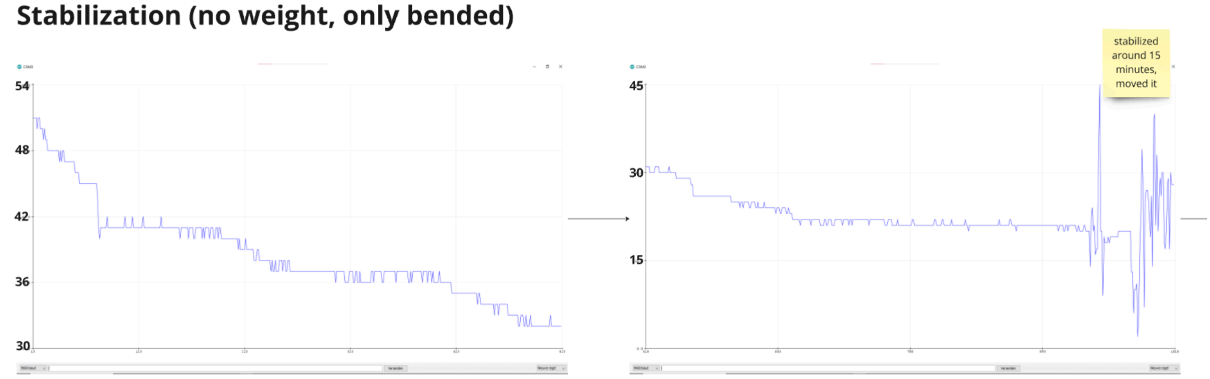
Square FSRs Static, Bent (130 gram)

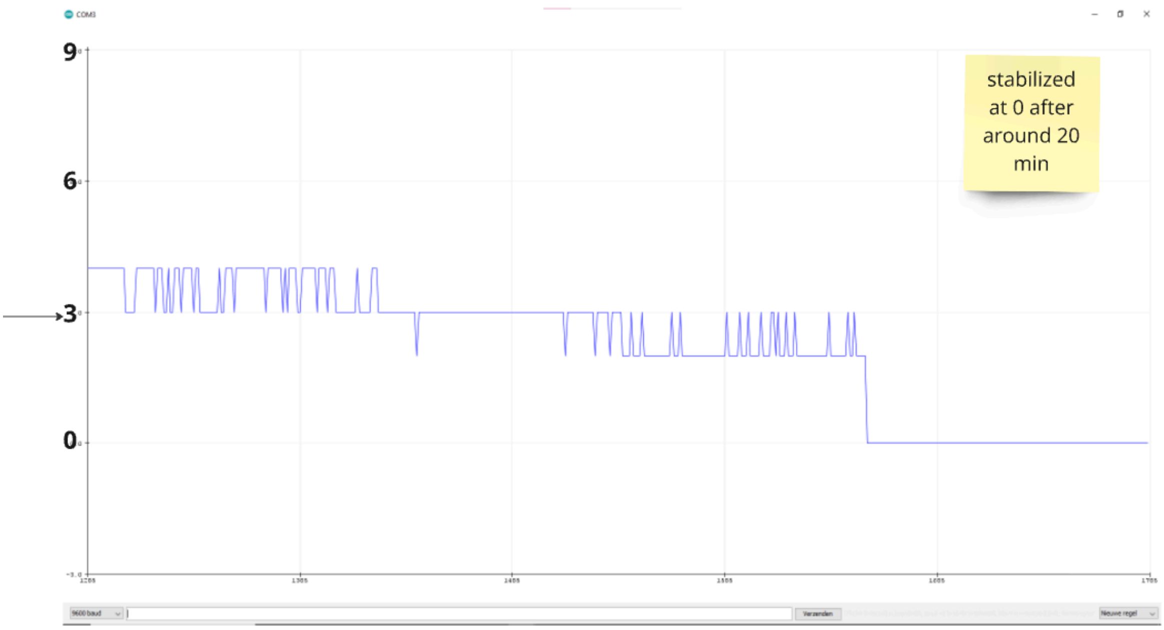
FSR0 is bent in order to mimic the shape of a sensor in the limb. First, the sensor is bent without any weight applied. Once stabilized, a weight of 130 grams is placed on the sensor until it stabilizes again. This process is repeated five times. The results below were plotted using the Arduino serial plotter.



FSR sensor bended, without and with weight

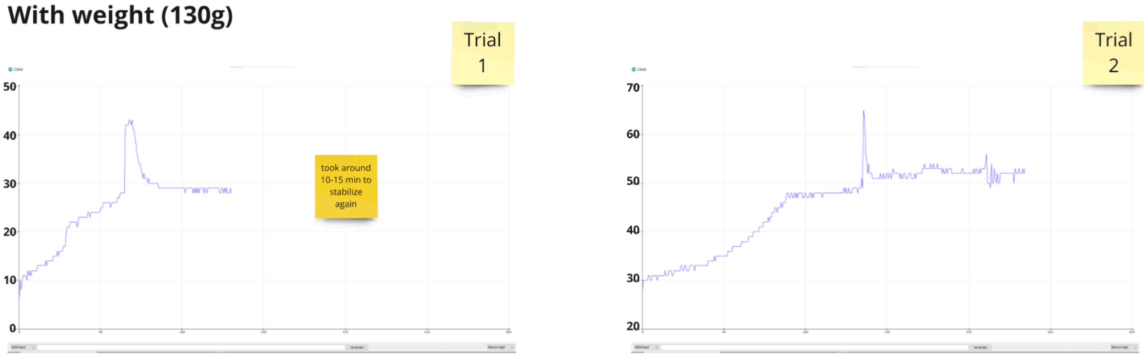
Stabilization (no weight, only bended)

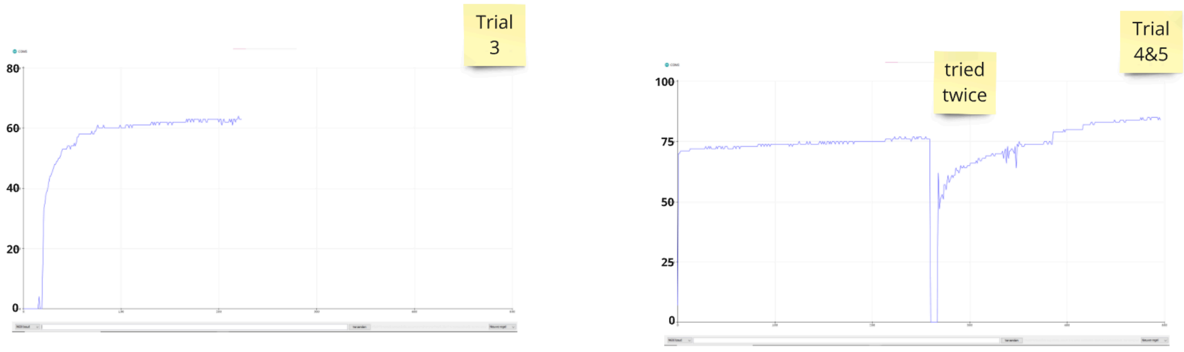




Stabilization of FSR sensor without weight

With weight (130g)





Stabilization of FSR sensor with weight

- Stabilization to 0 takes approximately 20 minutes for the first trial.
- Stabilization with weight reduces after every trial. In the first trial it took 10-15 minutes, while in the last trials took a few seconds for the sensor to stabilize
- The stabilized readings with weight are inaccurate. Despite the applied weight being 130 grams, the measured values varied significantly across trials, showing 30, 50, 60, and 75 grams. These results also indicate that the measured load tends to increase with each trial.

These findings suggest that FSRs perform poorly when bent, showing inaccuracies and long stabilization times. Therefore, I would not recommend this type of FSR sensor inside a socket.

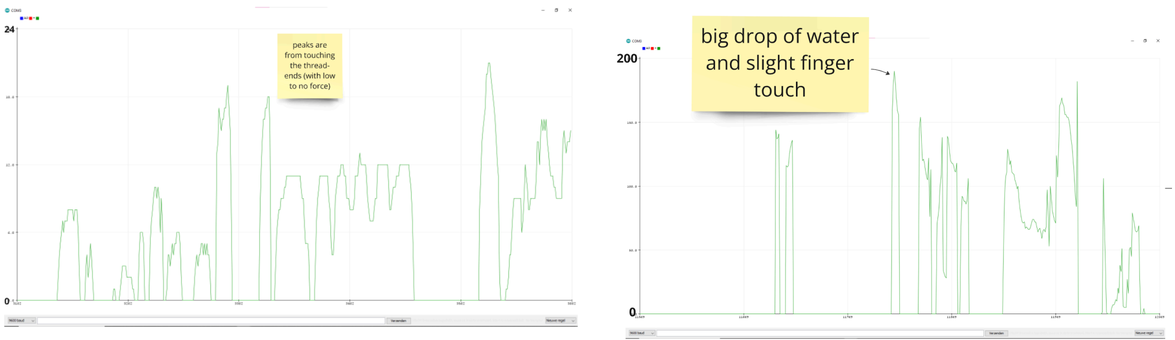
Piezoelectric sensor Dynamic

A single piezoelectric sensor is measured under dynamic conditions. Unlike the FSR experiments, weight measurements were not registered due to the need for excessive force which could not be produced with the available tools at the time. Additionally, the piezoelectric sensor's limited surface area made it infeasible to apply a sufficiently substantial weight for measuring results. Instead, the experiment focused on testing the sensor's response to dynamic forces to observe its behaviour and identify potential faults. The results in Figures below were plotted using the Arduino serial plotter.

Weight on small area (pen point)

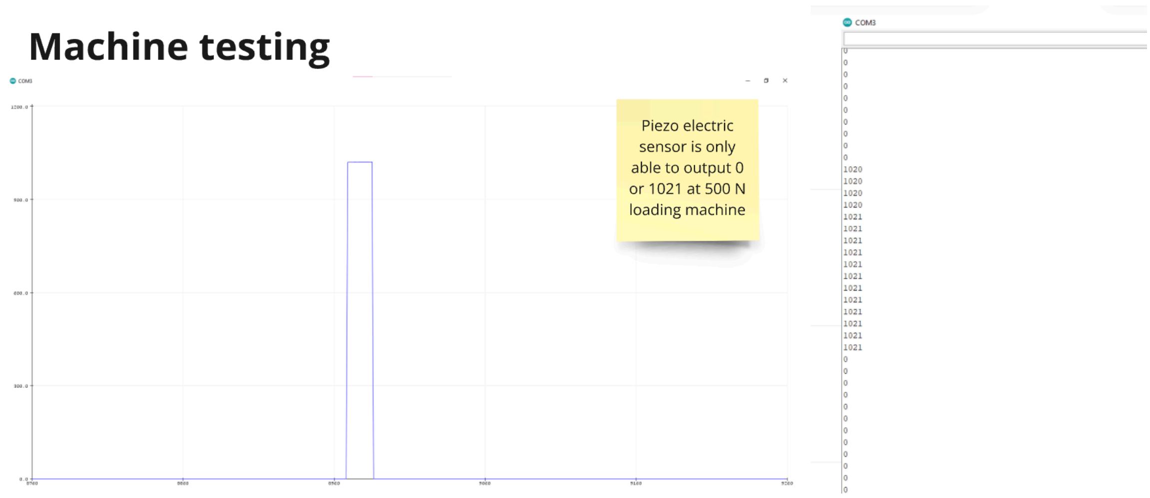
Pushing a pen point onto the piezoelectric sensor.

Systematic errors



Perspiration and liquid on the piezoelectric sensor

- The numbers return to normal once the water is removed, but perspiration could still pose a problem if the sensors are not properly sealed.
- Movement of wires may cause inaccuracy, but deviation measurements were small in this experiment.

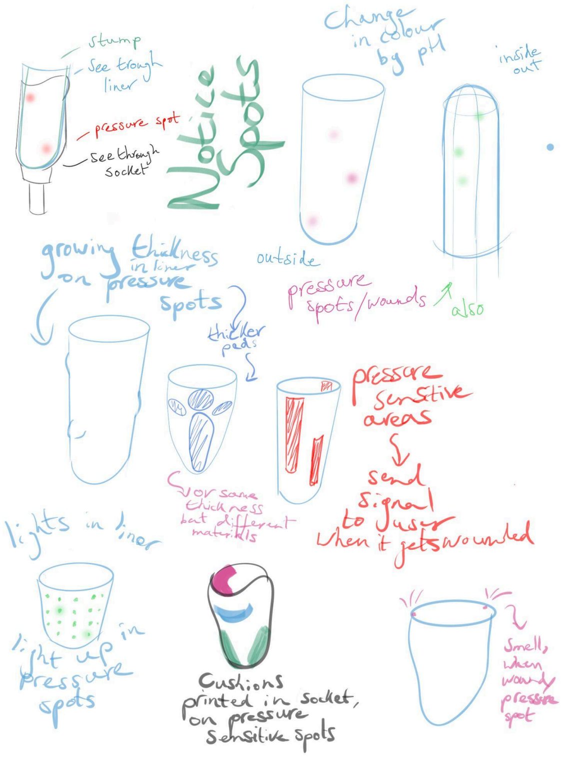


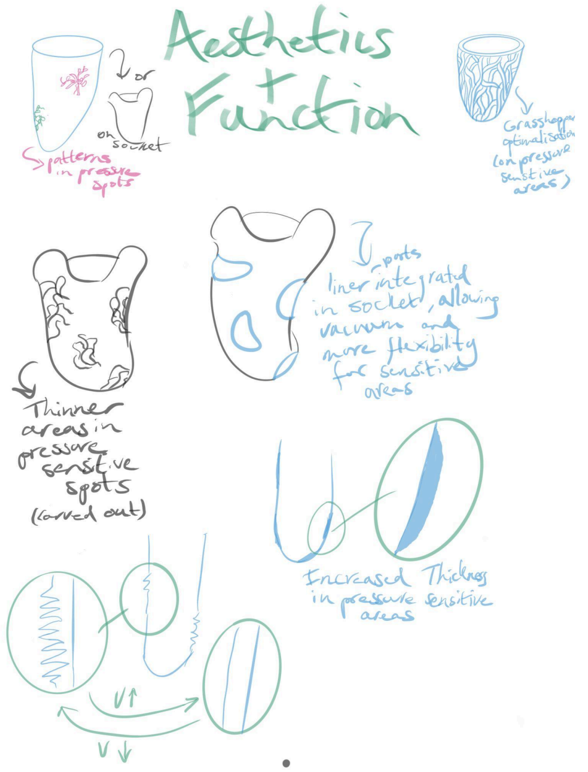
Machine testing output

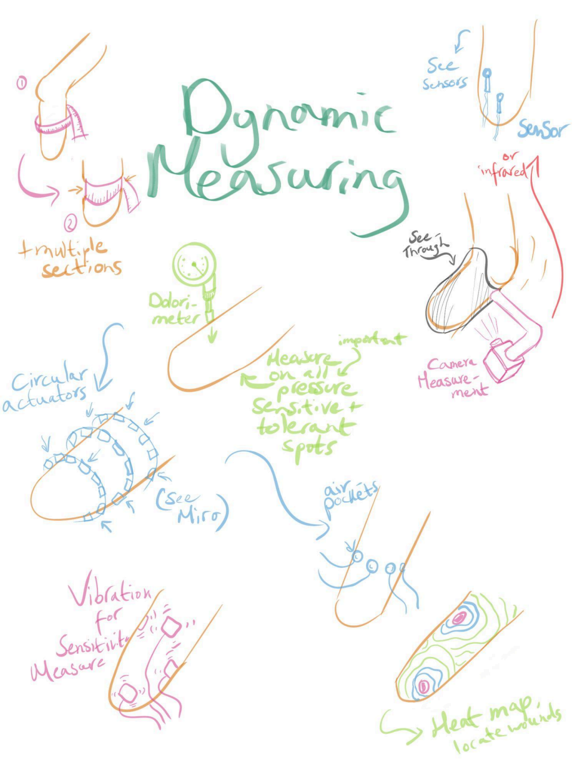
The Instron ElectroPuls E10000 cyclic loading machine is used for the machine testing

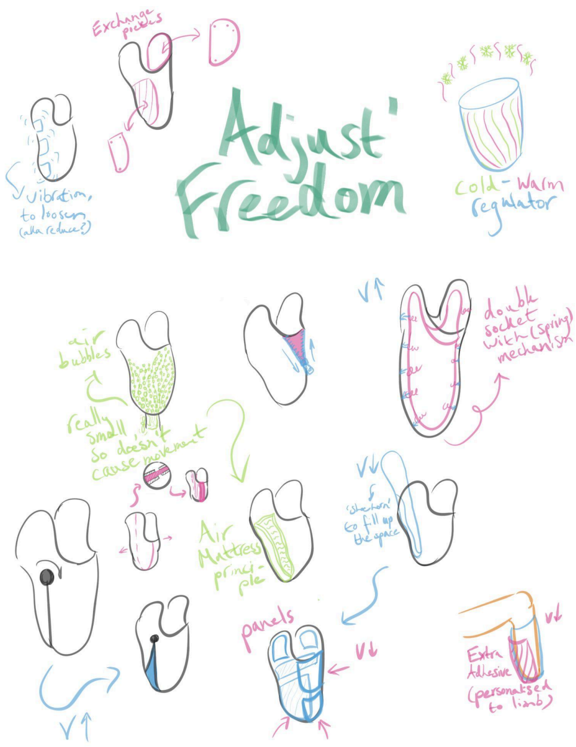
- This piezoelectric sensor is not suitable for big loads such as 500N, because it is unable to accurately detect the increase and decrease in load.

I. Brainstorm and Sketches


Notice Spots
stump
See trough liner
pressure spot
see through socket
Change in colour by pH
inside out
outside
pressure spots/wounds
also
growing thickness in liner on pressure spots
thicker pads
or same thickness but different materials
pressure sensitive areas
send signal to user when it gets wounded
lights in liner
light up in pressure spots
Cushions printed in socket, on pressure sensitive spots
Smell, when wounded pressure spot

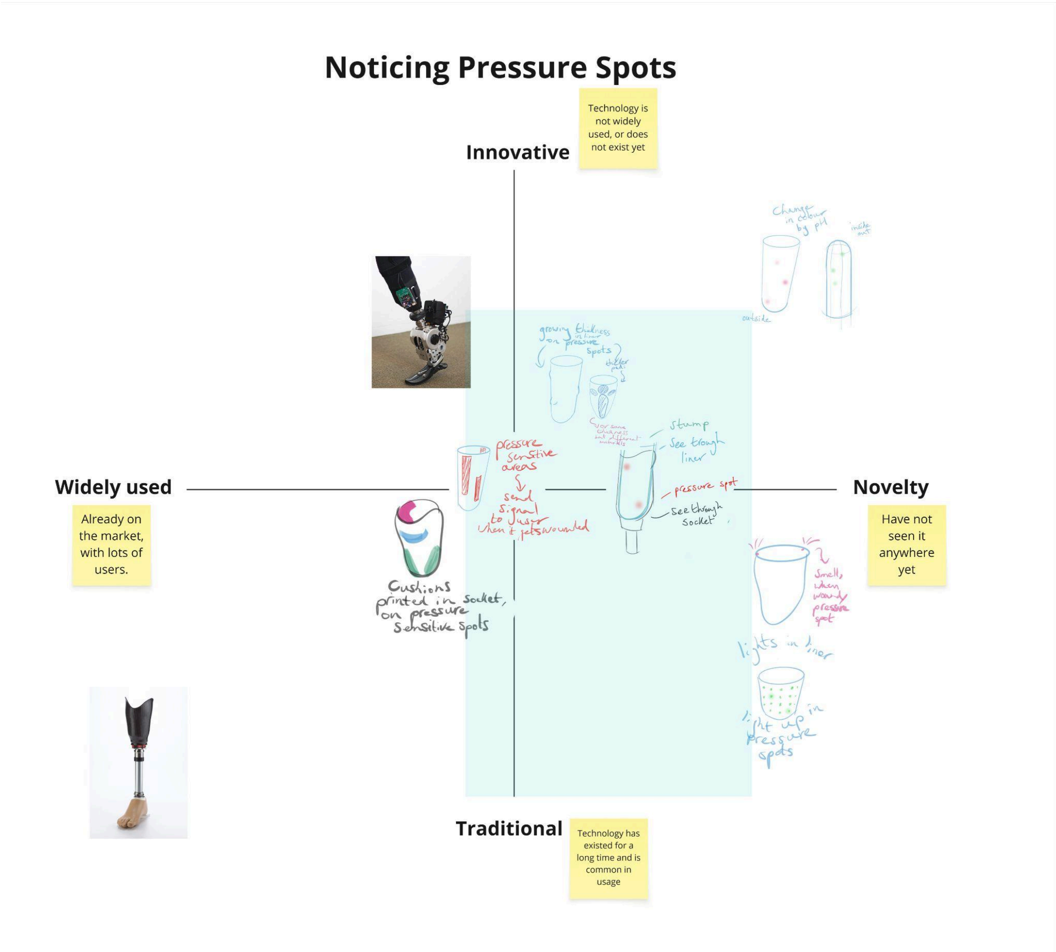

Aesthetics + Function
or
on socket
patterns in pressure spots
Grasshopper optimalisation (on pressure sensitive areas)
Thinner areas in pressure sensitive spots (carved out)
spots liner integrated in socket, allowing vacuum and more flexibility for sensitive areas
Increased Thickness in pressure sensitive areas


Dynamic Measuring
+multiple sections
See sensors
sensor
or infrared
See Through
Camera Measurement
Dolorimeter
important
Measure on all pressure sensitive + tolerant spots
Circular actuators
(See Miro)
air pockets
Vibration for Sensitivity Measure
Heat map, locate wounds

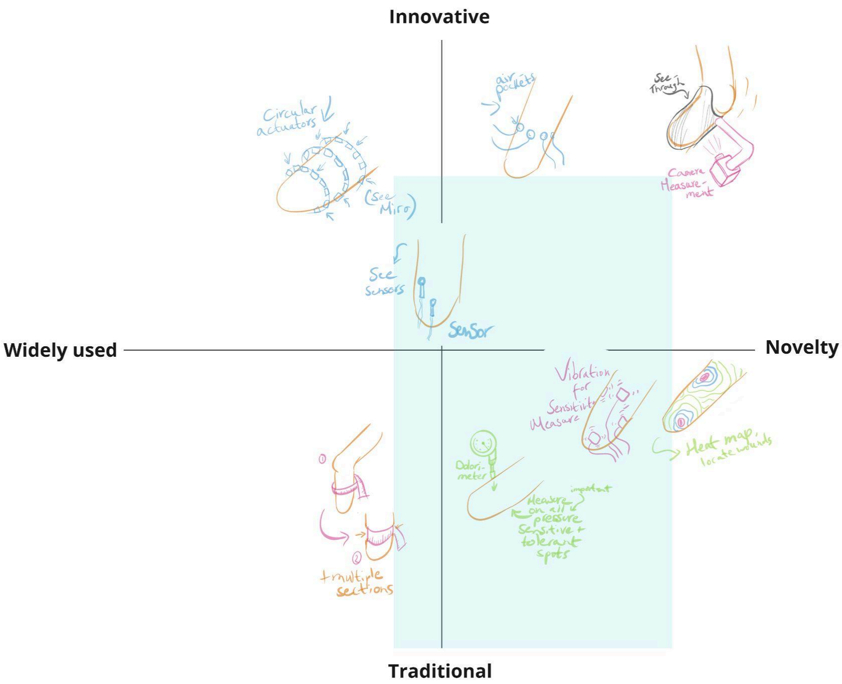

Adjust' Freedom
Exchange pieces
vibration, to loosen (alla relaxed)
Cold-Warm regulator
air bubbles
really small so doesn't cause movement
double socket with (spring) mechanism
Air Mattress principle
'Skeleton' to fill up the space
panels
Extra Adhesive (personalised to limb)

J. Matrices

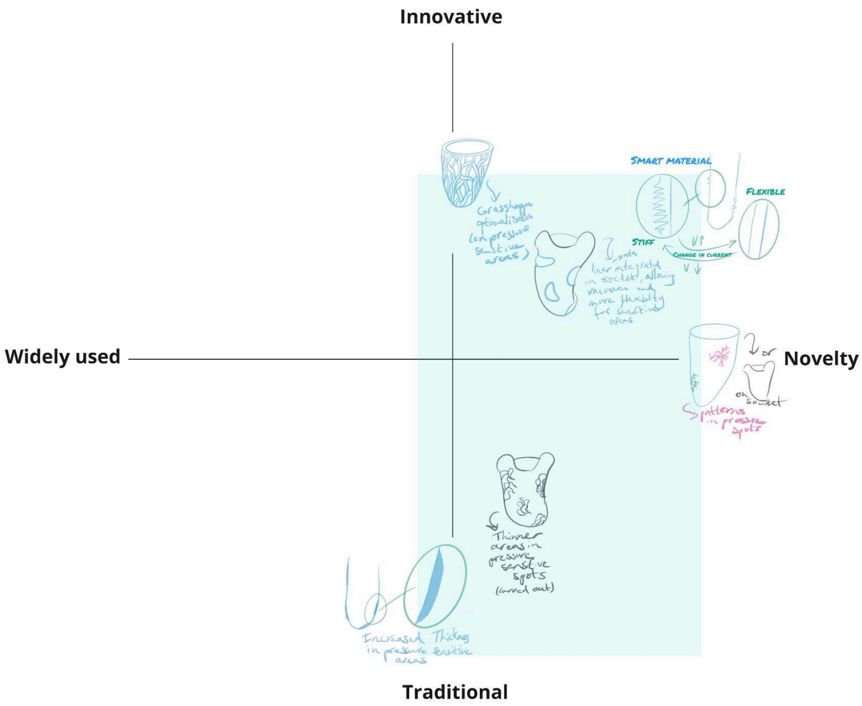
The matrices are based on finding "the sweet spot", which is not too far into the new concept and the innovativeness. This allows for concept exploration and feasibility within the project, and further research in the near future. However, the more innovative and novel ideas can still be explored in future research for more advanced designs.



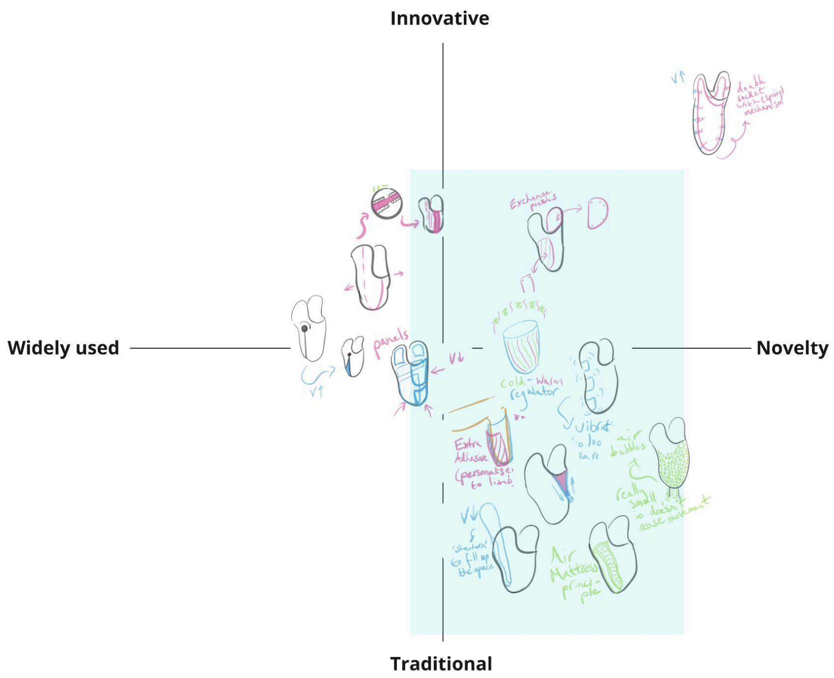
Dynamic Measurement



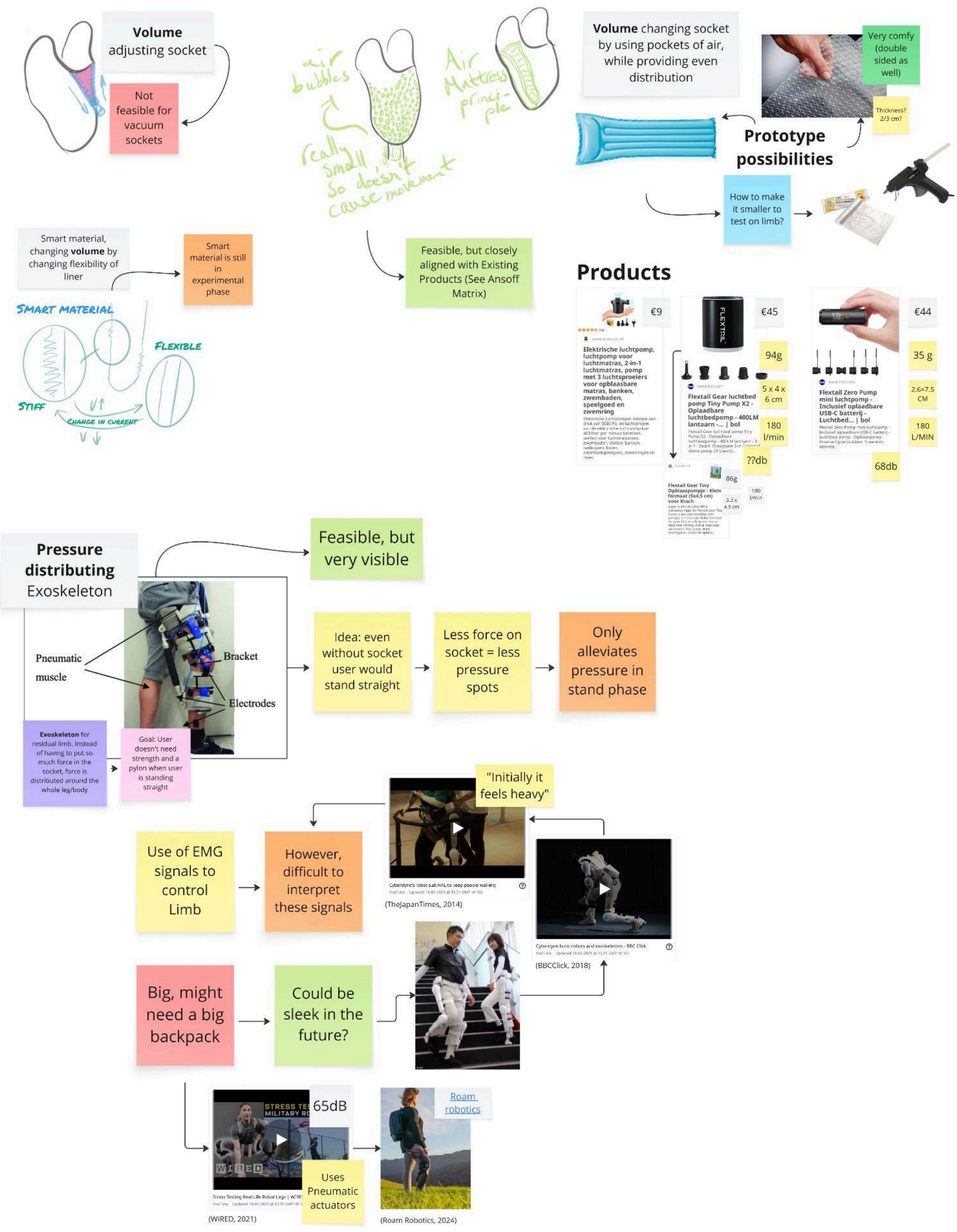
Aesthetic, but funcional



Freedom to adjust



K. New and Refined Ideas




How does the socket react to these higher and lower temperature (change)s?
Cold-Warm regulator
Warm
Cold
Reusable
HEAT HAND WARMERS REUSABLE
Instant hand warmers
Warming element in glove
(Bol, 2025)
(ORTOREX, n.d.)
Reusable
Groots(e) voordelen
TwoTherapy
Doeltreffend
Bevordert
Compact
Klein en groot
Hot cold element
Need to be put in microwave or freezer
(Groots, 2025)
No suitable light-weight cooling method (liquid + equipment)
1x use
Instant cold compress
HeltiQ
Instant Koud Kompres
(De Online Drogist, n.d.)
Cooling/Colder materials
Ethylene Vinyl Acetate
Temperature Regulating Fabric for Ultimate Comfort | Outlast
Increased quality of life due to reduced sweat production
$385 (Adaptive Direct, n.d.)
Average Liner
$350-625 (Zepeda, 2023a)

L. List of requirement and wishes

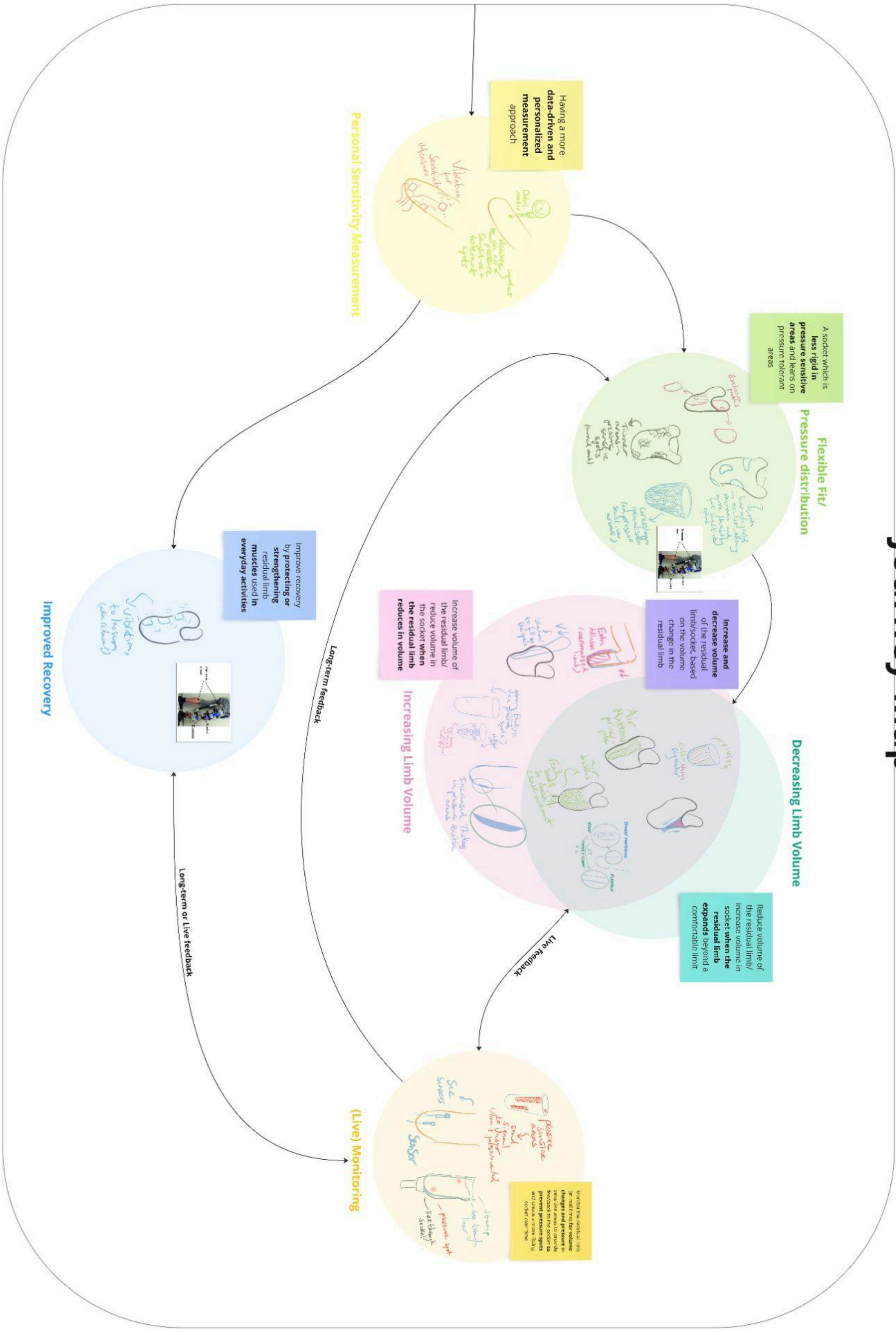
Requirements

- Must be compatible with the vacuum suspension socket.
- Must provide more comfortability than the traditional socket.
- Must be able to sense or prevent pressure spots.
- Must be affordable for the regular citizen, which is lower than €8,500 (Durett's Orthotics & Prosthetics, 2024).
- Must be feasible within 5 years.
- Must be around the same weight as a regular socket.
- Must take less than 30 seconds to use/wear.
- Must not make more sound than 50 dB, which is the average room noise (Hearing Health Foundation, n.d.)

Wishes

- As light as possible
- As affordable as possible
- Provides comfort whenever needed
- Takes as less time as possible to wear or use
- Not larger than the traditional socket
- Can automatically adjust to volume change in the socket
- More aesthetically pleasing than the traditional socket

M. Revised Journey map



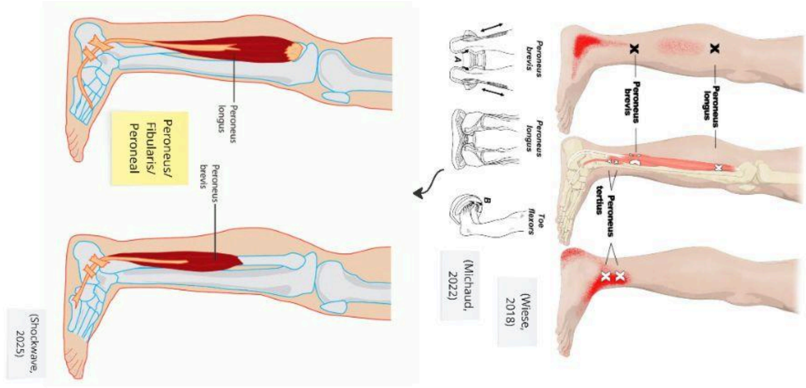
N. Arduino Testing LRA

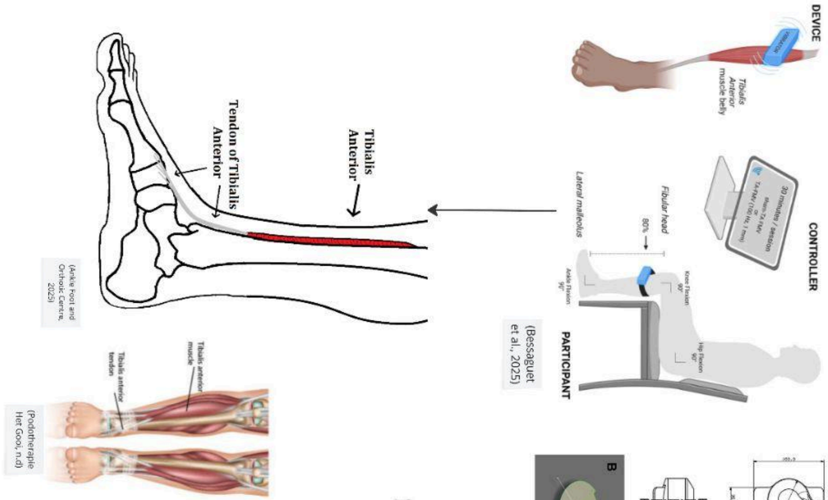
Vibration motor with Frequency modification and Amplitude estimation

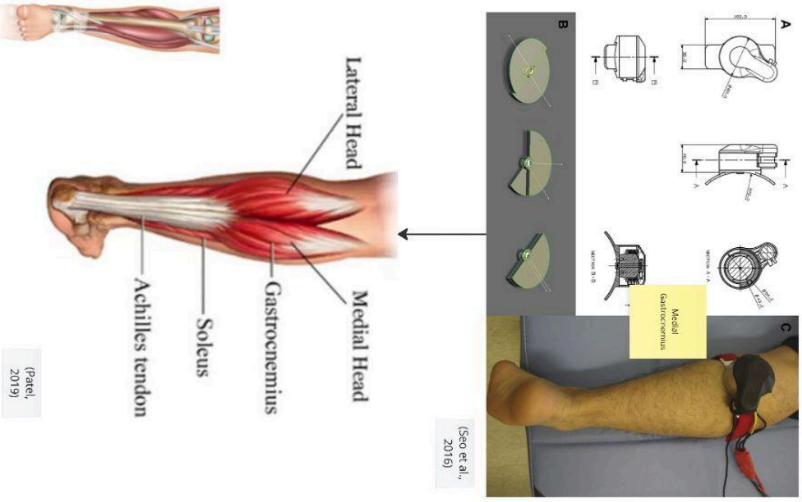
```
  #include <PWM.h> //library for frequency change included

int vmotor = 3;
int32_t frequency = 170; //frequency
int dutyValue = 127; //duty value can be 0 to 255. 127 = 50% duty

void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  InitTimersSafe();

SetPinFrequencySafe(vmotor, frequency);

}

void loop() {
  // put your main code here, to run repeatedly:

  pwmWrite(vmotor, dutyValue);

  float dutyPercent = dutyValue*100.0/255.0;
  Serial.print("Estimated Amplitude");
  Serial.print('\n');
  Serial.print(dutyPercent);
  Serial.print('\n');

  delay(100);
}
```

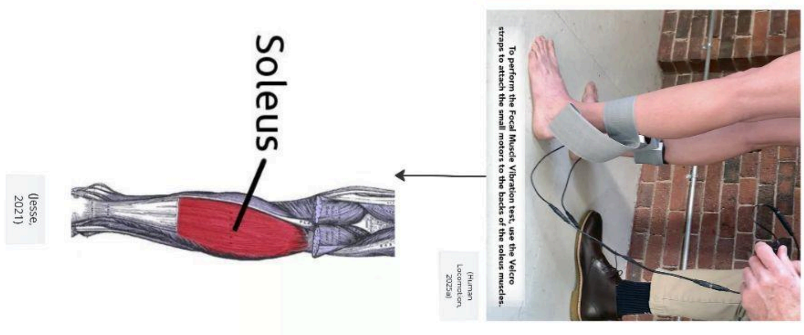
```
COM3

49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
Estimated Amplitude
49.80
```

O. Muscles & Focal vibration locations

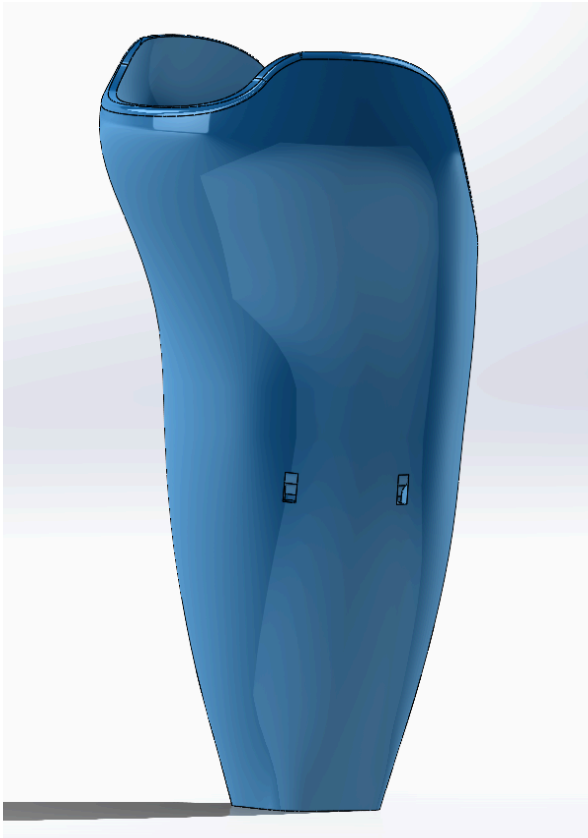
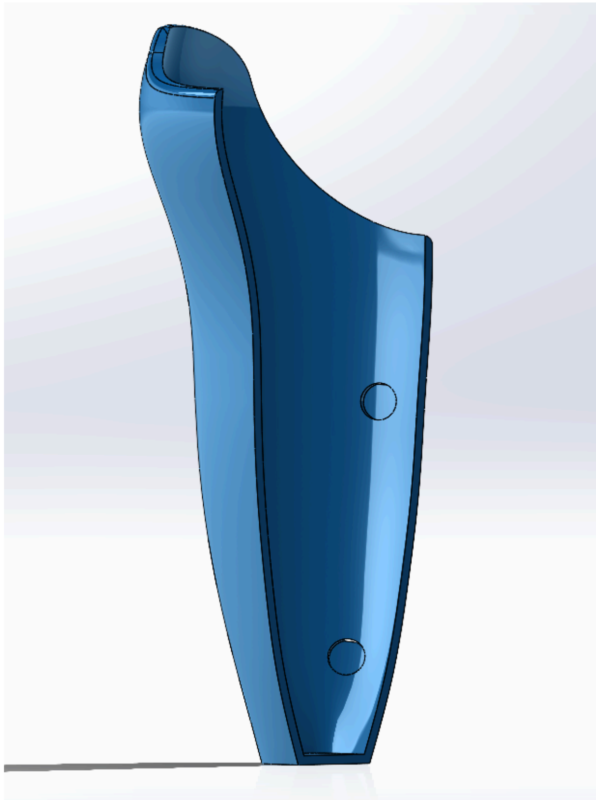
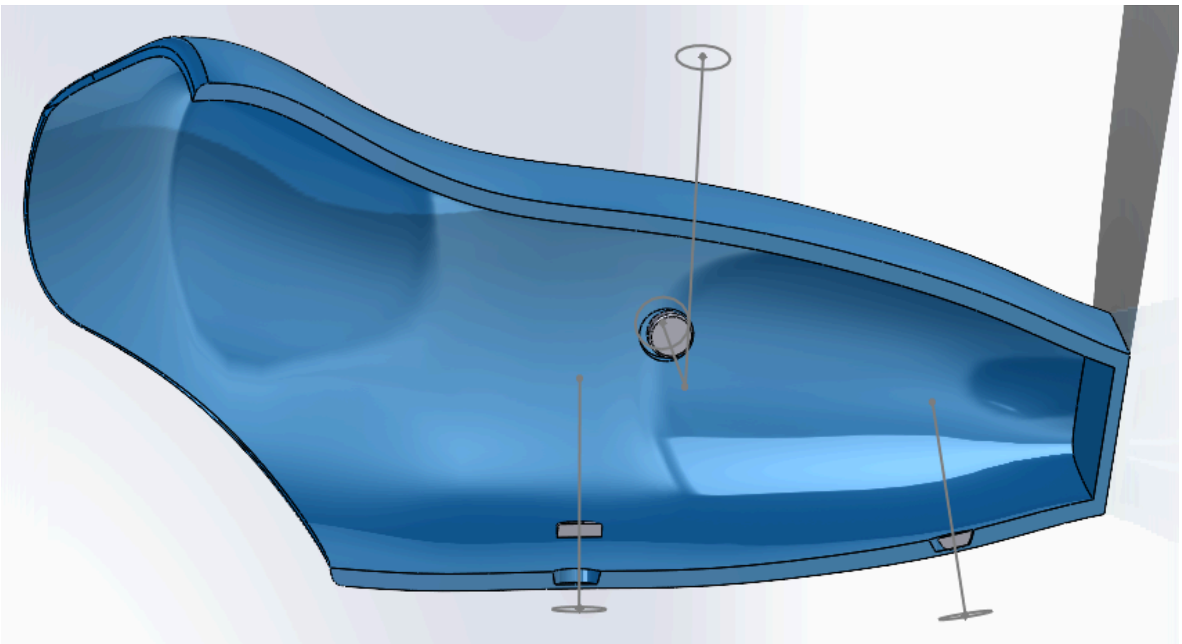








P. Solidworks

Q. BOM Sources

Price and weight sources

- 3D-printed socket weight (Owen & DesJardins, 2020) and cost (van der Stelt et al., 2023).
- Voice Coil Actuator (Aliexpress, n.d.). around €36 a piece, dxh = 20x12,2 mm, 3.7V, 0.41A
- Copper wire (Made-in-China, n.d.), $1 per 100 meter
- Lithium battery 3.7V, 2000 mAh (Amazon, n.d.)
- Lithium battery 3.7V, 4000 mAh (Otronic, 2023)
- PCB estimated price, size and weight: €5 a piece by an order of 100 pieces (PCBWay, 2024), 12x16 cm (Fritzing, n.d.), 75g (Leiton GMBH, n.d.)
- Button (Kiwi Electronics, n.d.), €5 for 15 pieces.

PCB components

- MCU: ESP32 C3 super mini bord, includes wifi (HobbyElectronica, 2025)
- Motor Driver IC: DRV8874 (Pololu, n.d). To control each actuator separately
- Charging IC: TP4056 (HobbyElektronica, 2025a). Allows charging of the battery safely
- Capacitors: For MCU and Motor driver

R. Battery Calculations

Calculation battery 2000mAh:

- Total Current draw from 4 vibration motors: 0.41A x 4 = 1640mA
- Time = 2000 mAh / 1640 mA =1.22 hours = 73 minutes = 1 hour and 13 minutes
- Sessions = 73/15 = 4.9 → 4-5 sessions (without extra components)

Calculation battery 4000mAh:

- Total Current draw from 4 vibration motors: 0.41A x 4 = 1640mA
- Time = 4000 mAh/1640mA = 2.44 hours = 146 minutes = 2 hours and 26 minutes
- Sessions = 146/15 = 9.7 → 9-10 sessions (without extra components)

S. Arduino Code: Wave-pattern

```
#include <PWM.h>

int vmotor = 3;
int32_t frequency = 30;
const int minDuty = 51;   // 20% duty (for 0.01 mm)
const int maxDuty = 255;  // 100% duty (for 0.1 mm)

void setup() {
  Serial.begin(9600);
  InitTimersSafe();
  SetPinFrequencySafe(vmotor, frequency);
}

void loop() {
  // Increase frequency from 30 to 120 Hz
  for (frequency = 30; frequency <= 120; frequency += 5) {
    SetPinFrequencySafe(vmotor, frequency);

    int dutyValue = map(frequency, 30, 120, minDuty, maxDuty);
    analogWrite(vmotor, dutyValue);

      //check frequency and amplitude
    //Serial.print("Freq: "); Serial.print(frequency);
    //Serial.print(" Hz, Duty: "); Serial.println(dutyValue);

    delay(500); //wait for 0.5sec
  }
  // Decrease frequency from 120 to 30 Hz
  for (frequency = 120; frequency >= 30; frequency -= 5) {
    SetPinFrequencySafe(vmotor, frequency);

    int dutyValue = map(frequency, 30, 120, minDuty, maxDuty);
    analogWrite(vmotor, dutyValue);

      //check frequency and amplitude
    //Serial.print("Freq: "); Serial.print(frequency);
    //Serial.print(" Hz, Duty: "); Serial.println(dutyValue);

    delay(500); //wait for 0.5 sec
  }
}
```

Personal Project Brief – IDE Master Graduation Project

Name student Cindy Low

Student number 4,666,593

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Smart transtibial socket: Exploring sensors for comfort and fit during activity

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

A transtibial socket is a prosthetic that fits over the residual limb of the amputee below the knee. The current transtibial socket being explored is a vacuum socket. It consists of a liner, suspension sleeve and air evacuation pump. Even though the vacuum socket provides a lot of benefits, such as a more even pressure distribution and less pistoning than other sockets, it is not fitting and comfortable enough, and still presents challenges over time. These challenges are mainly skin problems and infections and are caused by various factors: shear stress, volume fluctuations, interfacial pressure, and temperature. Especially during physical activity, the temperature increases more than 2 Celsius, which exceeds the threshold of comfortability in the socket. During and after activity, a change of liner is needed to prevent the change of interfacial pressure and shear stress. To prevent and improve several experienced problems of the transtibial socket users, sensors can be integrated to provide on-time feedback on pressure distribution during various daily activities.

Stakeholders

The goal is to enhance user comfort and fit to create more independence for the user. It is preferred to keep the cost and time consumption low in order to keep it accessible for as many people as possible. However, more stakeholders are going to be involved on top of the current stakeholders (users, health care professionals), such as researchers, data analysts and data translators. This may increase the cost.

➔ *space available for images / figures on next page*

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

For the Master Graduation Project, I want to contribute to a more fitting and comfortable transtibial socket during the most important daily activities, by reducing interfacial pressure in the sensitive areas of the residual limb. Walking will be taken as the most important activity, with other activities to be explored. User comfortability will be assessed by implementing the sensors (to gain insight about the pressure areas during these activities) and research.

Preferably, I would also like to gain insight into the other problem factors, such as shear stress and temperature. Based on the chosen sensors and their necessity, I will decide if the sensors can be combined without interference and if it should be integrated in the liner or socket

Thus, the main focus of the project would be doing research about fitting sensors and gait dynamics, and conduct experiments based on the research conclusions.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Investigate and test sensors in order to improve comfort and for patients with a transtibial socket during the most important daily activities. The deliverable will be a working prototype to gain insight about the pressure areas: sensors integrated in a socket. (Based on the results, ideas for future research will be explored.)

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

Research on user anatomy, comfortability and activity will be done by using desktop resources and TU Delft resources.
Field trip to a company will be done in order to gain more insight into the user and the socket.
Research on sensors will be explored by using desktop resources and TU Delft resources.
The sensors are going to be callibrated by using different types of weights on flat surface first, and afterward callibrated and tested with the researched challenges. After this, the sensors have to be tested by mimicking force and activity from a phantom leg. Iterations will be made throughout the testing phase.
If possible and feasible, the prototype will be tested in the end phase with a transtibial socket user.
The ideation, HKJ and Harris profile will also be used to explore ideas and make (idea) decisions.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	14 Feb 2024
Mid-term evaluation	24 Apr 2024
Green light meeting	12 Jul 2024
Graduation ceremony	21 Aug 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:
One day off once in 2 weeks. 1 week of vacation. Also a few days off inbeteween.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I am interested in this project, because it resonates with my passion for designs solutions that could really make a difference in people's lives. Especially when I can improve their quality of life. This interest started with my AED project, where I was describing my values to my groupmates and they immediately gave the suggestion of participating in the Medisign track. After I finished a course and several electives within this track, I realised I was more interested prevention and revalidation of mental and physical health. On top of that, I also preferred something which I could learn a lot from. And this project fits in perfectly in all that I am interested in.

Personal goals:
With this project, I would like to explore more about different types of sensors, and learn to work and prototype with it.
I would also like to learn more about the unique challenges this target group faces, so I can gain a deeper understanding into their wants and needs.
On top of that, I would like to improve my skills in modelling, especially for presenting the design.