Exploring solutions for finger tremor patients:

Designing finger tremor suppression through passive wearable

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Master thesis

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Terminology

ADL
Activities Daily Life

BEAM
Supportive orthosis from STIL for people with Essential Tremor, suppress the tremor in the forearm pronation/supination and wrist flexion/extension.

DOF
Degrees of freedom

DIP
Distal interphalangeal, the first knuckle from the top of the finger.

EFE
Elbow flexion/extension

ET
Essential Tremor, a neurological disorder. Mostly characterized by an action and postural tremor and affects the hands.

FPS
Forearm pronation/supination

MCP
Metacarpophalangeal, the third knuckle from the top of the fingers

MS
Multiple sclerosis, a condition that can affect the brain and spinal cord, causing a wide range of potential symptoms, including problems with vision, arm or leg movement, sensation or balance.

PIP
Proximal interphalangeal, the second knuckle from the top of the finger.

SAA
Shoulder adduction/abduction

SFE
Shoulder flexion/extension

SIER
Shoulder interior/exterior rotation

TETRAS
The Essential Tremor Rating Assessment Scale, easily and fast quantify essential tremor severity.

TMC
Trapeziometacarpal
WFE
Wrist flexion/extension

WRUD
Wrist ulnar/radial deviation

WTSG
Wearable Tremor Suppression Glove, from Zhou et al. (2018)

Figure 1: final prototype

Abstract

This report presents an explorative study in finding solutions for finger tremor patients diagnosed with Essential Tremor (ET). Tremors restrict patients from performing delicate movements, creating difficulty in daily activities, such as drinking, writing, cooking or eating. Besides the challenges in performing tasks, social anxiety often occurs and negatively influences social life.

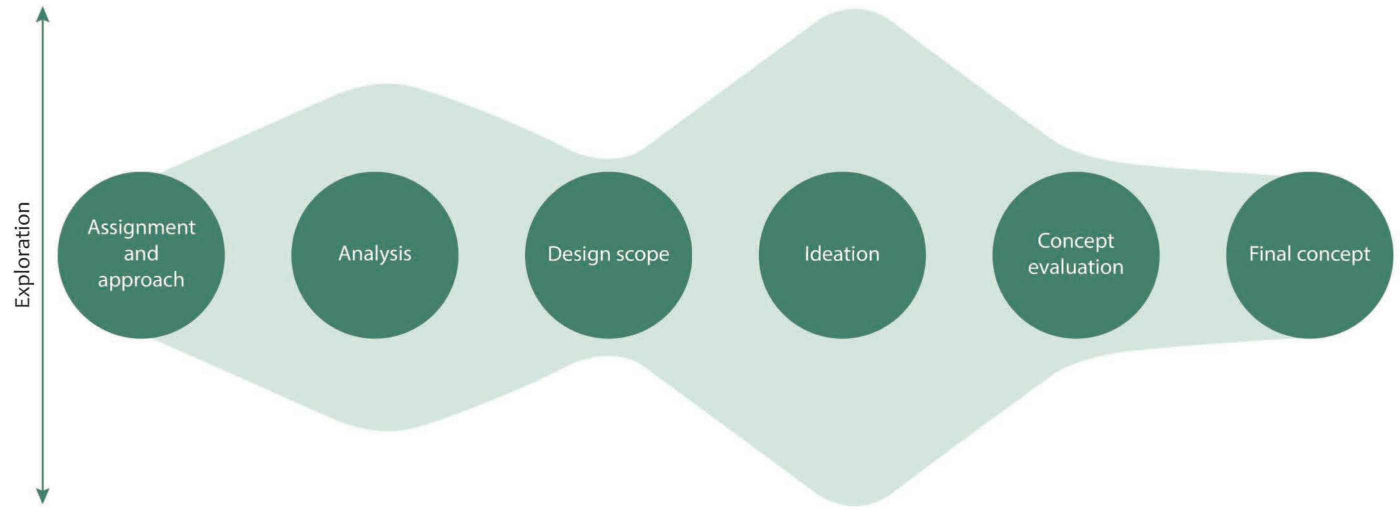
Currently, solutions for people with tremors are limited. STIL recognized this need and designed an orthosis for people with wrist tremors. The solution from STIL is an orthosis called the BEAM. The BEAM mechanically suppresses the wrist flexion extension and forearm pronation-supination tremors. Evaluation of the current BEAM concluded that wrist tremors are successfully suppressed, but tremors situated mainly in the fingers need additional stabilization. This study aims to design a functional wearable that mechanically suppresses finger tremors.

To better understand finger tremors, the project provides information on hand anatomy, the current market for finger wearables, and a video analysis of previous tests from STIL. The research found that there is limited knowledge about finger tremors and available wearables specifically designed for them. In user tests STIL saw many people with tremors also deal with a finger tremor, people can benefit from a finger wearable . In addition, the design scope research aimed to identify the specific needs and desires of people with finger tremors. The focus is on discovering a healthy and comfortable balance between freedom of movement and suppression of the fingers. The research conducted with three participant showed that the thumb, index, and middle fingers at the MCP (third joint from top of finger) and PIP (second joint from top of finger) joints need to be suppressed and that participants desire an inconspicuous and open design.

The ideation phase exists out of multiple iterations. The basis of the ideation is a meeting with an expert in Emerging Materials, a morphological card, and brainstorming with the team of STIL. The basis concluded in four promising design directions, which could suppress the finger tremor: wires with springs, gel/air damping, elastic bands, and splints with different stiffnesses. Prototypes were built to research and test the four directions. Finally, the most interesting concepts are elastic bands and splints with different stiffness. The elastic bands give a counterforce to the fingers by pulling them backward. The silicone splints in a glove are made of silicone with spring steel which lies on the fingers.

The working principle and ergonomics of the elastic bands and silicone splints have been validated in patient research. The results showed that the silicone splints were better in terms of performance and comfort, while the elastic bands were preferred in terms of design and adaptability. The final concept used the working principle of silicone splints. The final iteration focuses on appearance, ergonomics, usability, and connection to the BEAM.

In conclusion, this report provides a foundation for STIL to further develop a wearable solution for people with finger tremors. The working principle of using silicone splints to suppress finger tremors is promising, but additional iterations are necessary.



Graph 1: Project proces

Content

01

Assignment and aproach

Chapter 1 introduces the project introduction, problem definition, assignment and planning.

1.1 Introduction

One of the most prevalent movement disorders are tremors. Tremors are involuntary rhythmic muscle contractions that lead to shaking movements in one or more body parts (Deuschl et al., 2008b). Daily activities such as taking care of yourself, moving, eating, drinking, writing, cooking and computer work can be consideraly disrupted by temors (Louis et al., 2001). The overall frequency of human tremor ranges between 3 to 12 Hz and occur predominantly in the upper extremities (Hallett, 2008). On top of the physical impact, tremors also have a mental effect. Limitations in participation in social activities brought on by tremors can have a complex and significant effect on the state of mind of a person, such as feelings of loneliness or depression (Chunling & Zheng, 2016). Louis et al. researched that people with tremors are two times more likely to report depression. The leading causes of tremors are multiple sclerosis (MS), stroke, traumatic brain injury, or neurodegenerative diseases (Parkinson's disease). There are currently no known cures or treatments for most tremors within medical science. However, some treatments help alleviate the symptoms of tremors.

STIL saw a need for better solutions for tremor treatment. The company initially focused on an active responsive brace that used an "anti-vibration" to suppress the lower-arm vibration of the tremor. In 2022 STIL shifted focus toward a mechanical stabilizing orthosis. The orthosis, named the BEAM, is meant for people with an essential tremor (ET) in the lower arm. An essential tremor is a tremor for which no demonstrable cause is known. The tremor mainly occurs when the user tightens the muscles. This occurs, for example, when grabbing a coffee cup. The technology used within the BEAM focuses on the high frequency of the tremor. Dampening technology is used to suppress these high frequencies.

Figure 2: user

1.2 Problem defintion

STIL is currently in the beta phase of the orthosis and focuses on the required medical certifications. A beta-phase prototype is representative of the entire product. It could be lacking packaging or final colors. The working principles and design specifications can be tested with this prototype.

This graduation project will focus on opportunities to suppress the tremor in the fingers. The main focus of the BEAM is on tremors in the lower arm. In this way, STIL can help a large group. The BEAM suppresses tremors in two degrees of freedom (DoF); in those DoFs, the tremor is most commonly found (Pigg et al., 2022). Tests from STIL b.v. shows that people with mainly tremors in their fingers or a combination of wrist and finger tremors will not benefit enough from the orthosis. In order to work toward a more inclusive design, STIL has provided an assignment to research opportunities in helping people that suffer from tremors located in their fingers. Cooperation with the user and research in technology, ergonomics, and anatomy is essential to assess these opportunities. The end goal of this project is to deliver a valuable design concept for a finger wearable. To achieve this design, STIL needs an industrial designer who can explore the possible solutions to suppressing the tremor and be an addition to the current orthosis.

Evaluation of the current BEAM orthosis concluded that wrist tremors are successfully suppressed, but tremors situated mainly in the fingers need additional stabilization. One example of this need for additional stabilization becomes clear when evaluating the BEAM during cutlery-based eating movement. Finger tremors cause great discomfort during this activity and while the BEAM stabilizes the wrist, cutlery still moves due to tremors in the finger. People with a finger tremors could not comfortably eat or do other tasks like using the computer or drinking from a cup. People with a finger tremor need an addition to the BEAM. This project aims to provide a wearable that suppresses the tremor in the fingers.

Current research and solutions for finger tremor patients are limited. Therefore this project will have an explorative character. The working principle from the BEAM orthosis is mechanically suppressing the tremor in the wrist. Researching the feasibility of the working principle for finger tremor patients is valuable for STIL.

1.3 Assignment

In order to create an inclusive design for the orthosis from STIL, there is a need for an additional solution for the BEAM that focuses on people with a finger tremor. This project aims to design a functional wearable that mechanically supresses finger tremors.

1.4 Planning

The project's planning is based on the two-week sprints from STIL; there is one sprint every two weeks; see figure 3 for the planning overview. The first three sprints will be part of the analysis phase. The analysis phase aims to understand the stakeholders, finger tremor, hand anatomy, the scientific and commercial market, and an evaluation of patient videos. This understanding will be a basis for the first requirements and wishes. The planning present three or four sprints for setting the design scope. In these sprints, there is time planned for a research setup, building prototypes, and testing. The testing has to indicate the design scope. With the design scope, the ideation and conceptualization phase can start, which will consist of four sprints. In these sprints, the focus is on ideation, brainstorming, prototyping, testing, and evaluation. During the prototype time, different prototypes will be made and tested. Finally, all the findings have to be reported. In the last three sprints, the focus is on designing the final concept. At the end of every sprint, a presentation with the result from the sprint will be given. This will be a presentation for STIL. This presentation is used as a base with information for the final report.

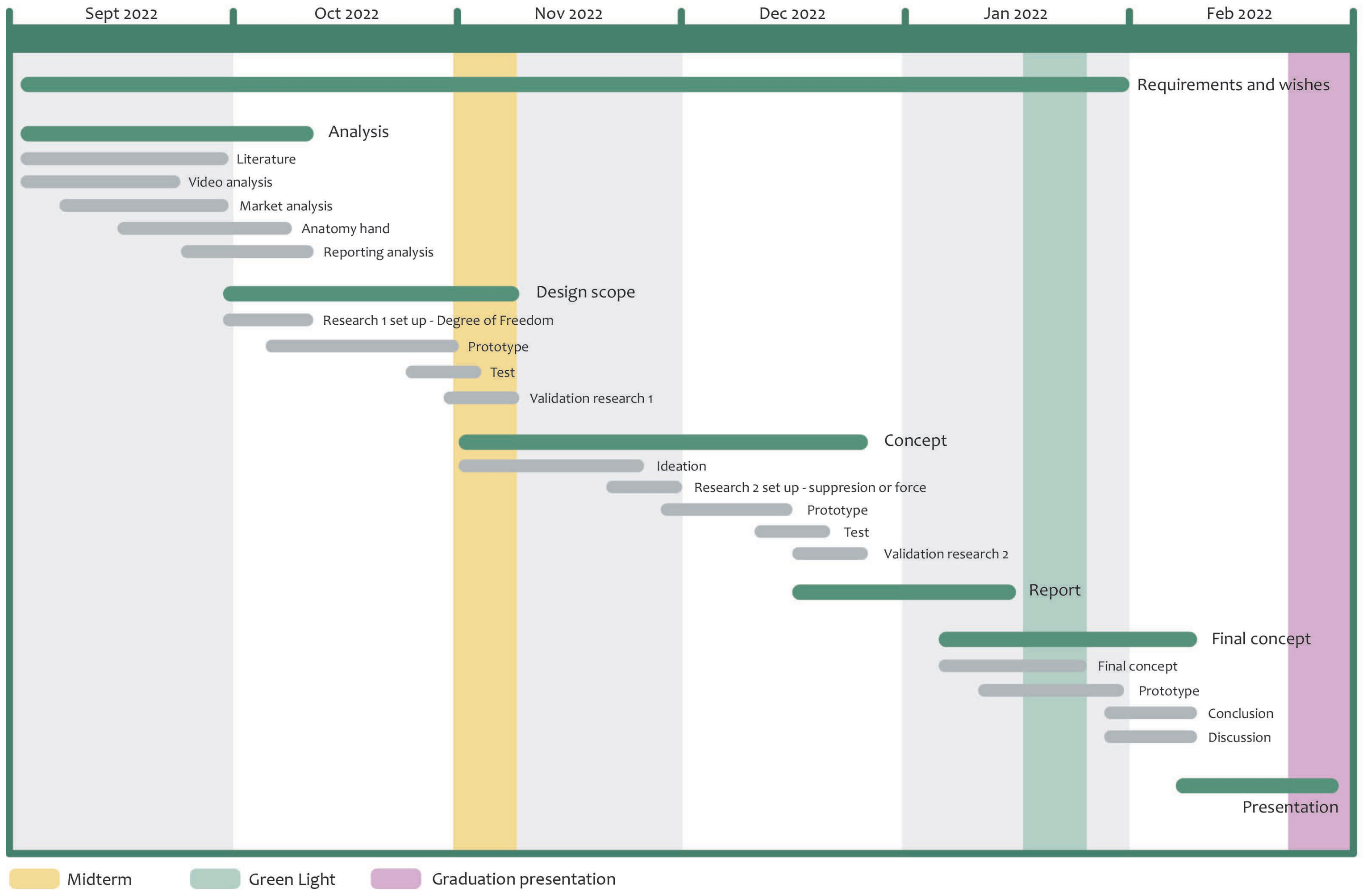


Figure 3 : planning overview

02 Analysis

In the analysis phase, the main goal is to better understand tremors and the field of wearables for finger tremor suppression. This chapter discusses the main findings from the literature, market study, and video analysis. The subchapters are; explanation about the STIL orthosis, stakeholders overview, understanding of tremors, anatomy of the hand, reference study in the field of wearables, and video analysis from tremor patients. After each subchapter, the design insights are summarized.

2.1 STIL

2.1.1 The BEAM

The BEAM is a supportive orthosis for people with ET worn around the arm. An orthosis is a wearable to support the limbs or to prevent or assist relative movements. The BEAM (see figure 4) has a handcuff and elbow cuff. The handpiece goes on top of the hand; with the soft fabrics around the thumb and palm, the handpiece is held in place. On top of the handpiece is the wrist flexion-extension damper (WFE). The WFE is the horizontal hand movement up and down. Between the hand and the elbow cuff is the slider, the slider can extend easily. The extension gives the user ergonomic freedom. Pulling in and out the slider gives no mechanical damping. Rotating the slider gives damping so that the forearm pronation-supination (FPS) tremor will be damped. The tremor forces mechanically transfer to the arm piece. Here, the user's upper limb will give stability. The design from the BEAM provides an almost natural range of motions and mechanically suppresses the forearm and wrist tremor. With the orthosis, the user can independently perform daily life activities.

Confidential information

2.1.2 Target group

STIL initial focus is on people with an ET in the Netherlands. Tremors occur from an average age of 57 (Louis & McCreary, 2021). This indication can be used to assess the age group for the design, specifically those of middle age and older. The target group for the BEAM are people with a Forearm Pronation Supination (FPS) or/and Wrist Flexion Extension (WFE) tremor. Pigg et al. 2020, shows that FPS and WFE tremor are the most common. It is expected that the BEAM could also help many people with these tremors because 80% of those with a tremor in the upper limb have essential tremor (Pringsheim et al., 2014). However, testing in practice learned that people have primarily multiple tremors in different DoFs. So even when people have an FPS and WFE tremor, it could be the case that there is also a shoulder or finger tremor. In these cases, the BEAM will work efficiently for WFE and FPS, with less noticeable effects.

People with an ET are the target group from the BEAM. So far, there is no convincing evidence that the BEAM would not perform sufficiently well for people with Parkinson's Disease or Dystonia. Further research has to show if people with Parkinson's Disease or Dystonia could also be included in the target group for the BEAM.

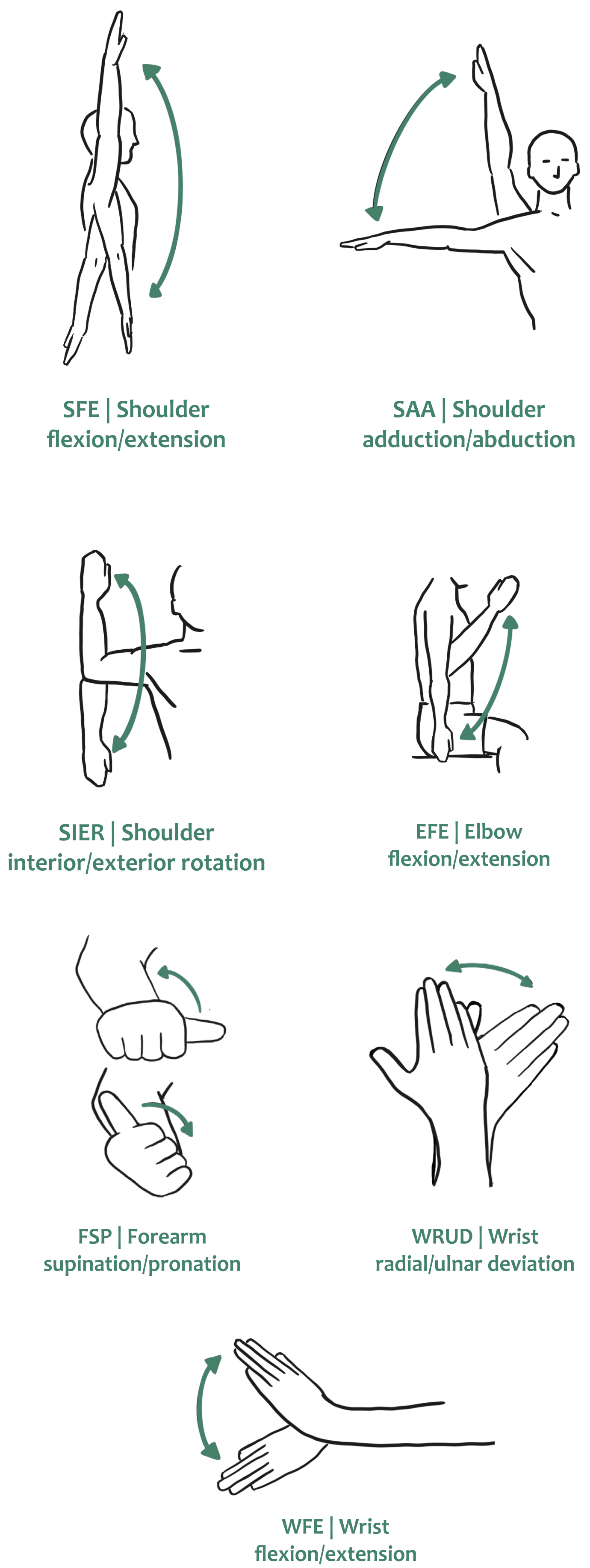


Figure 5: DoFs from upper limb

2.2 Stakeholders

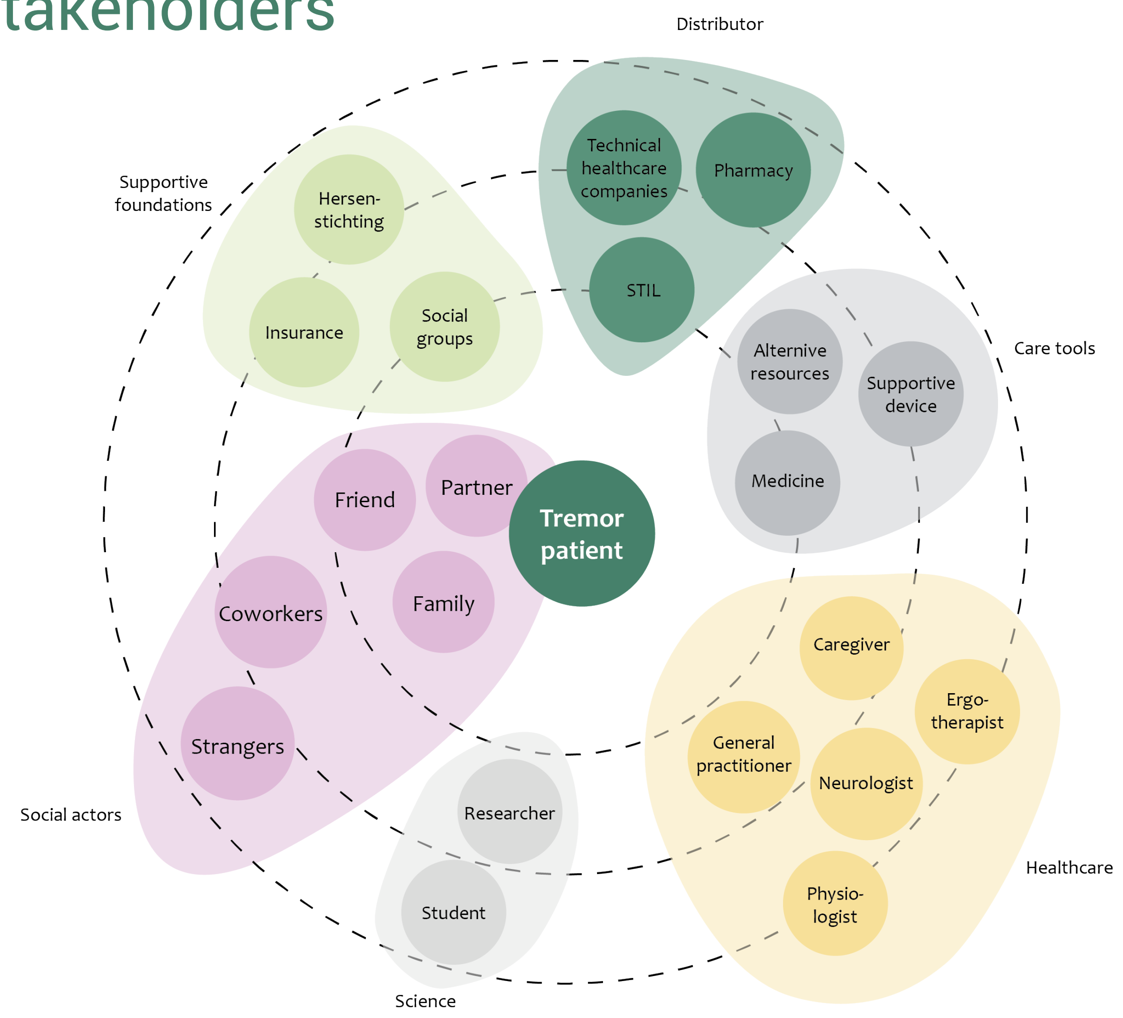


Figure 6: stakeholders overview

Tremor patient

Tremors have a significant influence on people's life. Social anxieties from potential tremors can significantly impact a person during events. In chapter three, research is done with three persons with a finger tremor. The research gave experience from people with a finger tremor; those experiences are used to describe the stakeholders. For example, one participant shows the impact tremors can have, even indirectly (appendix 16). After years of working for a company, it was his time to retire. In his company, has always been a tradition of an event surrounding any retirement. The company would arrange an event for their employee; in this event, coworkers come together, and the retiring person has to sign his retirement contract. This event provided much anxiety for the participant. He had to sit there, surrounded by his coworkers, and sign the contract. He was concerned that his coworkers would notice the tremor. In the end, the contract was sent to him online, and he did not have to sign it at the event. Even though the actual scenario he feared did not occur, the fact that he might have had to sign a document publicly had a mental effect on the participant (a scenario in figure 7). When discussing the presence of the orthosis, STIL often receives feedback concerning the present of the BEAM, people are considered that the BEAM will only draw more attention towards their tremor. People prefere that their tremors are not visible in public.

Social actors

Social actors are people close to a tremor patient, like friends, family, and coworkers. Social actors can also be new people, like the retail salesperson, someone on the street, the bartender, or a server on the terrace. The Design Scope research observes that especially loved ones and family are very close to the user (appendix 16). It also showed that loved ones complement the other with the tremor, therefore the partner circle is placed against the tremor patient in figure 6. The loved one would, for example, take the cup away so he/she would not spill. The user felt completely at ease with his/her own family. On the other hand, unfamiliar people create discomfort and stress, which could increase the tremor.

Supportive foundations

These foundations organize events where information about tremors can be shared. Foundations bring together people with a tremor to exchange knowledge and give more attention to this neurological condition. An example of a foundation is 'De hersenstichting'.

Science
Universities and research hospitals are researching tremors, but many ambiguities remain. It remains a question, for example, the actual cause of essential tremors. Neither is it clear what the best tremor treatment is. Currently, there is a lot of research in this field to clear the ambiguities (National Institute of Neurological Disorders and Stroke, n.d.). This research is vital to tremor patients as there is currently no normative treatment.

Non-human factors
For people with tremors, non-human actors can create solutions. People already use medicine to lower the symptoms. Alternative resources are, for example, alcohol. Participants from the Design Scope research mentioned that before going to a restaurant, they sometimes take a shot of allcohol; this lowers the tremor and the stress. Lastly, the supportive tools are braces, orthosis, or gloves. The market for supportive tools is still tiny. The orthosis from STIL is an example of a supportive tool for people with a wrist tremor.

Healthcare
The tremor patient mainly has contact with the general practitioner and less with a neurologist, physiologist, and occupational therapist. Opinions on healthcare institution contact were divided among participants of the design scope research. One participant with a moderate tremor often had contact with a neurologist from a hospital. However, another moderate tremor participant had never seen a doctor. Lorenz et al. (2011) showed in a study that of the 100 participants with essential tremor symptoms, only 26.7% had contacted a doctor.

Distributor
Care tool distributors have to some extent, contact with tremor patients. Distributors are pharmacies for medicine, technical healthcare companies, or STIL. For the development phase of care tools, it is essential to have enough feedback from the user, to create the optimal design. For the feedback, the privacy of the target group has high insurance.

Figure 7: retirement event

2.3 Tremor

2.1.1 Tremor

The most prevalent movement disorder is a tremor (Aisen et al., 1993), leading to shaking movements. The scientific definition of tremor is a rhythmic, involuntary, oscillatory movement in a body part (Deuschl et al., 2008). While tremors commonly affect the hands, they can affect other body parts such as arms, vocal cords, legs, the torso, and the head. (Schneider, 2013). The frequency of the tremor depends on the origin. There are three categories of frequencies in tremors; slow (3 to 5 Hz), intermediate (5 to 8 Hz), or rapid (9 to 12 Hz) (Charles, 1999).

2.3.2 Tremor actions

Tremors occur at different moments; the tremor occurs in three situations: rest, postural, or action tremor. A resting tremor occurs when the patient's body parts are at rest, such as when the hand lays in the patient's lap. Another tremor is a postural tremor. These tremors can occur when the patient moves against gravity, like holding the hand in front of the body. An action tremor occurs when a body part moves from one point to another; this tremor is only present when the patient has to perform a highly skilled activity (Charles, 1999). An action tremor can be separated into sub-tremors, like; kinetic tremor, intention tremor, tasks-specific tremor, and isometric tremor. Table 1 shows these different tremors. These tremors have different frequencies; a postural tremor has a frequency of 5 to 9 Hz, a rest tremor has a frequency of 3 to 6 Hz, and an action tremor has a frequency of 3 to 10 Hz.

Type of tremor	Frequency	Etiology	Position
Rest tremor	3 to 6 Hz	Tremor which manifests when the muscles are not voluntary activated and are completely supported against gravity.	Rest forearm on legs, flexed elbos and palms in supinated position.
Postural tremor	5 to 9 Hz	Appears only when actively compensating against gravity.	Keep arms and fingers in stretched position
Action tremor - Kinetic tremor	5 to 9 Hz	Occurs during the coordination of a voluntary movement.	Finger tapping
Action tremor - Intention tremor	5 to 9 Hz	Tremor during visually guided movements towards a target, where the highest intensity occurs when the target is almost reached.	Finger tapping
Action tremor - Task specific tremor	5 to 9 Hz	Tremor whilst performing a highly skilledmotor task, like handwriting	Writing down a sentence
Action tremor - Isometric tremor	5 to 9 Hz	Isometric muscle contraction that is not accompanied by movement	Making a fist or contraction against static object.

table 1: type of tremors from Buijink et al., 2012

2.3.3 Tremor causes

There are different causes for tremors, they are listed in the following table:

Tremor causes	Diagnosis	Therapy
Essential tremor (ET)	Is mostly characterized by an action and postural tremor and mostly affects the hands. Essential tremor is a progressive neurologic disorder (Pahwa and Lyons, 2003). It typically starts by a bilateral tremor, this means that the tremor affects both sides of the body (Kahn, 2019).	Pharmacologic: • Primidone, Propranolol (first-line treatments) • Benzodiazepines, gabapentin, topiramate, Botulinum toxin Medication-resistant • Thalamotomy • Deep brain stimulation (Pahwa and Lyons, 2003)
Parkinsonian tremor	A parkinsonian tremor is usually a resting tremor. Parkinson disease is a heterogeneous disease with rapidly and slowly progressive forms. The tremor is caused by the depletion of dopamine in the basal ganglia. The basal ganglia are a group of nuclei in the brain. (Armstrong and Okun, 2020)	Pharmacologic: • Levodopa Non-pharmacologic • Exercise and physical, occupational and speech therapies. • Deep brain stimulation • Treatment with levodopa-carbidopa enteral suspension
Functional tremor	Functional tremor is an uncontrollable shaking of a part of the body, usually arm or a leg. This is due to the nervous system which doesn't work properly, but there is not a underlying neurological disease. (Functional Tremor – Functional Neurological Disorder (FND), n.d.)	For better outcome, diagnostic delay should be avoided and treatment is best offered in a multidisciplinary approach, including symptom-focused cognitive–behavioral therapy approaches and physical interventions. There is a terrible need for clinical treatment trials (Schneider and Deuschl, 2013).
Dystonic tremor	Dystonia results in a Dystonic tremor which causes continuous muscle contractions, leading to twisting and repetitive movements or abnormal postures. In some causes the dystonic tremor is caused by a chemical imbalance in a particular area of the brain. Most common a postural and action tremor. (Pandey and Sarma, 2016)	Pharmacologic • Anticholinergics, • Beta-blockers, • primidone, • benzodiazepines, • tetrabenazine • levodopa. • Botulinum neurotoxin or surgery: Deep Brain stimulation
Cerebellar tremor	Patients with cerebellar tremor have both postural and kinetic tremors. Has a frequency of 3 to 5 Hz. The most common cause of cerebellar tremors is multiple sclerosis, but brain-stem tumors or strokes and degenerative and paraneoplastic disease can also be responsible. (Anouti and Koller, 1995)	No effective treatment exists for cerebellar tremors.
Orthostatic tremor	Is a tremor which occurs in the legs, it gives a feeling of unsteadiness while standing. A pathognomonic 13 – 18 Hz tremor is seen on surface when patient is standing. (Whitney et al., 2018)	Pharmacologic: • Benzodiazepines • Beta-blockers • or surgery Deep Brain Stimulations shoud be further explored for treatment.
Physiologic tremor	A tremor which is caused by certain drugs, alcohol or medications.	It will usually go away if you eliminate the cause.

table 2: causes for tremors

A tremor can have several causes. In this thesis project, the focus will be on tremors caused by essential tremor. At STIL, the focus is mainly on people with essential and dystonic tremor. Orthosis may be tested in some mild parkinsonian cases.

2.3.4 Tremor impact

Tremors can considerably disrupt a person's life, for instance, in daily activities such as taking care of yourself, moving, eating, drinking, computer work, writing, or cooking. Research from E.D. Louis Et al. showed that the tasks in table 3 are the hardest for people with an ET tremor. This functional disability relates to the mental stage of people with a tremor. The research shows that significant depression or anxiety was associated with greater self-reported disability. This is an exciting design direction; when people with a tremor feel confident, will they have fewer self-reported disabilities? Limitations in participation with one's surroundings brought on by tremors can have a complex and significant effect on the state of mind of a person, such as feelings of loneliness or depression.

Item	Percentage receiving scores >1
Drinking	74
Writing	68.5
Pouring	68.5
Signing one's name	67.4
Carrying a cup	67.4
Using a spoon	66.3
Carrying food	58.4
Threading a needle	56.2
Using a key	52.8
Eating in a restaurant	51.7
Cutting nails	50.6

table 3: Eleven items on the Tremor Disability Questionnaire from Louis et al. 2007 for which greater than 50% of percent essential tremor cases received scores of 1 (no disability, but a need to modify or a loss of efficiency) or higher

2.4 Hand

2.4.1 Finger anatomy

The human hand is a complex and dynamic system. To design a wearable for the hand, it is essential to know more about the anatomy of the hand and the fingers. The fingers have two DoFs (see figure 8), which are:

- The **metacarpophalangeal (MCP)** joints move in the
  - Flexion and extension direction
  - Adduction and abduction direction
- The **proximal interphalangeal (PIP)** joints move in the
  - Flexion and extension direction
- The **distal interphalangeal (DIP)** joints make in the
  - Flexion and extension direction

The metacarpal muscles created those movements. The **dorsal interossei** create the flexion and extension of fingers 2-4. The **palmar interossei** create the flexion and extension of fingers 2, 4, and 5. The last metacarpal muscles, the **lumbricals**, create the flexion and extension of the finger 2-5. (see figure 9). With those muscles, people can make a fist and bend their fingers.

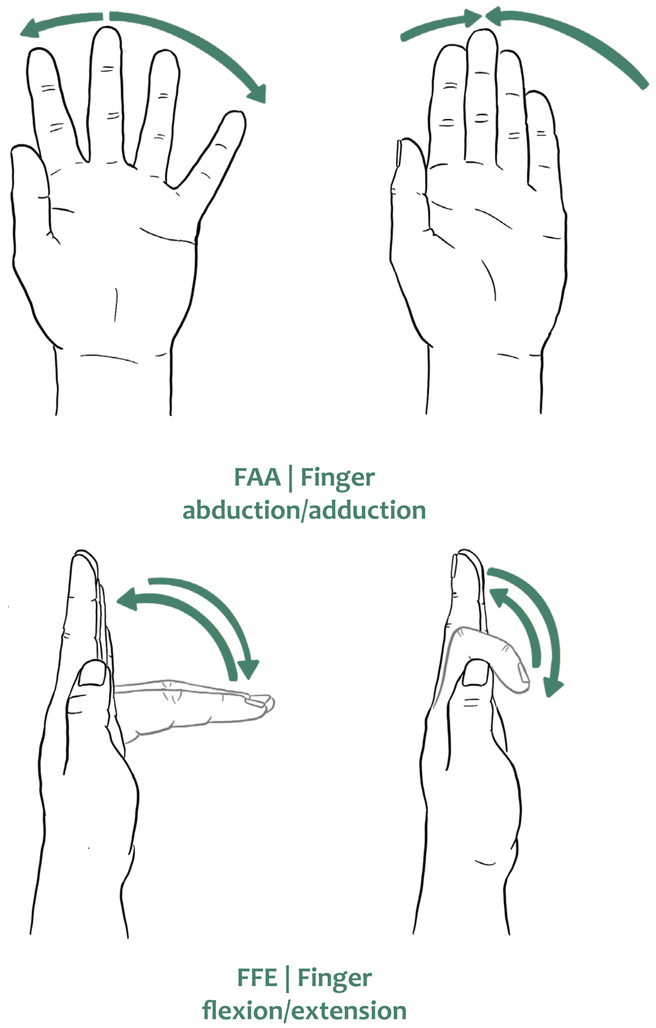


Figure 8: DOFs fingers

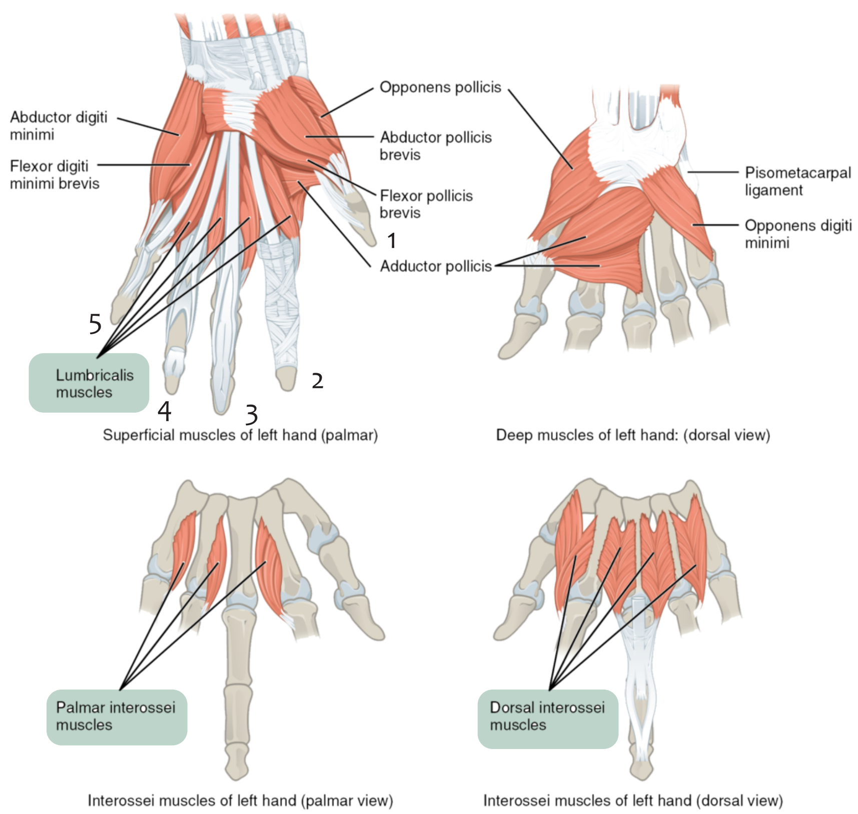


Figure 9: anatomy hand (CourseHero, n.d.)

2.4.2 Finger tremor

Study shows that the highest movement volumes are in the distal joints of the hand and, mainly in the thumb and the little finger (Kwaounjoo et al., 2022). Big muscles go to the thumb and little finger; this can be why the thumb and the little finger have the most significant volume, see figure 10. The volume increases from the metacarpal to the distal for all the fingers. For measuring a tremor, the best place would be the end of the distal joints or the wrist. Research by Zhou et al. 2018 shows that the tremor motion increases from the propagation of the tremor from one joint to another (Zhou et al., 2018b). In another study by Zhou et al., the aim was to determine the characteristics of finger and wrist tremor for people with Parkinson's. The researchers did the study with 17 people with Parkinson's. The results show that the harmonics (one golf of a graph) differ. The second and third harmonics make a significant contribution to the tremor. The difference in harmonics is critical to consider in testing with tremor patients. All harmonics should be taken into consideration as opposed to just the first. The frequency of the first harmonic, second harmonic, and third harmonic of the resting tremor for all joints lie within the range of 3.5 Hz to 5.8 Hz, 6.9 Hz to 11.5 Hz, and 10.4 Hz to 17.3 Hz, respectively. For the postural tremor the first through the third harmonics are within the ranges of 3.9 Hz to 7.7 Hz, 7.7 Hz to 11.2 Hz, and 11.5 to 16.8 Hz, respectively. There was no significant difference between the index finger, thumb, and wrist (Zhou et al., 2016).

In a study by Montagnani et al., 2016, the role of independent fingers was studied for specific tasks. The study concluded that specific tasks only need independent fingers; this could be interesting for people with a finger tremor. Independent fingers are optional for many tasks.

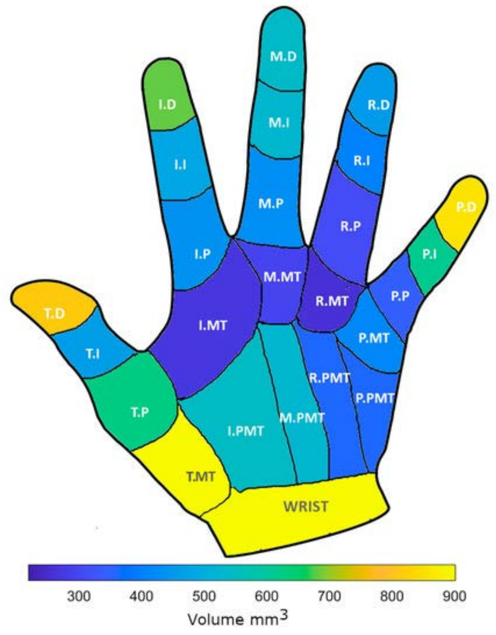


Figure 10: volume from hand tremor (Kwaounjoo et al., 2022)

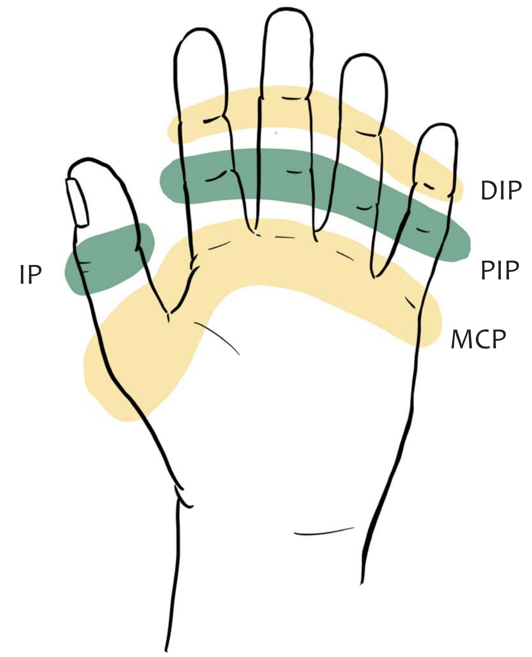


Figure 11: hand with joints

Design insights

- Suppression of MCP joint tremor is insufficient, as the tremor magnitude in the distal joints increases when the tremor in the MCP joint is suppressed (Zhou et al., 2018)
- The volume of movement from the tremor is the most prominent in in the thumb and pink. There may be a need for more damping in those fingers.
- Independence of fingers is considered valuable in precision grasps (Montagnani et al., 2016). The design could not splint fingers together.

2.4.3 Thumb anatomy

The thumb has more DOF's and is, therefore, a complex joint. The thumb is essential in more specific tasks, like writing and eating. The thumb has three DoF's (see figure 12), these are:

- **Carpometacarpal joint**
    - Flexion and extension
    - Abduction and adduction
    - Opposition and reposition (impor tant for small tasks, like writing and eating)
- **Metacarpophalangeal joint (MCP)**
    - Flexion and extension

The thumb has its own muscle group called the thenar muscles. In the thenar muscle, four muscles create movement in the thumb. The first is the abductor pollicis brevis; this is for thumb abduction. The other muscle, the adductor pollicis, is meant for thumb adduction. The flexion movement uses the muscle flexor pollicis brevis. Moreover, the opponents pollicis muscle creates the thumb opposition. With those muscles, the thumb can move in three different directions.

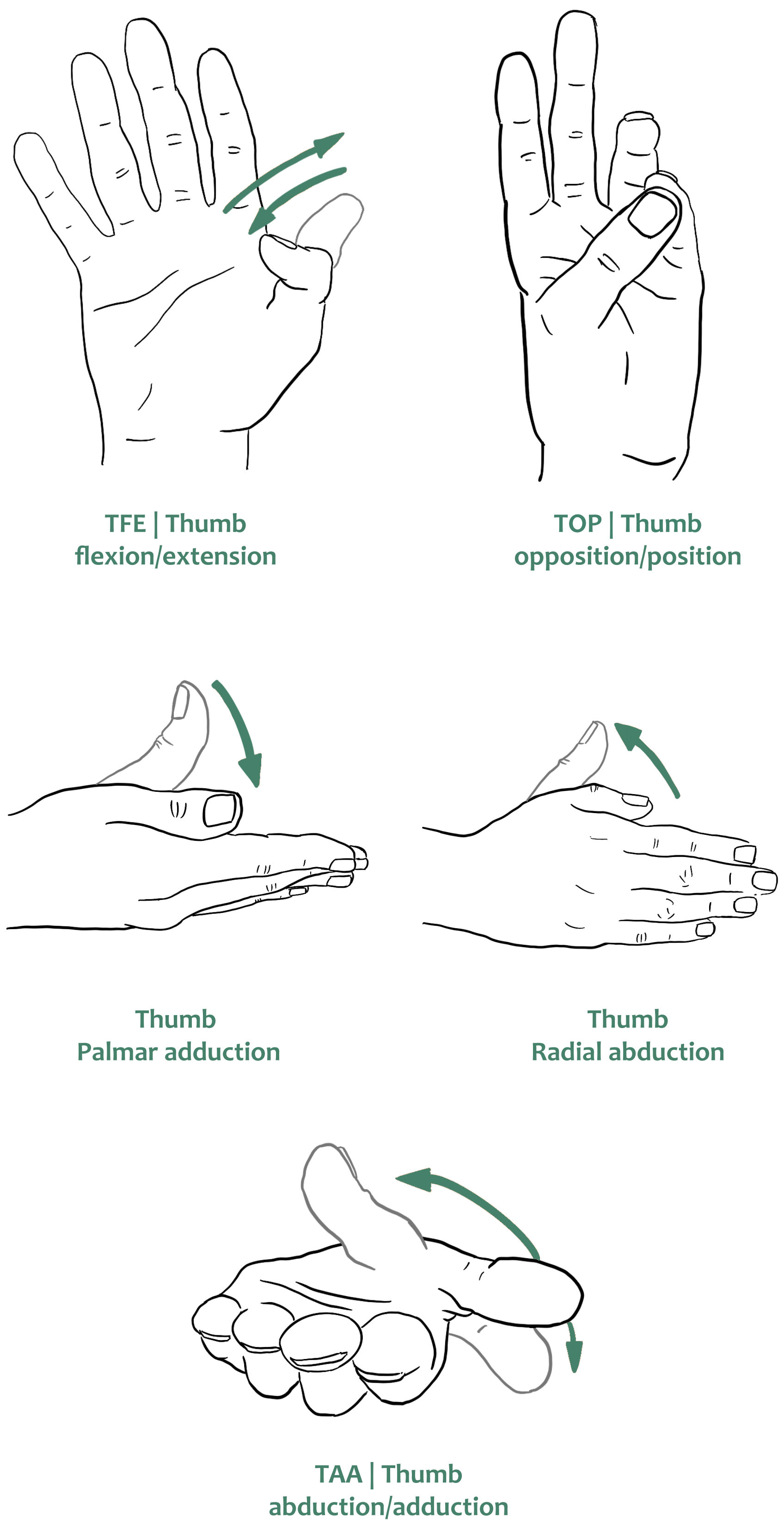


Figure 12: degree of freedoms thumb

The thumb provides 40% of overall hand function in the uninjured setting. Especially the opposition from the thumb is significant to successfully grabbing objects. Opposition of the thumb is the result of angular motion, which comes from abduction at the trapeziometacarpal (TMC) joint, flexion, and rotation of the TMC and MP joints. For the movement opposition, the thumb needs the muscles, abductor pollicis brevis, opponens pollicis, and superficial head of the flexor pollicis brevis (Zhao et al., 2019). It is hard to fixate the thumb because of the multiple DoFs from the thumb. A thumb is essential and can not be considered out of the scope of this research.

Montagnani et al., 2015, researched how people will perform when they cannot use all the DOFs of the hand and wrist. The research showed that when the fingers are fixed together or have all the freedom, does not give a significant difference in performance. The following grips is relatively easy when the fingers are fixated: spherical, power, tip, tripod, lateral, and extension.

Figure 13: hand positions (Montagnani et al., 2015)

Design insights

- The thumb is a crucial finger in many aspects of grips. The design scope must pay attention to the use of the thumb.
- Only fixating the thumb can be uncomfortable, especially in the tripod and tip grip. A fixation of the thumb in one position is undesirable for specific tasks, creating discomfort.
- No literature has been found on the frequency of the thumb tremor in a certain DOF.
- A finger wearable for tremors could specifically be interesting for people with Parkinson's. In most cases of Parkinson's the tremor starts in the finger.

2.4.4 Hand grips

The Southampton Hand Assessment Procedure (SHAP) measures hand functionality, see figure 14 (Stanley & Tribuzi, 1992). Table 4 shows which grips are most important for daily activities. Comparing the SHAP grips to daily activities with a high degree of difficulty for people with tremors resulted in four difficult grips (Louis et al., 2001). The most difficult grips for people with tremors are; tripod, tip, lateral, and power. The grip's spherical or extension will not be needed for activities perceived as complex by people with tremors.

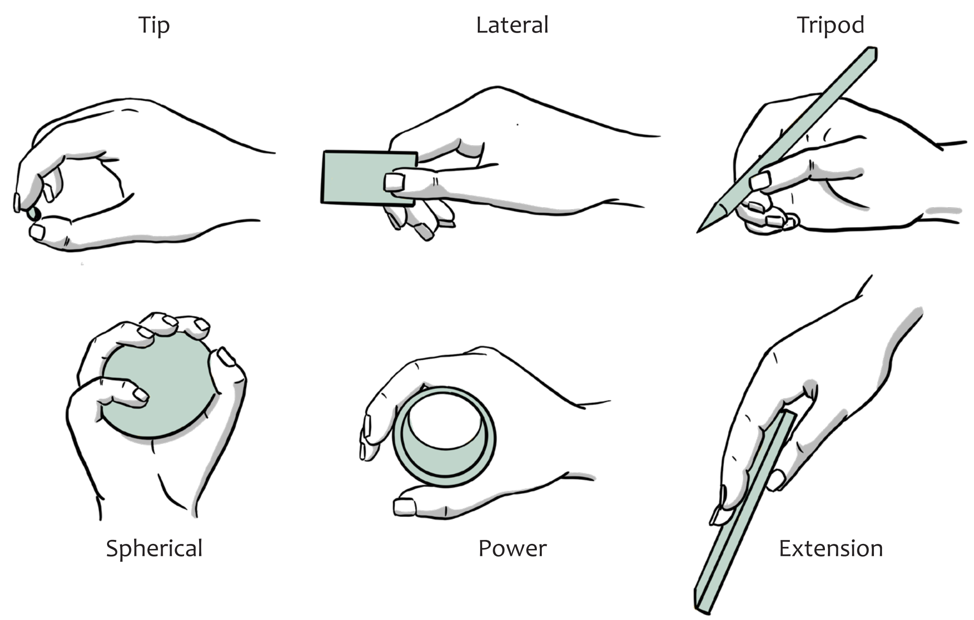


Figure 14: tasks in correlation with grips (Stanley & Tribuzi, 1992)

Tip	Lateral	Tripod	Spherical	Power	Extension
An intelligent hand prosthesis and evaluation of pathological and prosthetic hand functions, Light CM 2000					
Pick up coins	Pour water from jug	Food cutting	Pour water from cartoon	Move a full jar	Page turning
Undo buttons	Move a tray	Writing	Remove jar lid	Move an empty tin	Move a tray
Rotate a key 90*	Open/close a zip	Signing one's name		Rotate a screw 90*	
Open/close a zip	Rotate a key 90*	Using spoon		Rotate a door handle	
		Undo buttons		Food cutting	
Correlates of functional disability in essential tremor, Louis et al. 2001					
8. Threading a needle	3. Pouring	2. Writing		1. Drinking	
	9. Using key	4. Signing one's name		5. Carrying a cup	
	11. Cutting nails	6. Using spoon		7. Carry food	
		10. Eating in restaurant			

Most chosen

Less chosen

Table 4: grips compared to functional disabilities in essential tremor

2.5 Wearable

2.5.1 Tremor wearable

There is currently no specific pharmacologic solution for people dealing with their tremors; research on wearables that damp the tremor can provide new solutions. This section discusses wearables for tremor reduction. The selection is based on passive wearables. A passive wearable does not need any energy. Appendix 9 provides an overview of wearables. The overview explains the following aspects: passive/active, wearable, working principle, damping force, scalability for finger, cost, tremor amplitude reduction, degree of freedom, weight, and testing results.

The overview gives the following solutions as interesting:

Airbag orthosis

The orthosis from Fromme, 2020, makes use of air, see figure 21. The orthosis places a filled airbag on the wrist; the filled airbag suppresses the tremor. This proof-of-concept case study shows that the orthosis reduced tremor power significantly for three out of six tasks (Drinking, Pouring, and Drawing-Spiral), with a tremor suppression efficiency of 74 to 82% for these three tasks (Fromme, 2020). The study was only tested with one person. The orthosis is lightweight, low in cost, and can easily be adjusted to finger size. For best suppression, the airbag can be full or empty. However, for optimal use of this wearable, energy is needed.

2.5.2 Reference study

A reference study was done to review wearables for upper arm tremors. In appendix 10 the references are listed. Figure 15 shows the words used for the searches in PubMed. The search was performed for publication between 2017 and 2022. The focus was on wearables for finger and hand orthoses with a passive mechanism. The table shows four hand wearable devices, two for the finger and one for the wrist, were found. Of the finger wearables, both had a semi-active mechanism. Section 2.5.3 provides more information on these wearables.

The reference study shows the knowledge gap for finger tremors solutions. There are only a few examples of wearables for finger tremors in research, patents, and commercial products. The solutions found in research give promising results for suppressing a tremor, especially in the wrist. Unfortunately, there are no solutions or products for people dealing with finger tremors in the commercial world. Emphasizing the importance of a resolution.

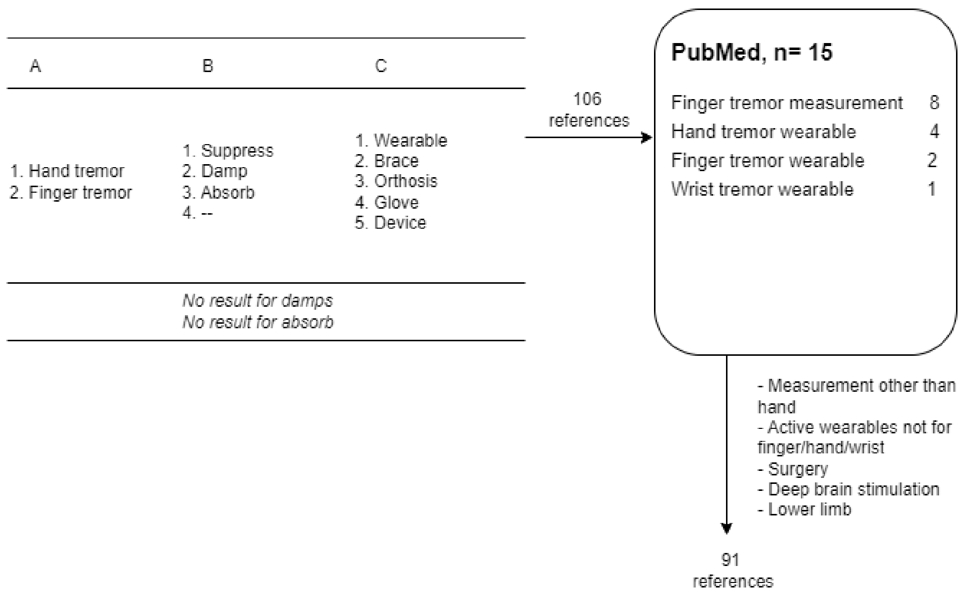


Figure 15: overview reference study

2.5.3 Finger wearables

Within the references study, two studies focused on finger tremors. The first study by Wanasinghe et al. 2021, includes the development of a finger tremor glove that suppresses tremor by layer jamming principle. The layer-jamming gloves suppress the little, middle, index, and ring fingers. Underneath the fingers is a strip of layer-jamming elements. Layer jamming can increase the stiffness and so suppress a tremor. These elements create a resistant force and absorb the vibration of a tremor. For layer jamming to function, a vacuum must be created. The layer jamming mechanism works with the negative pressure from a vacuum. In figure 16 the design of the layer jamming is displayed. The design includes multiple layers in sealed polythene; the frictional force will increase when the vacuum removes the air between the layers. The layer jamming will resist bending and therefore suppress the tremor. For layer jamming, the researchers chose sandpaper as the working material. The sandpaper provides a high stiffness when the layer jamming is a vacuum with a low weight. Testing with 11 tremor patients shows the result of a suppression of 41.74 ± 12.11% on the ring finger and 41.99 ± 14.82% on the middle finger. However, the tremor suppression of the fingers is not excessively high, and the usability and wearability of the glove are high. Thus, by giving the finger stiffness, tremor suppression can be achieved. A vacuum is needed to create the stiffness. Therefore the wearable is semi-active.

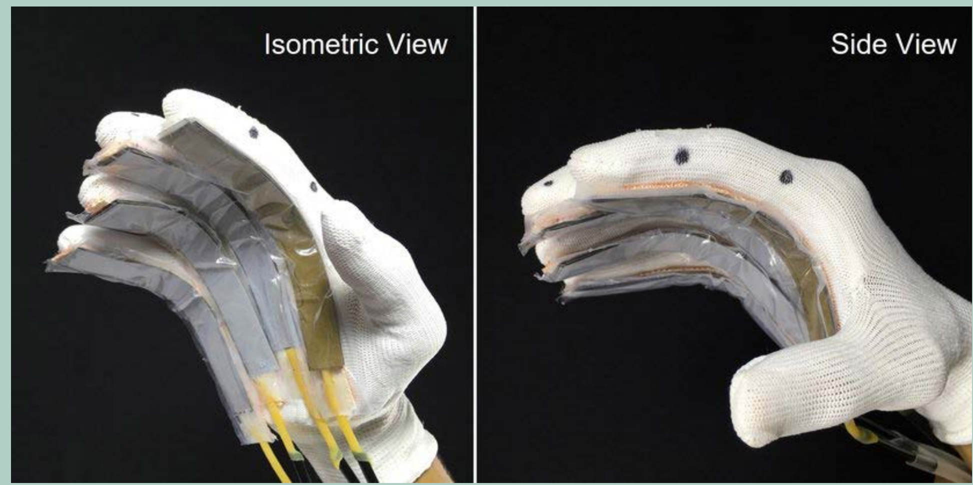
Research by Zhou et al. from 2018 shows a wearable (see figure 17) that suppresses thumb and finger tremor in addition to the wrist. The wearable suppresses the MCP movement in the index finger and thumb and the flexion and extension in the wrist. The wearable suppresses only the proximal joints; this is not enough to suppress the entire finger. Further research should also include the DIP and PIP joints. This wearable tremor suppression glove (WTSG) uses non-elastic cables; the glove guides these cables from the wrist to the index finger and thumb. A motor on the wrist pulls the cables when a vibration occurs, thereby controlling flexion and extension movement. The glove leads the cables over the top and inside of the hand. The wearable has not been tested on actual patients but on a test setup. This setup shows a damping of 85%. Figure 17 shows the wearable.

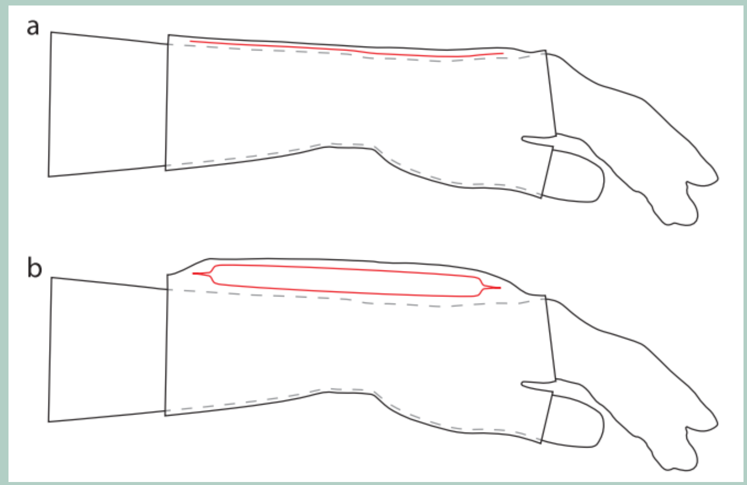
2.5.4 Patents and comercial products

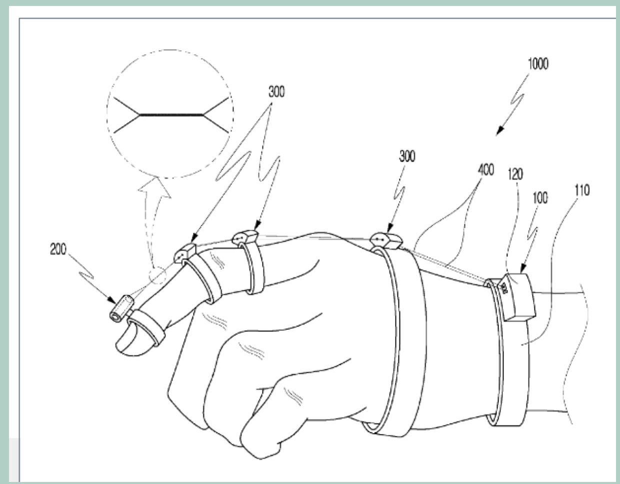
A patent- and commercial products analysis was made to understand the current market. Appendix 7 and 8 provide an overview of the patents and products. A wearable, which passively suppresses a finger tremor, is currently not found in the patents or products. Besides wearables for tremors, the search also included finger gloves, orthoses, braces, wearables, or devices for other conditions.

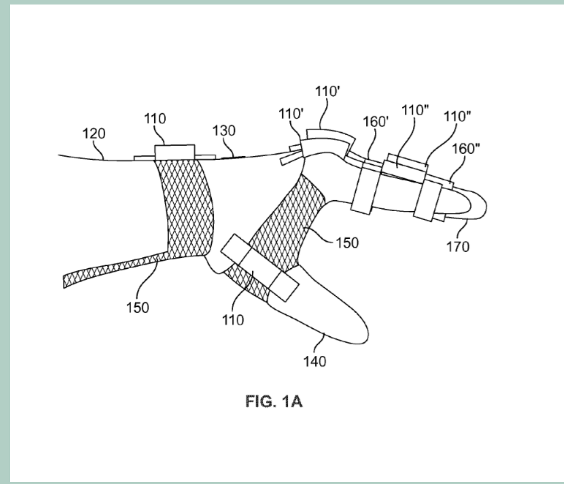
Three patents showed suppression of the finger joints by a ring or a fixation point at the end of the finger (Appendix 6, patents 5, 12, and 15). Patent 5 is showed in figure 19. The wearable suppresses the distal joints. The wearable is used for surgeons who have to perform precision tasks. The wires give some resistance. For the design, it is interesting how the wires run across the fingers and give resistance. Figure 18 shows a wearable from a shape memory alloy wire. Shape memory alloy wire functions using thematerial property of the tendancy to return to the original shape.

In the case of a trigger finger (figure 20), the tendon cannot move freely through the tendon sheather and gets stuck at the tunnel's beginning. The person can only stretch the finger when someone else or the other hand helps. Orfit made a customizable orthosis for the finger with a spring. This orthosis provides support and stretches the finger. The product is easily made and can be user-specific. Other commercial products can be found in appendix 8.









Design insights

- The expectation is that only suppressing the MCP phalanges is not enough. For the WTSG wearable, only suppressing the MCP joints was not enough. However, the glove has not been tested on people with tremors.
- Layer jamming provides a user-friendly design. The low stiffness and the semi-active part could be a drawback.
- User-friendly and stiff mechanical dampening could be filled airbags, shape memory alloys, or a resistant wire.
- Orthosis for a trigger finger could provide relevant insight into a potential finger tremor orthosis for people with a finger tremor. The design of a trigger finger orthosis is minimalistic and user-friendly.

Figure 16 (top right): layer jamming glove (Wanasinghe et al. 2021), Figure 17 (top left): WTSG wearable (Zhou et al, 2018), Figure 18 (tip left): Finger tremor correction device(KR102463021B1, 2020), Figure 19 (Bottem right): MYOELECTRIC HAND ORTHOSIS Bryant (2014), Figure 20 (middle right): trigger finger (Orfit Trigger Finger, n.d.), Figure 21: airbag orthosis (Fromme, 2020)

2.6 Video analysis

STIL has an extensive collection of video data, which has been collected in tests before. In 2022 STIL did a formative test with 15 participants. The test showed that a finger tremor played a role in certain tasks by 10 participants. For this video analysis, the researcher watched the videos from 15 participants. The formative test asked the participant to perform tasks with and without the orthosis. Tasks were stretching the arm, bending the arm, drinking from a cup, eating soup with a spoon, cutting a sandwich and taking a bite, carrying a cup, drawing a spiral cord, and using a computer mouse. The videos are watched and analyzed for tremors in the fingers.

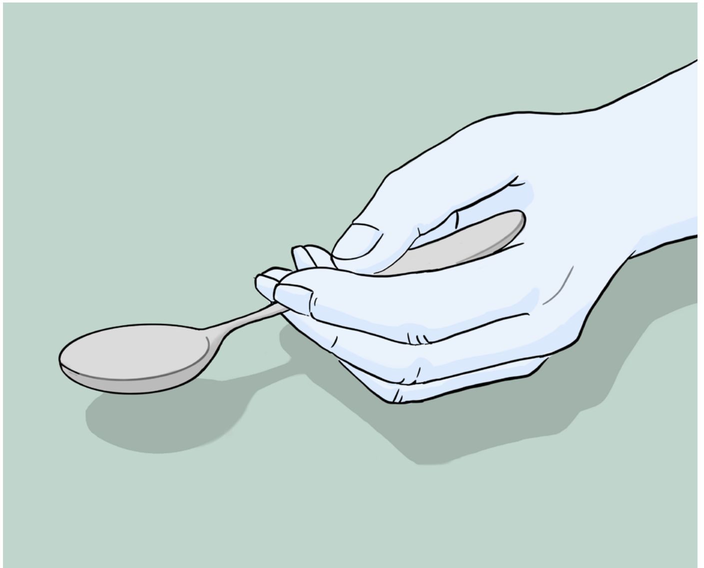


Figure 22: tripod grip with spoon

2.6.1 Eating with cutlery

Eating with cutlery and operating the mouse was the task where the finger tremor was most dominant. The spoon had to be held in a tripod grip to eat soup. Expected is that the tremor has more effect because the user cannot fixate their fingers. The tester also asked to grab the spoon overhead (figure 23). In this position, the user makes a fist and can fixate the finger. Of the 10 participants, 3 grabbed the spoon directly overhead. The video analysis showed that a person with a finger tremor could fixate their tremor by squeezing hard.

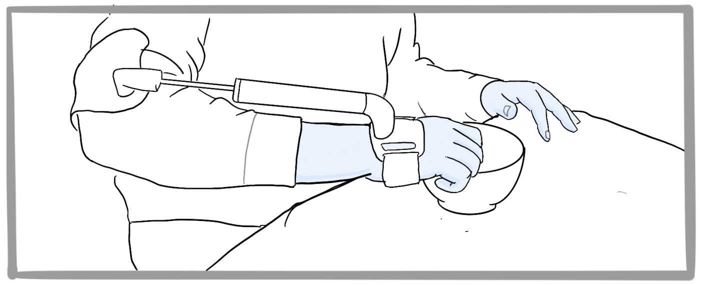


Figure 23: participant 1 eating soup - overhead

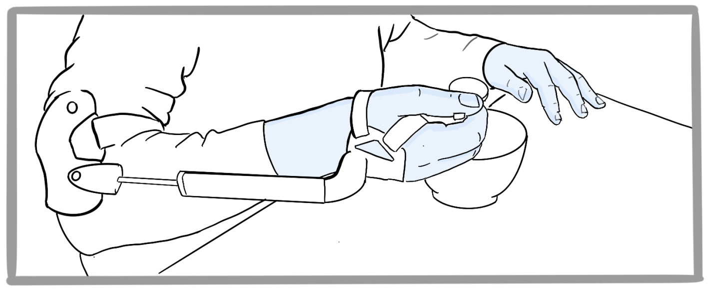


Figure 24: participant 1 eating soup - tripod

2.6.2 Use of computermouse

Another task that was hard for people with a finger tremor was using the computer mouse. For two from the fifhteen participant, the fingers moved at a high frequency up and down. The fingers also moved individually. Due to the tremor, it was hard for the participants to have control, because the tremor causes unwanted clicks. As discussed with the clinical researcher from STIL, the conclusion was that this participant has an intention tremor. The tremor becomes severe when the user moves toward the object. What can be seen in the video is that the tremor is severe before the click. Participants 1 and 3 mentioned that using a computer mouse is complicated with a finger tremor.

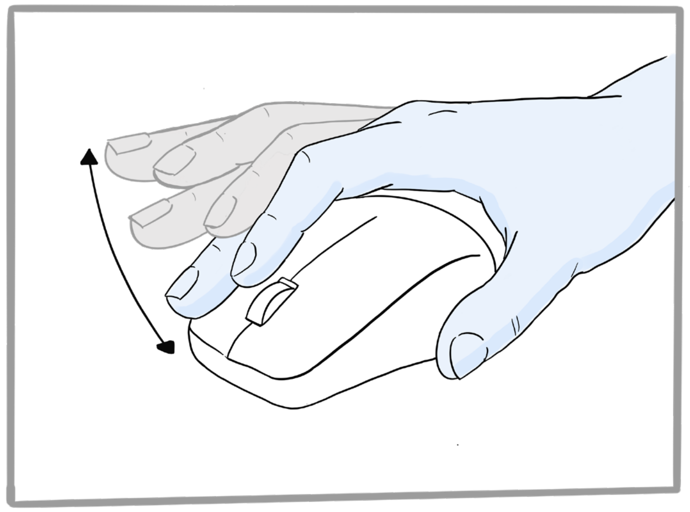


Figure 25: use of computermouse

2.6.3 Baseline

Observations showed a finger tremor when the hands of the participants stretched out. Often a finger tremor could be seen in the baseline. One prticipant has a significant finger tremor with a high amplitude, especially because of his rest tremor the finger tremor is good visible when the arms are stretched. This participant has trouble with many tasks due to his finger tremor.

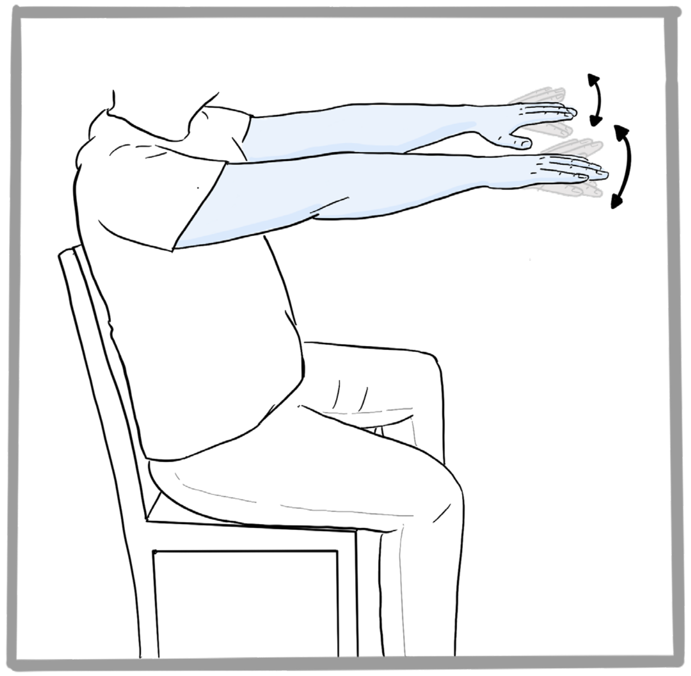


Figure 26: participant with arm stretched

Design insights

- The design of the wearable should take into account the tendancy of people with finger tremors to grip objects unconventionally to compensate for a lack of squeezing force. It is still unclear wether this tendancy should be incorporated or if an alternative solution should discourage it.
- The video analysis showed that finger tremors are mostl visible present when the participants had to reach out their hand.

03 Design scope

This chapter establishes the design scope. The main question in this chapter is, “Which combination of fingers and joints do people with a finger tremor need to perform grips like tip, lateral, tripod and power?”. This chapter contains the following subchapters: introduction, method, results, discussion, design scope, and evaluation.

3.1 Introduction

Solutions for tremors are limited in the commercial world and science. In addition, wearables for tremors focus mainly on the wrist, which is logical when considering that most people have a tremor in their wrist (Pigg et al.,2020). For people living with a finger tremor, there are almost no solutions. The limited research and products on this subject result in a vague vision of the desires and requirements for a finger wearable.

This research aims to set the design scope for a wearable design for people with a finger tremor. A design scope has to give an image of the desired combination of fingers and joints to perform tasks. A part of the design scope is for which fingers and movements intervention is needed to perform acceptable tasks. A prototype for testing is developed; the prototype is a modular glove where all the fingers can be fixated. Fixation means that the fingers are splinted in a position, and the splints give a force back when the user wants to move through the splint. The gloves could fixate the fingers in different variants. For the study, the glove with all the splints fixates all the fingers; after this version of the glove, more and more freedom is given. With the different versions, the participant has to perform tasks. This study focuses only on the four grips that majorly affect daily activities for people with tremors (see chapter 2.4.4). These grips are tip, lateral, tripod, and power. The research has to answer questions like; what is the desired degree of freedom? What is a good and healthy balance between freedom and suppressing the tremor? How are tasks done with different variations from the glove?

3.1.1 Research questions

Which combination of fingers and joints do people with a finger tremor need to perform grips like tip, lateral, tripod and power?

- *What happens with the tremor when all **fingers** are splinted?*
- *What happens with the tremor when the **thumb, index and middle fingers** are splinted?*
- *What happens with the tremor when the the **index, middle, ring and little fingers** are splinted?*
- *What happens with the tremor when the **MCP joints** are splinted?*

3.1.2 Proposition

Experience with the BEAM from Stil gave that the tremor can be suppressed with dampers. The expectation is that splinting the fingers will reduce the tremor. How many fingers and which joints need suppression, needs to be researched.

The second and third research questions are: “What happens with the tremor when the **thumb, index and middle fingers** are splinted?” or “What happens with the tremor when the **index, middle, ring and little fingers** are splinted?”. There is a high expectation that only suppressing the thumb, index, and middle finger is enough for the essential grips. Montagnani et al., 2016, researched the independent role of fingers in the human hand. This research showed that independent fingers provide a measurable advantage in performing ADLs only when precision grasps are involved. The precision grasps used the tripod grip; for this grip, independency from the fingers where desired. The expectation is that the index and thumb are necessary for the precision grips. The expectations is, therefor, that the thumb is needed for the tasks. So, the expectation is that four fingers splinted will give more trouble performing the tasks.

The expectation of the subquestion, “What happens with the tremor when the **MCP joints** are splinted?” is that the suppression of only the MCP joints is not enough to suppress the tremor in the total finger. Research from Zhou et al. 2018, stated, “our recent study showed that it is not sufficient to suppress only the tremor in the proximal joints.”. However, the test setup was a simulation of a tremor hand and was not done with actual tremor patients. The simulated hand tremor does base on natural tremors. For the tremor finger wearable, which joints from the fingers need suppression is from a significant value. The MCP and PIP joints may need suppression. Research has shown that the fingertips have the most significant movement in velocities and accelerations (Khwaounjoo et al., 2022). So, there is probably a need to suppress all the distal joints of the finger. This research tests a glove variation with only MCP suppression.

3.2 Method

3.2.1 Participants

The participants are selected from the formative evaluation test STIL conducted in 2022. For the selection of this test, STIL has an inclusion protocol. An essential criterion is that the Bain & Findley score (questionnaire where questions can measure the severity of tremor) should be between 40 and 60. For this study, people with a clear FFE are interesting. Reviewing the videos from the formative evaluation resulted in 8 people (Appendix 1) with an FFE tremor. After a discussion with the clinical investigator within STIL, three participants are included.

Confidential information

Table 5: selected test participants

Participant 1

Participant 1 has a **moderate tremor** with high amplitude and frequency in the fingers. Performing tasks was complex, even with orthosis, due to his finger tremor. He has a **rest tremor**, which means his tremor moves constantly.

Participant 2

Participant 2 also has a **moderate tremor**; this person has **multiple tremors** in the wrist, shoulder, and finger. The participant said in previous tests that there is a struggle with the finger tremor, and therefore the orthosis from STIL is not working correctly. Because this person can give clear feedback and the usefulness of a finger wearable, the participant is chosen. This person has an **action tremor,** so when tasks are performed against gravity, the tremor occurs.

Participant 3

Participant 3 has a **mild tremor**, especially in the fingers. This person has **an intention tremor**; this means that the tremor occurs when moving towards the object. The STIL orthosis was also not working correctly for this participant due to the finger tremor.

3.2.2 Procedure

The graduate student will ask the participant to sign an Informed Consent (appendix 11). After the agreement, the participant gets more information about the research. Appendix 4 gives a step-by-step overview of shifting in glove variations and tasks.

To answer the main question, ‘’Which combination of fingers and joints do people with a finger tremor need to perform grips like tip, lateral, tripod, and power?”, the grips need to be performed in specific tasks. The tasks correspond with a grip (see chapter 2.4.4), and a score can be given with the "The Essential Tremor Rating Assessment Scale (TETRAS)"; more information is in chapter 3.2.6. So the tasks have to let the user perform the grips: tip, lateral, tripod, and power. The versions of the glove have to give answers to which combination of fingers is preferred. Therefore there are four combinations of splints: all fingers splinted; the thumb, index, and middle fingers splinted; the index, middle, ring, and little fingers splinted (so more information about the need of the thumb) and lastly, and the MCP joints splinted. In table 6 the glove variations and the tasks are presented; the glove variations are on the vertical side, and the grips on the horizontal side. For the first task is asked to set a baseline. For the baseline, the user has to hold his/her arm straight for 20 sec; next, the user has to bend his arm before his/her chest and hold it there for 20 sec. Then the user is asked to perform the other five tasks:

- Power: pouring water and drinking from a cup
- Tripod: eating soup
- Tripod: drawing spiral cord and ollowing a straight line
- Tip: move little blocks from one paper to another paper
- Use the computer mouse
- Lateral: put the key in a keyhole and rotate 90°

See Appendix 3 for a list of questions during the research. During the study, we will create a safe environment where a person can easily talk about her/his tremor.

Degree of freedom/tasks	Power: pouring water and drinking from a cup	Tripod: eating soup	Tripod: Drawing spiral cord and straight line	Tip: move domino blocks from one paper to another	Use the computer mouse	Lateral: rotate 90* key
Baseline: no fixation (with orthosis)						
Fixation from all fingers						
Fixation from the MCP joints						
Fixation from four fingers						
Fixation from thumb, index and middle finger						

Table 6: all tasks and variantions from the glove

3.2.3 Material

A prototype in the form of a modular glove was developed in order to test. The prototype is a glove with strips; in the strips are splints, which can be removable. The different variations of the glove will be:

- All fingers fixated
- Only the fingers fixated (not the thumb)
- Only the thumb, index finger and middle finger fixated
- Only fixation of the MCP phalanges
- Baseline: no fixation

See figures 28 untill 31 for the prototype and see appendix 5 for the process.

Figure 28: glove with splints, band open

Figure 29: glove with splints, band open

Figure 30: splints in prototype

Figure 31: glove with splints

3.2.4 Test environment

In order to create a safe environment for the participants, the researchers did go to their houses. A house visit could also reduce the threshold for participation. Previous research concluded that participant 1 could feel tension from a test environment and could have the feeling that he had to perform well. The researcher has to emphasize that this research is a validation of the prototypes and exploring the desired degree of freedom. When someone with a tremor does not feel at ease, there is a greater chance that the tremor will change during the testing, this could influence the test data.

For a safe environment, the following points should be considered:

- Emphasize that it is a study to learn more about finger tremors and validate the prototype. The participant should not feel they can do or say anything wrong. All information is helpful.
- Take time in between for tea. Necessary to take time for the examination, allow the tasks to take up to an hour and a half, and have time between the tasks and variations.
- Researchers are wearing their own clothes to lower the threshold of business appearance.

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Figure 32: home set up

3.2.5 Data management

The following data types are used for the results: type of tremor, the impact of the tremor on daily life, amount of tremor, places of residence, hand size, and videos of participants.

Type of data	File format	How will data be collected	Purpose of processing	Storage location
Observe participants with a tremor in the research from STIL, where they use the BEAM	Mp4.	Filming particpants	Video recordings gives insights in the location of tremor, amplitude and frequency.	One drive STIL
Type of tremor, impact of the tremor in ADL, degree of tremor, residence and dimensions from the upper limb.	.cvs files	Online survey	Used for collecting suitable participants with a finger tremor for evaluating the prototype for finger tremor.	One drive STIL
Information from participants, through answering questions	Mp4. .cvs files	Questions	Gives insights about the thoughts from users	One drive STIL

Table 7: data management

3.2.6 Data analysis

The researcher will review the collected data in three forms. These three forms are evaluation of tasks, tremor extent and feedback/observation from the user and researcher.

Evaluation of tasks - The evaluation looks at the tasks performed. For this evaluation, the "The Essential Tremor Rating Assessment Scale (TETRAS)" is used as a baseline (Ondo et al., 2020). The Tremor Research Group developed TETRAS to easily and fast quantify essential tremor severity. The TETRAS take into account the impact on activities of daily life. TETRAS uses a daily living (ADL) section and a performance section. This study uses the ADL section; this section evaluates daily activities. Tables 8 until 13 give for all the asked tasks, the TETRAS scale. For the evaluation of the spiral scores the study "Spirals and Handwriting Samples: Determination of Optimal Scoring Examples" is also used. This research provides spiral cords and scores (W. Ondo et al., 2021).

For the task "Moving blocks from one paper to another", there is no defined TETRAS scale. This study gives a scale based on the other TETRAS scales. The tasks with gloves are compared to the baseline, where the user wears the STIL orthosis.

Tremor extent - the tremor extent results give the length of the amplitude of the finger tremor. Kinovea can measure the height of the amplitude. Kinovea is a video annotation program for sports analysis; measuring motions is possible. The program follows the tip of the index or middle finger and the MCP joint; this allows measuring the size of the finger tremor (see appendix 15, for the calculations). In the video, Kinovea needs a reference point for the length so that pixels can convert to an actual distance. Data collection happens when the user has to keep his/her arm forward. The difference in height and length are given and compared. The results round the length to one number behind the point. The distance measuring is on the x-axis and the y-axis.

Feedback/observations- the third point is the user's feedback, data that gives insights into the user's thoughts.

Rating from TETRAS	Spiral scores
0	Normal
1	Slight; barely visible
2	Mild; obvious tremor
3	Moderate;parts not recognizable
4	Severe; figure not recognizable

Table 8: task spiral score

Rating from TETRAS	Pouring
0	Normal
1	Slightly abnormal. Tremor is present but does not interfere with pouring.
2	Mildly abnormal. Must be very careful to avoid spilling but may spill occasionally.
3	Moderately abnormal. Must use two hands or uses other strategies to avoid spilling.
4	Severely abnormal. Cannout pour.

Table 10: pouring

Rating from TETRAS	Drinking from a glass
0	Normal
1	Slightly abnormal. Tremor is present but does not interfere with drinking from a glass
2	Mildly abnormal. Spills a little.
3	Moderate abnormal. Spills a lot or changes strategy to complete task such as using two hands or leaning over.
4	Severly abnormal. Cannot drink from a glass or uses straw or sippy cup.

Table 12: drinking from a glass

Rating from TETRAS	Feeding with a spoon
0	Normal
1	Slightly abnormal. Tremor is present but does not interfere with feeding with a spoon
2	Midly abnormal. Spills a little.
3	Moderate abnormal. Spills a lot or changes strategy to complete task such as using two hands or leaning over.
4	Severely abnormal. Cannot drink from a glass or uses straw or sippy cup

Table 9: feeding with a spoon

Rating from TETRAS	Using keys
0	Normal
1	Slightly abnormal. Tremor is present but can insert key with one hand without difficulty.
2	Mildly abnormal. Commonly misses target but still routinely puts key in lock with one hand.
3	Moderately abnormal. Needs to use two hands or other strategies to put key in lock.
4	Severely abnormal. Cannot put key in lock.

Table 11: using keys

Rating	Moving domino blocks from one paper to another
0	Normal
1	Slightly abnormal. Tremor is present but can move domino blocks without difficulty
2	Mildly abnormal. Some difficulty with grabbing and putting down domino block.
3	Moderate abnormal. Difficult to grab block, needs two hands. Block cannot put down on one location.
4	Severely abnormal. Cannot grab the block or put it down.

Table 13: moving domino blocks

3.3 Results

3.3.1 Participant 3

	Tremor extent*	Evaluation tasks**	Feedback/observations***
Baseline I	Height distance: 2,3 cm Vertical distance: 1,6 cm		
All fingers fixated	Height distance: 0,5 cm Vertical distance: 0,4 cm	**Improved:** Transfer blocks, Drawing and Computer mouse **Same:** Drinking, Pouring, Eating soup, Rotate key **Deteriorated:**	Participant named that it felt nice that the fingers are still and almost not movable when drinking from a cup. Also mentioned is the increase in stability, especially with putting the domino blocks down. Another feedback point is that the fingers do not go up and down when using the computer mouse, therefore more control. For the participant, multiple times mentioned, it felt hard to grab objects because the glove was slippery.
Thumb, index and middle finger	Height distance: 1,2 cm Vertical distance: 1,2 cm	**Improved:** Drinking, Transfer blocks, Eating soup, Drawing and Computer mouse **Same:** Pouring, Rotate key **Deteriorate:**	The participant said that the stability felt like the glove with a splint for all the fingers. However, this version gives more freedom and allows grabbing objects more easily.
Four fingers fixated (no thumb)	Height distance: 3,1 cm Vertical distance: 0,7 cm	Improved: Drinking, Drawing and Computer mouse **Same:** Pouring, Transfer blocks, Eating soup, Rotate key **Deteriorated:**	Participant said it felt easy to grab the cup because the thumb splint was removed. By task moving blocks, the thumb tremor is visible again, and the participant also notices the thumb tremor. The participant felt discomfort at the little finger; the splint was removed.
Only MCP joints fixated	Height distance: 0,60 cm Vertical distance: 1 cm	**Improved:** Eating soup, Drawing and Computer mouse, Rotate key **Same:** Drinking, Pouring **Deteriorated:** Transfer blocks	Participant said the shorter splints felt good because there was more freedom. However, the participant mentioned that he felt less stable in the tasks. Especially the task where the blocks had to be moved became difficult.

Table 14: results participant 3

* Appendix 15.2: Kinovea and excel measurement for participant 3
** Appendix 17.2: scores for all the tasks with graphs
*** Appendix 16.2: observation notes

3.3.2 Participant 1

	Tremor extent*	Evaluation tasks**	Feedback/observations***
Baseline I	Horizontal distance: 27,3 cm Vertical distance: 7,5 cm		
All fingers fixated	Horizontal distance: 4,6 cm Vertical distance: 3,4 cm	**Improved:** Drinking, Eating soup, Drawing, Computermouse **Same:** Pouring, Transfer blocks, Rotate key **Deteriorated:**	Participant mentioned that the stability felt good. It was hard to grab some objects, like a cup.
Thumb, index and middle finger	Horizontal distance: 2,5 cm Vertical distance: 4 cm	**Improved:** Drinking, Pouring, Transfer blocks, Eating soup, Drawing, Computermouse **Same:** Rotate key **Deteriorate:**	Participant named that more freedom felt good. No feedback about the less stability. Especially with the task 'eating soup', the participant mentioned that the tremor felt less; the researchers observed this.
Four fingers fixated (no thumb)	Height distance: 5 cm Vertical distance: 4 cm	**Improved:** Drinking, Eating soup, Drawing, Computermouse **Same:** Pouring, Transfer blocks, Rotate key **Deteriorated:**	The participant notes that he did not feel much difference from the previous version. The participant said that the splint by the little finger felt uncomfortable. Halfway through the tasks, the researcher removed the splint from the little finger. Participant has more grip on the rotating key task.
Only MCP joints fixated	Height distance: 7,7 cm Vertical distance: 5,3 cm	**Improved:** Drinking, Transfer blocks, Eating soup, Drawing **Same:** Pouring, Rotate key, Computermouse **Deteriorated:**	Participant notes that the shorter splints felt better and gave more movement freedom. During the drawing task, the participant named the little finger splint again; this splint is removed. The edges of the splints do not feel sharp.
Only MCP joints from thumb, index and middle finger	Height distance: 3,2 cm Vertical distance: 9,7 cm	**Improved:** Eating soup **Same:** Drinking, Pouring, Transfer blocks, Drawing, Rotate key, Computermouse **Deteriorated:**	Also, the ring finger splint is removed. The participant notes that more freedom felt good. The participant felt tired; observations showed that tremors increased with this glove.

Table 15: results participant 1

* Appendix 15.1: Kinovea and excel measurement for participant 1
** Appendix 17.1: scores for all the tasks with graphs
*** Appendix 16.1: observation notes

3.4 Discussion

This research aimed to investigate the question, "Which combination of fingers and joints do people with a finger tremor need to perform grips like tip, lateral, tripod and power?". The evaluation gave the following discussion points:

Tremor
The evaluation from the prototype resulted in less tremor. The extent of the amplitude showed that the finger tremor had a smaller amplitude for participant 1. However, by participant 1, the tremor moved from the fingers to the shoulder; however, after discussion with the clinical specialist from STIL, the movement from the tremor could also be the difference in body posture. Observations from participant 1 showed clear improvement in the severity of the tremor. The visibility of the tremor was good measurable. By participant 3, besides the four fingers fixation, there are improvements in the severity of the tremor amplitude. However, through the intention tremor of the participant, the tremor is slight when the user stretches the arm. An intention tremor gives a tremor when moving towards the object. A small tremor is hard to track with the tracking program, so miscalculations can easily be made. Evaluation of the tasks shows that the fixation of the fingers helped performing the tasks. Overall, the tasks with the glove mainly improved the performance. The feedback from the user was that the prototype gave stability but low comfort.

Three fingers fixated
The study concluded that all the fingers fixated or only three fingers (thumb, index, and middle finger) give the same TETRAS score. The ability to perform the tasks with the two variations is the same. Opinions from the participants gave that the three fingers glove felt more comfortable and manageable.

- Example: Participant 3 - picking up and putting down the cup while drinking improves when the glove only fixates the thumb, index, and middle finger.
- Example: Participant 3 - holding the spoon for eating the soup feels better when the gloves fixate on the thumb, index, and middle finger. The spoon is easier to hold.

Thumb
For both participants, the performance from the prototype with four fingers fixated did go less well. Overall the performance did go better than without the glove. The tremor from participant 4878 is mainly in the MCP joint from the four fingers; even then, the tasks were performed better with the thumb fixated. Recommendation to splint the thumb in the design.

- Example: participant 3 - thumb tremor is visible when moving the blocks.
- Example: Participants 1 and 3 - both mentioned the discomfort from the little finger splint.

MCP joint
The glove variation with only the MCP joint fixation is considered comfortable by the users. Observations showed that the tremor is more severe with the tasks, especially by participant 1.

- Example: participants 1 and 3 - both said the short splints felt more comfortable than the long splints.

Tremor extent
In the program Kinovea the amplitude of the tremor is measured. However, the researcher tracked the amplitude manually, which could have resulted in mistracking. In the study, there needed to be a provided reference length. This could have been done with a ruler in the same area of the arm. Now the program uses the dimensions of the orthosis as a reference so that the amplitude length can be measured. However, this can lead to miscalculations. The tremor extent can be used as an indication but needs an evaluation from the tasks, feedback, and observations.

Fabric from glove
The glove's fabric made grabbing difficult because the object mostly slipped through the fingers. Maintaining the feeling in the fingertips is valuable.

- Example: participant 3 - during the writing task, the participant named the difficulty in grabbing the pen, but the glove gave stability. Pen slips out the hand.
- Example: participants 3 and 1 - Participant named their preference towards an open design, which allows the user to feel the objects they are holding.

Splints uncomfortable
When the fingers are bent, the splint causes a pinching sensation against the knuckles. It is comfortable to wear the prototype for a short time, but the glove gets uncomfortable after some time. For this product, there must be no pressure on the knuckles; the freedom of movement of the hand is essential.

- Example: participant 3 - during the task of rotating the key, the bending of the fingers results in the splint pressing against the knuckles and causing a pinching feeling.

Little finger
The little finger splint did not sit comfortably for participants 3 and 1. The little finger splint felt so uncomfortable for both participants that they asked to remove it. What could have happened is that there is not much space for the splint at the little finger. The prototype strap is pulled over the splints to keep them in the right place; however, the splints are close together, which could cause discomfort.

- Example: participant 3 - during drawing tasks, the thumb tremor stays away. However, the glove feels uncomfortable due to the little finger splint.

Unobtrusive design
At the end of the research the participants are asked to pick the wearable they like to wear out of a list of wearables (appendix 6). Participants 3 and 1 prefer the design of the thumb orthosis (see figure 33).

- Participant 1 - found it functional and more durable when the wearable is made of one piece. So, the thumb orthosis exists in one piece and looks appealing through the open design.
- Participant 3 liked the thumb orthosis because of the minimalist and unobtrusive design. In addition, he named wearable 5 in appendix 5 as a wearable he would buy because of the open design. He also mentioned he does not need fixation in all fingers; the little and ring fingers are unnecessary.

Design color
Both participants named the skin color their favorite wearable (appendix 6 for the wearables), the argument being the unobtrusiveness of the design. Both test subjects repeated that unobtrusiveness is essential.

Corona
Due to corona, participant2 could not participate at the scheduled time for the research. The researcher concluded the design scope with the results from participants 3 and 1. For the second research, 2 did participate. For 2, research two included the glove's 'all fingers fixation', 'three fingers fixation', and 'MCP joint fixation'. Chapter 5 will evaluate the design scope with the results from 2.

Audio recordings
The recorded videos were without sound. During the research time, one researcher took notes. However, important details may accidentally get left out when only using notes. For future research, it is therefore recommended to also record the conversations.

Figure 33: thumb orthosis (JawsTec, 2022)

3.5 Conclusion

The research gave the answers to the questions and can give a design direction of a wearable for finger tremor patients.

The first subquestion stated, ''*What happens with the tremor when all **fingers** are splinted?*''. Results show a reduction of the tremor. The extent of tremor is almost by every glove lowered, except for 3, the glove with four fingers. Overall, the performance of the tasks improved, despite the task "Rotate key". In this task, there was no difference between the glove and without. The participant mentioned the increase in stability; however, both also mentioned the discomfort from the glove. Observation showed that both participants benefited from the glove, especially seen in the "Eating soup" task. For both participants, this was difficult; with the glove, water could stay on the spoon, resulting in the ability to eat soup.

The second subquestion stated, "*What happens with the tremor when the **thumb, index and middle fingers** are splinted?*". The results state that fixation in the thumb, index, and middle finger gives enough stability. The extent of the tremor by participant 3 is greater with three fingers, and with participant 1, almost the same. Both participants improved in performing the task with three fingers. Participants noted that the freedom felt good, and the stability felt the same with the version all fingers fixated. Observations gave no significant difference.

The third subquestion stated, "*What happens with the tremor when the the **index, middle, ring and little fingers** are splinted?*". The results concluded that the thumb is needed. The extent of amplitude is for participants greater by four fingers fixated in comparison with all fingers fixated. Observations showed that participant 3 had a thumb tremor. Participant 1 tremor was mainly in the MCP joints of the four fingers.

The fourth question "*What happens with the tremor when the **MCP joints** are splinted?* ". The tasks could be performed with almost the same ability when all fingers were fixated. Participants showed a lower extent of tremor than the baseline. Both participants mentioned the comfort of the splints. Observations showed that the tremor was more present than in other glove versions.

For both participants, the appearance must be as unobtrusive. They do not want more attention towards their tremor.

The main question stated: ''Which combination of fingers and joints do people with a finger tremor need to perform grips like tip, lateral, tripod and power?'' Conclusions showed that without the ring and little finger splinted, the performance of the tasks improved, according to the TETRAS scale. The most comfortable versions were the 'thumb, index, and middle fingers fixated' and the 'MCP joints fixated'. To conclude, the design scope focuses on suppressing the thumb, index, and middle finger at the MCP and PIP joints.

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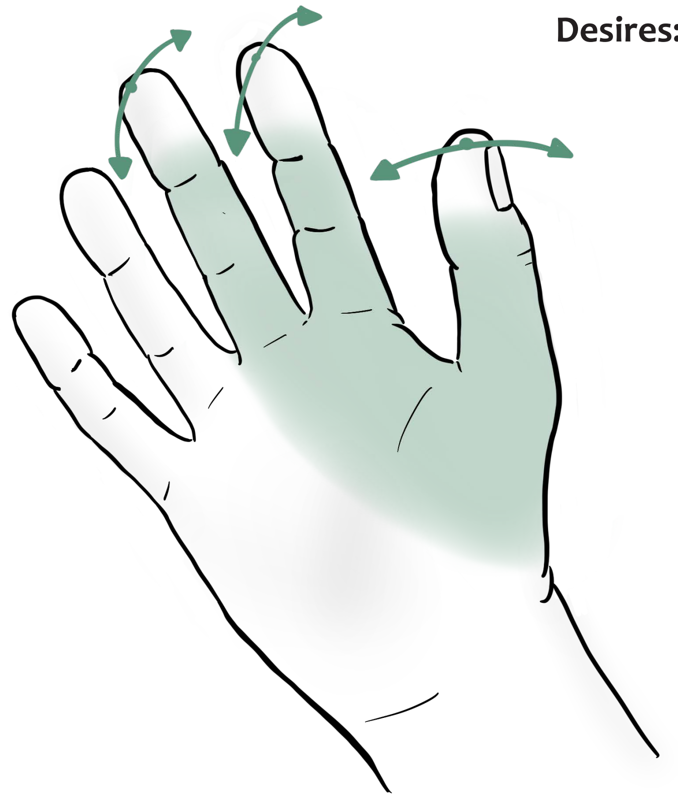
3.6 Design scope

The design scope resulted in the following requirements and desires. For all the requirements and desires, see appendix 1.

Requirements:

- Req 1.1.1.1 - The wearable suppresses the tremor in the **index** and **middle finger** in the **flexion** and **extension** direction.
- Req 1.1.1.2 - The wearable suppresses the tremor in the **thumb** in the **flexion** and **extension** direction.
- Req 1.1.1.3 - The wearable suppresses the **MCP joints** from the thumb, index, and middle finger.
- Req 1.1.1.4 - The wearable suppresses the tremor in the **PIP joints** from the thumb, index, and middle finger.
- Req 1.1.1.5 - The wearable provides **freedom of motion** from the **index and middle finger** in the **abduction** and **adduction** movement.
- Req 1.1.1.6 - The wearable provides **freedom of motion** from the **thumb** in the **abduction** and **adduction** movement.
- Req 1.1.1.7 - The wearable provides **freedom of motion** from the thumb in **opposition** and **reposition.**
- The wearable must be usable by **left and right** handed persons.
- Req 1.1.2.1 - The wearable does **not cover** the skin from the fingertips.
- Req 1.1.2.2 - The fabric from the wearable is **not slippery**.
- Req 1.1.2.4 - The wearable annoying when the user performs tasks.
- Req 1.1.2.6 - The wearable must be usable by **left** and **right** handed persons.



Desires:

- Des 1.1.2.7 - The wearable could be used for left and right hands with the **same components**.
- Des 1.1.1.9 - The device is **modular to different DOFs**
- Des 1.4.2.1 - The wearable should consist of the least amount of materials and parts so as to ensure design unity.
- Des 1.4.2.2 - The device has an **open look**.
- Des 1.4.2.3 - The device looks **minimalistic**.
- Des 1.4.2.4 - The wearable looks **durable**.
- Des 1.4.2.5 - The device is as **inconspicuous** as possible

Figure 34: degree of freedoms, which need suppression

3.6 Evaluation

The results from participants 1 and 3 resulted in the design scope. Due to corona, the test from participant 2 was postponed. The test with participant 2 was postponed between the research "Design Scope" and the new research "Concepts evaluation". The choice is made to evaluate the gloves "All fingers", "Thumb, index and middle fingers" and "MCP joints". The version ''Four fingers" is not included; there was no doubt about the essence of including the thumb in the finger tremor wearable. For the new research "Concept evaluation", one prototype is evaluated.

Table 1 shows the results from the research "Design Scope". Overall, the finger splints gave stability to the user; however, the glove size could have been better. The glove fit was too big; the size of the splints did not fit the fingers right. It could be due to the size that it becomes harder to perform tasks. The versions "Thumb, index and middle fingers fixated" and "MCP joints fixated" performed better than all fingers fixated. Observations showed that the tremor was more significant when the MCP joint fixation glove was used. Important to consider is that participant 2 became tired. She performed the tasks with great attention and perfection; this asked a lot of energy. During the tests, her atrosis also flared up, which caused discomfort where the handpiece was attached to the hand. Overall, splints help her perform the tasks, but sizing is essential. The two versions, "Three fingers fixated" or "MCP joints fixated," did not give a significant difference. A combination of the thumb, index and middle fingers fixated for only the MCP joints could be considered. However, participant 1 showed that more fixation is needed. The decision is made to keep the design scope the same.

Version	Evaluation tasks**	Feedback/observations***
Baseline I		
Baseline II - with orthosis	**Improved**: Pouring water, Drinking, Eating soup, Drawing, Magazine **Same**: Transfer blocks, **Deteriorated**:	Tremor is less in the FPS movement. Tremor in fingers more visable.
All fingers fixated	**Compared with baseline II** **Improved**: Eating soup, Drinking **Same**: Pouring, **Deteriorate:** Transfer blocks, Drawing, Magazine,	Glove is little bit big for participant. Some tasks could be performed better, especially eating soup. The glove makes it difficult to draw.
Thumb, index and middle finger	**Compared with baseline II** **Improved**: Drinking, Eating soup **Same:** Pouring water, Transfer blocks, **Deteriorated**: Drawing, Magaine,	Participant mentioned this version felt better because of the more freedom. Especially, drawing is more easy because the ring and little finger are free.
MCP joints	**Compared with baseline II** **Improved**: Pouring water, Drinking, Eating soup, **Same**: Transfer blocks, **Deteriorated**: Drawing, Magazine.	Task "Eating soup", the tremor is cleary visable, could be that participant is tired and therefor tremor is more severe.

Table 16: results participant 2

*** Appendix 28.3: scores for all the tasks with graphs*
**** Appendix 29.3: observation notes*

04

Ideation and Concepts

This chapter gives the design process for generating ideas and final concepts. The first subchapter lays out the ideation approach. Then four ideas will be presented. The evaluation of the ideas gives the final two concepts.

4.1 Ideation approach

The ideation phase exists out of multiple iterations. The basis for the ideation and the design directions are; meeting with Kasper Janssen (appendix 19), morphological card (appendix 20), and brainstorming session with the team from STIL (appendix 21). The basis resulted in the six design directions: wires with springs, gel/air damping, elastic, 3d printing different stiffness, splints, and liquid dampers. These design directions are further researched. A main map for liquid dampers is made (appendix 22). The liquid dampers are hard and bulky; smaller dampers are not found easily. Considering the needed size and comfort of the finger wearable, the prototype phase did not include the liquid damper. Because of the same working principle, the directions for 3D printing different stiffness and splints are combined. Kasper Janssen mentioned the Connex printer, which can print with different stiffness. This way, splints can be made with different stiffnesses, giving opportunities for more comfort. The prototype phase research this direction further. The following ideas were promising: wires with springs, gel/air damping, elastic, and splints with different stiffness (combination with 3D printing). Chapter 4.2 visualize the four ideas and the first prototypes. After the evaluation of the first prototypes, two concept directions were selected. The concept directions work with the working principles of elastic bands and splints with different stiffnesses.

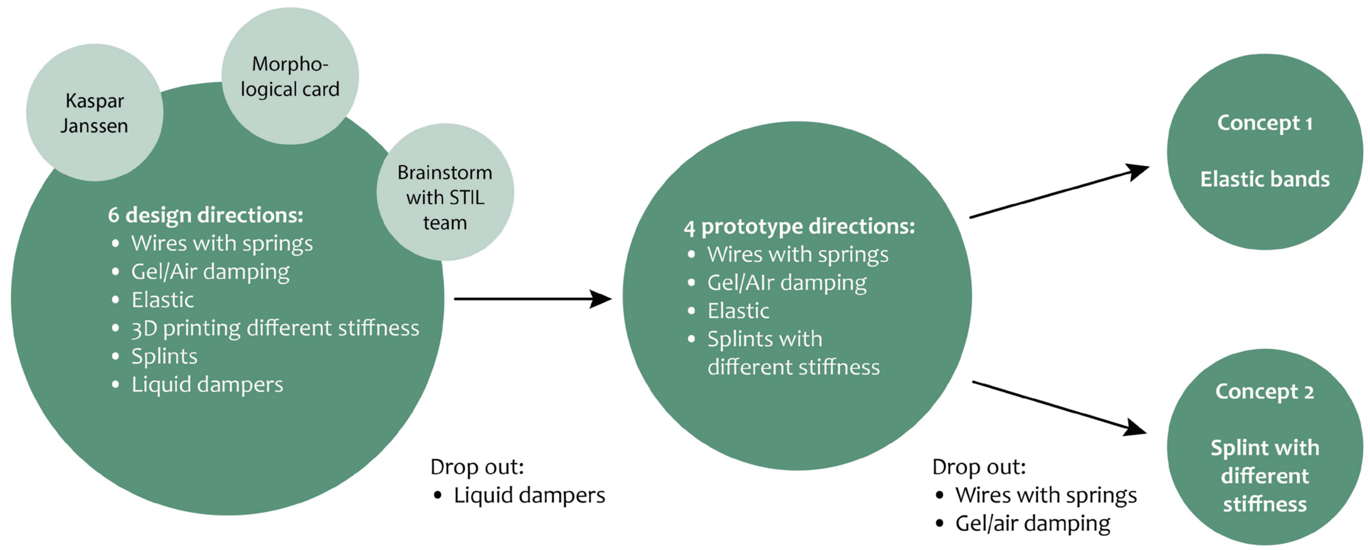


Figure 35: Ideation process

4.2 Ideas

This subchapter firstly visualizes the four ideas. Prototypes from these ideas are build, so the working principle can be tested.

4.2.1 Wires with springs

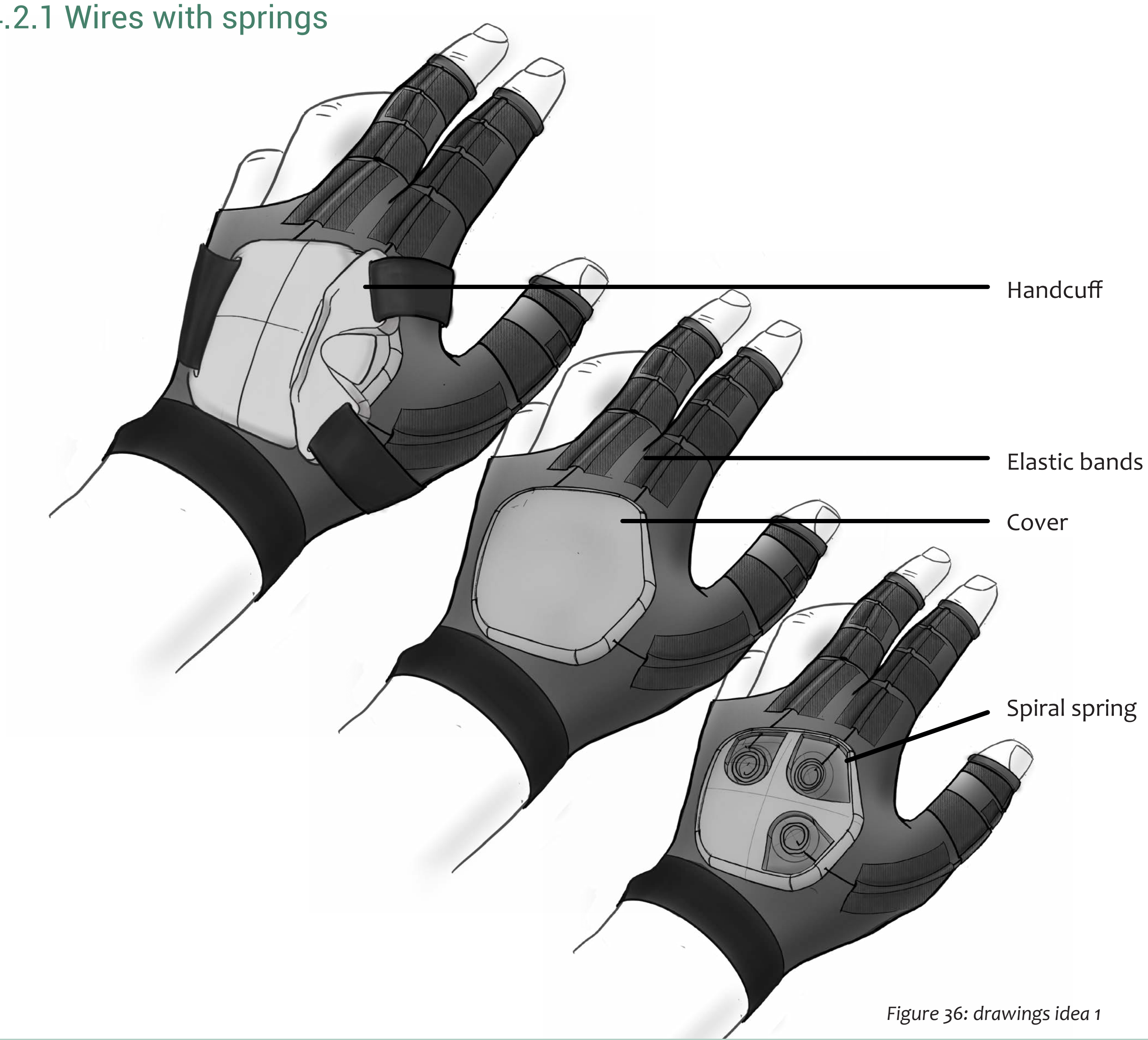


Figure 36: drawings idea 1

4.2.2 Elastic bands

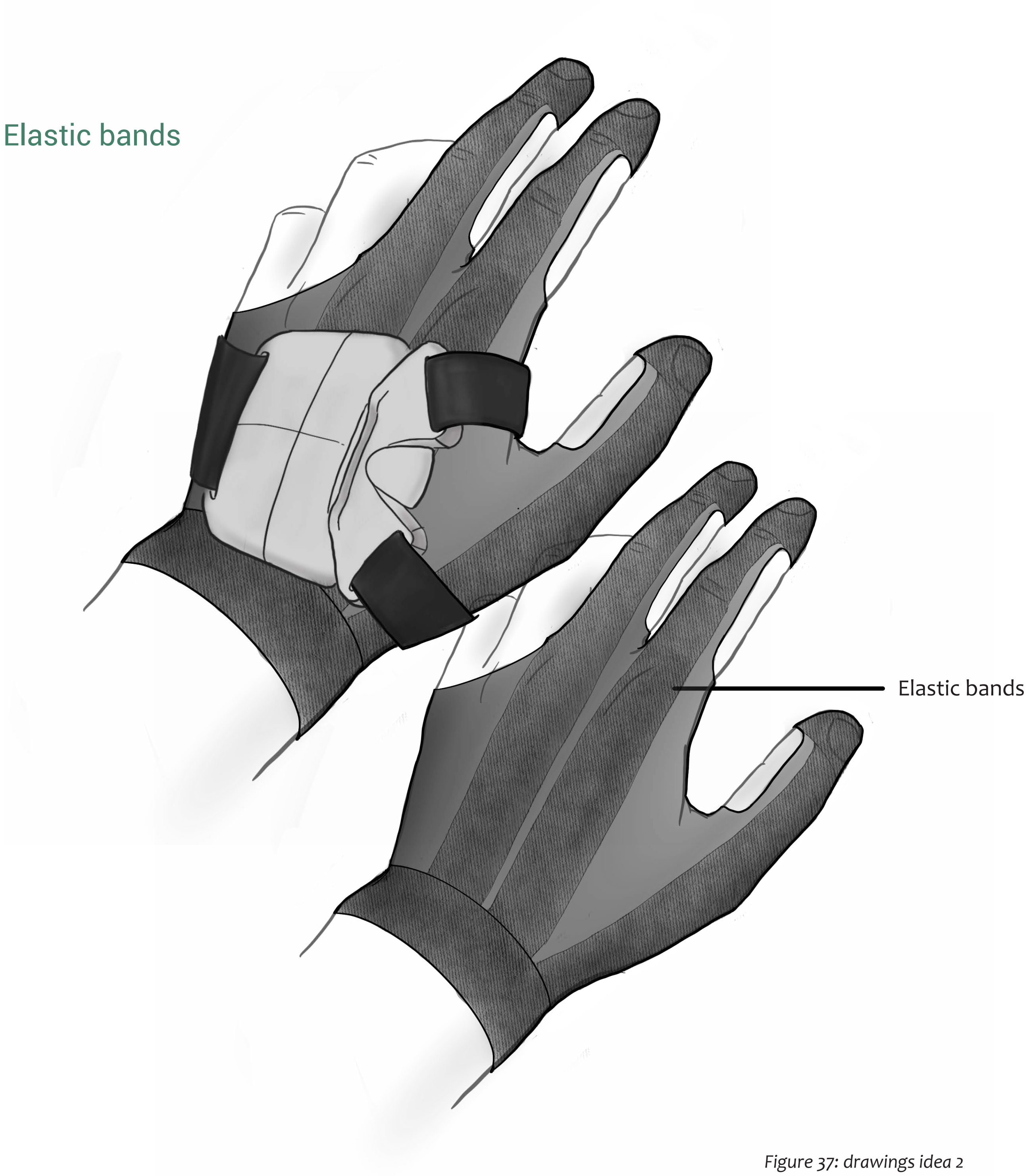


Figure 37: drawings idea 2

SPRINGS

The first idea works with a spring principle. A compressed or stretched spring exerts an opposing force proportional to its change in length. The wearable used the opposing force from the spring to reduce the tremor and pull back the fingers. The user has to move through the spring with more force than the tremor. The handpiece will have the springs integrated. Small spiral springs will be used to create a flat surface. The handpiece of the BEAM can be placed on the flat surface, see figure 36. The springs connect with the wires. The wires attached to the elastic bands between the joins apply force on the finger. The glove gives structure to hold the elastic band and wires in place.

ELASTIC

Based on elastic bands, the second idea pulls the fingers straight, reducing the tremor (see figure 37). Thin fabric covers the fingertips. The band needs enough stability; the fingertips provide this stability at the top of the finger. The elastic band begins at the fingertip and stops at the wristband. The band needs its elasticity; therefore, it can not be stitched all around. The soft fabrics and the ease of use are pros for this idea. The working principle would be that the tremor cannot move through the pull-back force from the elastic, and when performing tasks, the user can push through the elastic.

4.2.3 Gel or liquid damping

Figure 38: drawings idea 3

LIQUID

This idea based on gel provides damping and could reduce the tremor in the finger. The movement of the gel gives damping. In the idea, there are chambers and small transits. On top of the hand is one big chamber; from this chamber, three transits will go to the following chambers. These chambers locate at the MCP joint from the thumb, index, and middle finger. From each chamber located at the MCP joint, a transit will go to the next chamber. These chambers will be on the PIP joint from the thumb, index, and middle finger. The structure is filled with gel; this gel can move freely. When the fingers are bent, the chamber will be flattened, and the gel will move through the small transit. The gel will get resistance from moving; this will result in suppression. The structure base will be made of soft plastic. A fabric glove will hold the plastic structure in place. The structure will be stitched in the fabric glove.

4.2.4 Splints

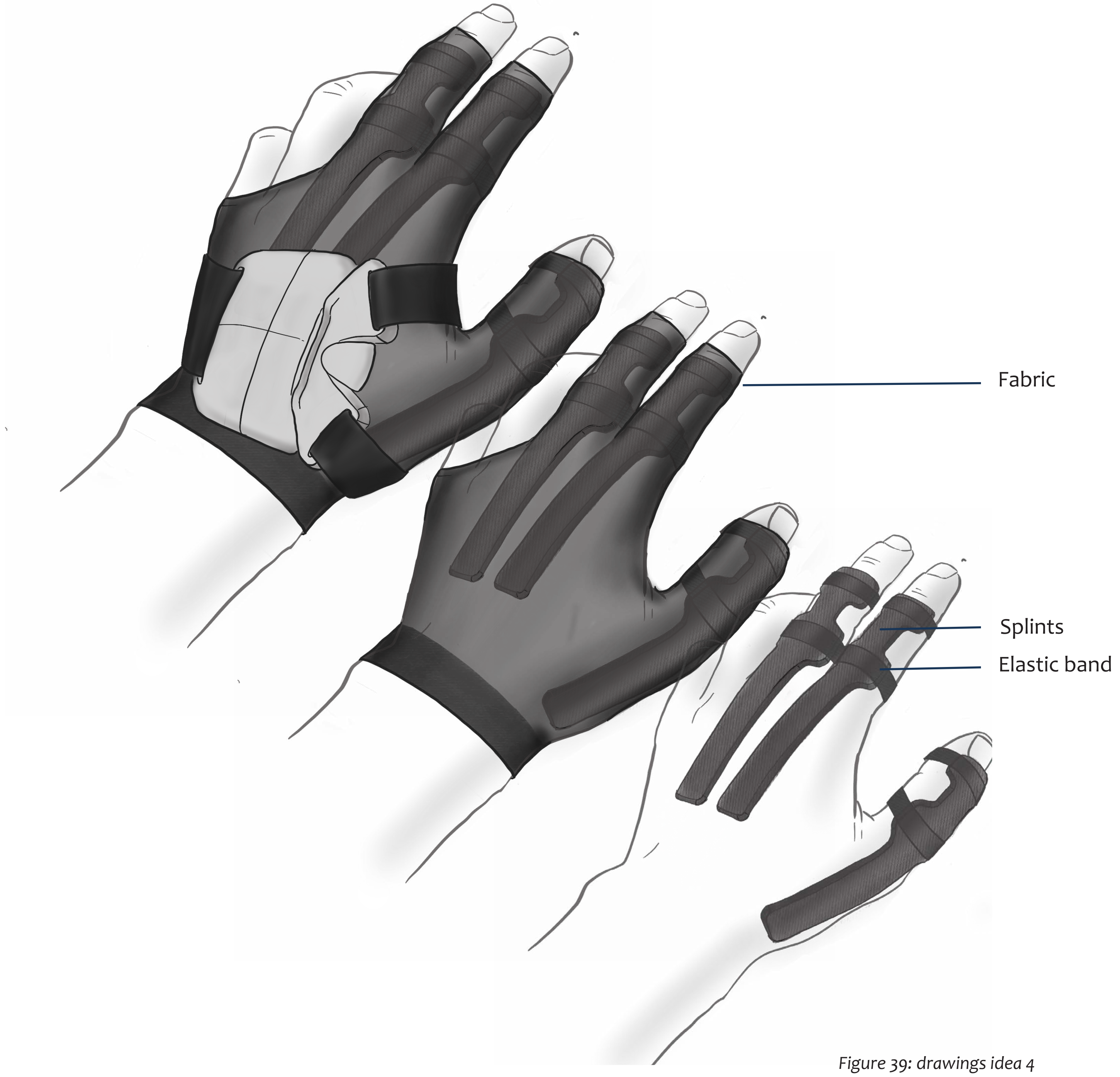


Figure 39: drawings idea 4

SPLINTS

The research Design Scope (see chapter 3) showed promising results for a working principle with splints; however, these splints were not user-friendly and comfortable. A soft plastic splint will give more comfort and could reduce a tremor. The splints forms around the finger. The splint is thicker and further rounded around the finger between the MCP and PIP joints. Between the MCP and PIP joints, elastic bands hold the splint correctly. The glove with cutouts holds the splints and elastic bands in place. The splints consist of soft plastics. The plastic needs to have enough stiffness to suppress the tremor. Further testing and research must show how much stiffness is needed and which material is most suitable. The mechanical loss or damping coefficient could be interesting for plastic selection. The mechanical loss coefficient measures the degree to which a material dissipates vibration energy.

4.2.5 Ideas review

Figures 40 until 43 show the first prototypes made. These prototypes investigate how promising the ideas could be. The most promosing ideas: elastic bands and glove with splints are chosen to develop further.

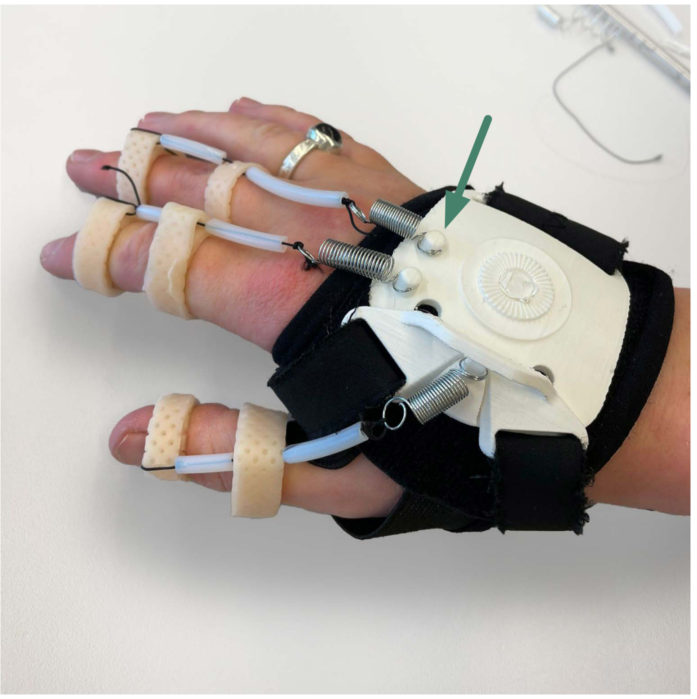


Figure 40
Wires with springs

Figure 40 shows the prototype for springs with wires. The springs are fixated on the handpiece, with modulated brackets (green arrow pointing at one bracket). The working principle of this prototype is the same as the elastic band prototype, shown in figure 41. Due to the same working principle and the higher comfortability and user-friendly of the prototype with the elastic bands, the choice is made to continue prototyping with the elastic bands.

Figure 41
Elastic bands

The prototype for the elastic bands looked promising. When bending the fingers, there is counterforce from the elastic bands; testing has to result in how much counterforce is needed.
The fit from the prototype is comfortable. A con is that the elastic bands move next to the finger when bending the fingers. Another setback is the fabric which is pulled upwards when the fingers bend.

Figure 42
Glove with splints

Figure 42 shows the prototype with splints. For the prototype, 3d splints are used to set the correct anatomy for the finger. Further prototyping needs to investigate the suitable flexibility in plastic for the splints.

Figure 43
Liquid damping

Figure 42 shows the prototype for suppression provided by gel/liquid. After discussion with STIL, this idea is challenging for large-scale production, next to the fact that it is hard to prototype. The choice is made to not continue with this idea.

4.3 Concepts

4.3.1 Splints

Two goals were formulated for the prototype with splints. Firstly, design an ergonomic splint for the thumb, index and middle fingers. Secondly, how much shore does the plastic splint need for enough suppression and comfort? Shore measures the hardness of flexible mold rubbers. For an ergonomic design, the anatomy of the hand is researched. The study of Vegara et al, (2017) gives the hand dimensions at the dorsal side. Most studies give dimensions only about the parmal side of the hand, which is unusable for the splints. Appendix 23, shows the iterations of the dimensions of the splints.

Designing molds were necessary to prototype the silicone splints. Splints with shore 25, 40, and 60 were cast; see figure 44 and appendix 24. The student and team of STIL thought the splints were not hard enough to suppress a tremor. Figure 46, shows the splint design in silicone 40 and 3d printed version; the silicone did not give enough hardness. For enough counterforce, a spring steel splint (0.2 mm thick and 5 mm wide) is included in the silicone splint (see figure 46). The testing prototype exists of three splints with spring steel.

Figure 44: silicone splints, dark splint (shore 40), yellow/orange splint (shore 60, white splint (shore 25)

Figure 45: Mold for splint figure 37

Figure 46: splint in front from silicone and in the back from 3d printing

Figure 47: used spring with spring steel

Figure 48 en 49: used prototype during evaluation

4.3.2 Elastic bands

The final prototype for the elastic bands is shown in figures 53 and 54. For the final prototype, multiple iterations were needed. The fingertips of the first two prototypes (figures 40 and 50) were from the elastic band. This resulted in difficulty with grabbing objects. For the final prototype, fingertips are bought. The fingertips exist out of thin fabric with copper wire so that touchscreens can be used. Another problem in the first two prototypes is the pulling up of the fabric. Prototype three was made from elastic bands in a glove. Each elastic band has three placements on the glove (see yellow parts in figure 51). When the fingers are straight, the elastic band is under little stretch; when the fingers are bent, there is more counterforce from the elastic band. The cons of prototype three were the limited counterforce and the shifting fabric. The handpiece from the BEAM was used for the fourth prototype (figure 53 and 54). Each elastic band can be stuck at the inside of the handpiece. This prototype can be adjustable, and the handpiece ensures stability. See appendix 26 for the prototype process.

Figure 50: second prototype elastic bands. Elastic too stiff and fabric around hand not stabile

Figure 51: third prototype elastic bands. Did not give a lot of counter force. The limit stretch from the glove fabric, limited the elasticity.

Figure 52: promosing prototype, the elastic bands are modular and good counterforce.

Figure 53 and 54: used prototype during evaluation

05

Concepts evaluation

In this chapter, the concepts are evaluated. The concepts work with elastic bands and silicone splints. The chapter first introduces the goal and questions of the research. Secondly, the method is provided. This research uses the method from the "Design scope" research. The subchapter lists the changes from the previous research. Thirdly, the results and discussion are given. The final subchapter gives the concept choice.

5.1 Introduction

This research aims to evaluate the two concepts. One concept works with elastic bands, and the other with silicone splints. Which concept improves the performance in tasks of people with a finger tremor? Besides the performance being essential, also the product's comfort and look&feel are taken into consideration.

Due to tremors, the fingers moved up and down uncontrollably, which can be very annoying and challenging in daily activities. The research for the design scope concluded that the wearable needs to suppress tremors in the thumb, index finger, and middle finger. The MCP and PIP joints need suppression or counterforce for these three fingers. The question is how this counterforce should be delivered and how strong it needs to be. This research evaluates two concepts. The first concept uses elastic bands that pull the fingers back; the user has to move against the elastic bands. The elastic bands range from light to heavy stretching. The second concept uses silicone splints with spring steel. The silicone should give comfort, and the light spring (0.2 mm thick and 5 mm wide) provides counterforce. This research compares the two different principles. In addition, the three elastic prototypes examine the desirable elasticity.

5.1.1 Research questions

What is the evaluation of the elastic band prototypes compared to the silicone splint prototype?

- *What is the difference in* **amplitude length** *between the elastic band prototypes and the silicone splint prototype?*
- *What is the* **user's experience** *with the elastic band prototypes compared to the silicone splint prototype?*
- *Is there an* **improvement** *between the elastic band and silicone prototype for the* **TERTAS-scored** *tasks?*

What is the desirable counterforce from the elastic band?

5.2 Method

Overall, the same method is used as the research design scope, presented in chapter 3. The subchapters give the changes in this research.

5.2.1 Material

For the evaluation of the two working principles, four prototypes are made. One prototype suppresses the tremor with silicone splints and spring steel. The other three prototypes suppress the tremor with elastic bands, which gave a counterforce. Three prototypes exist out of different elasticity. The prototype's elasticity is easy, medium, and hard stretchable. See appendix 24 and 26 for the making process.

- Elastic band light elastic - figure 55 and 57
- Elastic band medium elastic - figure 58
- Elastic band hard elastic - figure 59
- Silicone splints - figure 56

Figure 55: Elastic band prototype

Figure 57: light elastic band

Figure 58: medium elastic band

Figure 56: Silicone splints prototype

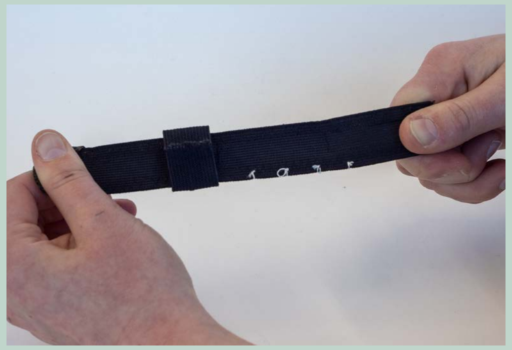


Figure 59: hard elastic band

5.2.2 Test environment

The previous study for the design scope is conducted in the participants' homes. For this study, the choice is again made to travel to the houses of the participants. Two months were separated between the appointments for participants 3 and 1. The first appointment showed that the home setting creates a space where the participants could speak honestly and give their opinions. In the previous study by participant 1, there was enough space for the equipment, like the tripods with cameras. The small setting by participant 3 caused discomfort; in the first test, the participant was on one side of the table, and the two researchers were on the other side with a tripod between them. Behind the participant and researcher was a wall. One researcher was, therefore, put in a small corner and could not walk freely. The camera is placed on the table for more space in this test setup. Also, the agreement was made to let the person in the corner take the notes so that this person does not need to walk. Like the following study, the points should be considered:

- Emphasize that the study is to evaluate the prototypes.
- Take time to rest between the different versions.
- Researchers are wearing their own clothes.
- Enough space for the researchers to walk freely

Confidential information

Figure 60: Test environment

5.2.3 Participants

The same persons participated in this research as the previous research; see chapter 3.2.1 for more information about the participants. Due to corona and the appointment delay for the first test, the choice is made to let participant 2 only try the elastic band prototype and the prototype from the previous study. So the results from participant 2 are used for the Design Scope research and this research. For this research, the results for elastic bands are used.

5.2.4 Procedure

This research procedure is almost identical to the design scope research; see subchapter 3.2.2. Table 18 shows the prototypes on the vertical column and the tasks on the horizontal row.

The task “rotating key 90°” is changed to “turn page from a magazine”. The previous research showed that the key task was hard to perform with a glove due to the slippery; the different variations of the glove could not be compared. Another attention point is the logistics; the camera had to be turned every time the task was performed.

The previous research conducted the baseline with the orthosis. In retrospect, the baseline without orthosis would be convenient. In previous research, there was no knowledge about the orthosis’s influence on the tremor behavior.

Prototypes / Tasks	**Power:** pouring water and drinking from a cup	**Tripod:** eating soup	**Tripod:** drawing spiral cord and straight line	**Tip:** move domino blocks from one paper to another	**Lateral:** turn over from a magazine
Baseline: without orthosis					
Baseline: with orthosis					
Prototype elastic: soft					
Prototype elastic: hard					
Prototype elastic: medium					
Prototype silicone splints					

Table 18: tasks for evalutions prototypes

5.2.5 Data management

A recorder will record the conversations during the research, the recordings are in Mp4. files. The recordings will be used to re-listen the conversions.

5.2.6 Data analysis

The data will be analyzed in three levels: tremor extent, evaluation from the tasks with the TETRAS scale, and feedback/observations from the user (see chapter 3.2.6). The TETRAS scale is used to evaluate tasks from the user. The new task, ‘Turning magazine page’, has not a specific TETRAS score. Therefore a score is made based on the TETRAS scale; table 17 shows the scale.

Rating	Turning magazine page
0	Normal
1	Slight; barely visible that the magazine page is shaking. No difficulty with grabbing the page.
2	Obvious that the magazine page is shaking. Little difficulty with grabbing the page.
3	The magazine page is shaking obvious. Difficult with grabbing the page.
4	Could not grab the page or breaks the page.

Table 17: tasks turning magazine page

5.3 Results

5.3.1 Participant 1

	Tremor extent*	Evaluation tasks**	Feedback/observations***
Baseline without orthosis	Height distance: 1,8 cm Width distance: 0,6 cm		
Baseline with orthosis	Height distance: 4,5 cm Width distance: 5,3 cm		
Elastic prototype - light	Height distance: 4,9 cm Width distance: 5,7 cm	**Improved:** **Same:** Pouring water, Drinking, Eating soup, Transfer blocks, Drawing, **Deteriorated:** Magazine	The prototype does not provide enough resistance. The prototype feels comfortable.
Elastic prototype - medium	Height distance: 3,7 cm Width distance: 7,6 cm	**Improved:** **Same:** Transfer blocks **Deteriorated:** Pouring water, Drinking, Eating soup, Transfer coins, Magazine	The elastic bands pull up the prototype. The participant dislikes the fact that his fingers are constantly pulled back.
Elastic prototype - hard	Height distance: 3,8 cm Width distance: 2,4 cm	**Improved:** **Same:** Pouring, Drinking, Eating soup, Transfer blocks, Drawing, **Deteriorated:** Magazine	Difficult to put on the prototype because the handpiece is pulled up. Participant reports that his MCP joints hurt because of the friction with the prototype.
Silicone splints prototype	Height distance: 3,9 cm Width distance: 3,9 cm	**Improved:** Pouring, Drinking, Transfer blocks, Drawing **Same:** Eating soup **Deteriorated:** Magazine	The participant mentioned the pleasantness of the natural hand position. This prototype is much better than the elastic prototype. The glove makes it less easy to grab objects because of less feeling in the fingers.

Table 19: Results participant 1

** Appendix 27.1: Kinovea and excel measurement for participant 1*
*** Appendix 28.1: scores for all the tasks with graphs*
**** Appendix 29.1: observation notes*

5.3.2 Participant 3

	Tremor extent*	Evaluation tasks**	Feedback/observations***
Baseline without orthosis	Height distance: 1,29 cm Width distance: 0,67 cm		
Baseline with orthosis	Height distance: 0,51 cm Width distance: 1,32 cm		
Elastic prototype - light	Height distance: 0,76 cm Width distance: 1,19 cm	**Improved:** Eating soup, Magazine, Computermouse **Same:** Pouring water, Transfer blocks, Drawing **Deteriorated:** Drinking	Participant liked the prototype, mentioned that there is not much counterforce, and it was easy to bend their fingers.
Elastic prototype - medium	Height distance: 0,76 cm Width distance: 0,67 cm	**Improved:** Pouring water, Eating soup, Computermouse **Same:** Drinking, Magazine, Drawing **Deteriorated:** Transfer blocks	Observation showed that there is enough counterforce to keep the fingers up. Prototype makes it difficult to perform precise tasks. It is challenging because the participant has to give extra force. During testing, the clip on the handpiece broke. The elastic bands pull up the handpiece; this could cause the breakdown.
Elastic prototype - hard	Height distance: 0,55 cm Width distance: 1,74 cm	**Improved:** **Same:** Pouring, Drinking, Eating soup, Transfer blocks, Drawing, **Deteriorated:** Magazine	The user finds it tiring to move through the rubber bands, which requires strength. The heavy elastic makes it challenging to move the domino. When the user releases the blocks, the fingers are immediately pulled back; the user mentioned losing control. The elastic bands pull up the handpiece.
Silicone splints prototype	Height distance: 0,83 cm Width distance: 0,95 cm	**Improved:** Pouring, Eating soup, Magazine, Computermouse **Same:** Drawing and Drinking **Deteriorated:**	The prototype provides a more natural position of the fingers. The participant feels more confident with the elastic band prototypes and feels like there is less resistance. The splints press on the joints.

Table 20: Results participant 3

** Appendix 27.2: Kinovea and excel measurement for participant*
*** Appendix 28.2: scores for all the tasks with graphs*
**** Appendix 29.2: observation notes*

5.3.3 Participant 2

	Tremor extent*	Evaluation tasks**	Feedback/observations***
Baseline without orthosis	Height distance: 1,4 cm Width distance: 1,4 cm		
Baseline with orthosis	Height distance: 2,3 cm Width distance: 0,1 cm	**Improved:** Pouring water, Drawing, Eating soup, Magazine **Same:** Transfer blocks, Drinking **Deteriorated:**	Because of the orthosis, there is less tremor in the FPS; the tremor in the fingers is more present. Less tremor in the wrist.
Elastic prototype - light	Height distance: 3 cm Width distance: 1,6 cm	**Improved:** eating soup **Same:** Transfer blocks, Drinking, Eating soup **Deteriorated:** Magazine, Drinking, Pouring water	The user states that she is tired, and that the handpiece fels uncomfortable. The user has arthrosis, which creates pain in the MCP joint of her thumb. The user indicates that the prototype at the fingers is comfortable and that her fingers are visibly pulled back, which reduces the tremor.

Table 21: results participant 2

** Appendix 27.3: Kinovea and excel measurement for participant*
*** Appendix 28.3: scores for all the tasks with graphs*
**** Appendix 29.3: observation notes*

5.4 Discussion

5.4.1 Elastic bands

Tremor extent

Two participants (3 and 1) used three different elasticity bands and one participant2 used the medium elastic band. For participant 3, the tremor's extent did not improve; almost all the dimensions are the same. For participant 1, the medium and hard bands give improvement. For participant 2, the elastic bands made the tremor amplitude higher.

Performance of tasks

Participant 3, the elastic bands improved the performance of the tasks. With the heavy elastic bands, most tasks improved. Participant 1, the elastic bands did show any improvement in tasks. The tasks were performed at the same level or deteriorated as the baseline with the orthosis. The user indicates that the continuous pulling back of the fingers, causing the fingers to be straight, is not pleasant. The resting position of participant 1 hand is under a slight curve, and his tremor occurs mainly in his MCP joint. It would be possible that the user does not like having his fingers pulled back and is not used to this position. For participant 2, one task improved, three were at the same level, and three deteriorated. At this point of research, participant 2 mentioned that she felt tired. Participant 1 and 3 performed the tasks the best with the hard elastic bands, compared to the light and medium bands. This is surprising because the feedback showed that the participant disliked this band the most.

Feedback and observations

Feedback showed that two of the three users reported liking the elastic prototype. However, one of these users has not tried the silicone prototype and different versions of the elastic bands. The users see the elastic prototype as applicable, although the ease of use with putting on and off must be made easier. All three users mentioned that the pulling force backward feels tiring. Participants 3 and 1 said that the heaviest elastic bands were tiring. For example, in the moving blocks task, the heavy elastic needs more power to push through the elastic. The heavy elastic bands made it hard to perform precious tasks.

Handpiece broke

Handpiece broke by participant 3, it needed replacement of handpiece. The handpiece brokes on the place where the strap goes through. The strap held the handpiece in place. The pulling upwards created tension at the place the handpiece pulled downwards, which could be the reason the handpiece broke.

Displacement of handpiece

The elastic band prototype pulls the handpiece upwards. The hard elastic bands pull up the handpiece (figure 61), and soft elastic the handpiece stays in place; see figure 62. The upwards handpiece creates discomfort for the user.

Fingertips

For participants 1 and 3, the fingertips do almost not fit around the thumb, especially for user 3. It may have affected performance.

Confidential information

Figure 61: participant 1 soft elastic bands

Confidential information

Figure 62: participant 1 hard elastic bands

Confidential information

Figure 63: participatn 3 medium elastic bands

5.4.2 Silicone splints

Tremor extent

For the prototype with splints, the amplitude extent from the tremor did not change much in comparison with the baseline with the orthosis. Participant 4815, almost the same distance, and participant 4878, there is a slight improvement.

Performance in tasks

Both participants' performance in the tasks is an improvement, especially compared to the elastic bands. Participant 3 showed that four tasks from the six improved and the other two at the same level. Participant 1 showed improvement for four tasks, one at the same level and one deteriorating task.

Feedback

Participant 1 reports that the silicone prototype is more comfortable and less laborious. Users 1 and 3 named the more natural hand position with the splints. User 3 does indicate that the splints can feel uncomfortable on the MCP joints. Another feedback point is; it would be nice and comfortable if the glove's fabric did not cover the fingertips.

5.4.3 General points

Texture fingertips

Hot glue provided texture on the fingertips. This texture helped with grabbing objects. Indicates that texture feels better than glove fabric, but the user still prefers skin.

Test setting

Participant 1 is, after some time, more at ease. Therefore, tasks could be performed better after some time

Testing time

For participant 2, the tasks take longer than for the other users; the user wants to do the exercises very well. Halfway through the tasks, the user says she is tired and that the orthosis and prototypes are uncomfortable. The person herself indicates that this is due to the atrosis in her hand, which makes joints hurt. Mainly, the thumb joint hurts

5.5 Conclusion

In the research, two concepts are tested. The main question stated: ‘’What is the evaluation of the elastic band prototypes compared to the silicone splint prototype?’’. The results are evaluated on three levels: the difference in amplitude from the tremor in the fingers, the user’s experience, and the improvement for the TETRAS-scored tasks. Overall there is no significant difference in amplitude length between the baseline, silicone splints, and elastic bands. The results showed that participants 3 and 1 improved in performance of the tasks when using the silicone splints. The user experience was divided. Two people said they preferred the elastic bands (one of the participants did not see and use the silicone splints prototype). However, all the participants mentioned that the counterforce from the elastic bands felt tiring. One of the participants preferred the silicone splint prototype above the elastic band. The participants mentioned that the natural position of the silicone splint prototype is better. Overall the performance of the silicone splint prototype is better. The look and feel of the elastic band prototype were preferred.

5.6 Concept choice

For the concept choice a harris profile is used:

	Elastic bands				Splints			
	Bad	Moderate	Good	Excellent	Bad	Moderate	Good	Excellent
Performance tasks	■	■					■	■
Tremor extent		■					■	
Comfort		■	■				■	
Confidence		■					■	
Design appearance			■	■	■	■		
Addable to the Beam			■	■		■	■	
Grip			■			■		

Table 22: Harris Profile, left elastic bands and right silicone splints

The silicone splint prototype performs better than the elastic band’s prototype. The research results give better performance of tasks and less tremor extent by the silicone splint prototype. The comfort from the splint prototype is slightly higher due to the hand’s natural position. The elastic bands were less comfortable because the prototype was perceived as tiring. The prototype was tiring because of the counterforce pulling the fingers straight. The counterforce also causes less confidence. The counterforce also pulled the handpiece upwards. The silicone splints gave confidence, but the glove’s design, especially the fingertips, did not give confidence. The design appearance of the elastic bands is higher than the silicone, even as the adaptability. The elastic bands can easily be added to the orthosis because the final product can be a glove under the handpiece. The grip from the elastic bands was better. For the silicone, prototype improvements have to be made. To conclude, the performance of the silicone prototype is better, and the design and adaptability of the elastic band are better. For the final concept, silicone splints are chosen. The performance is most important.

5.7 Requirements and wishes

The evaluation of the concepts provided the following requirements and wishes. For the complete list of requirements and wishes, see Appendix 1.

Requirements:

- Req 1.1.2.8 - The wearable provides damping with **silicone splints with spring steel.**
- Req 1.1.2.9 - The silicone splints exit outcast silicone from **shore 40**.
- Req 1.1.2.10 - The spring steel in the silicone steel are **8 mm wide and 0.4 mm thick**.
- Req 1.1.2.1 - The design d**oes not cover the fingertips**.
- Req 1.1.2.12 - The design, when no forces are present from the fingers, provides a **natural position** of the fingers.
- Req 1.2.7.6 - The splint design is **ergonomic** and formed around the finger.
- Req 1.2.7.4 - The wearable does not pull the fingers back.

Desires:

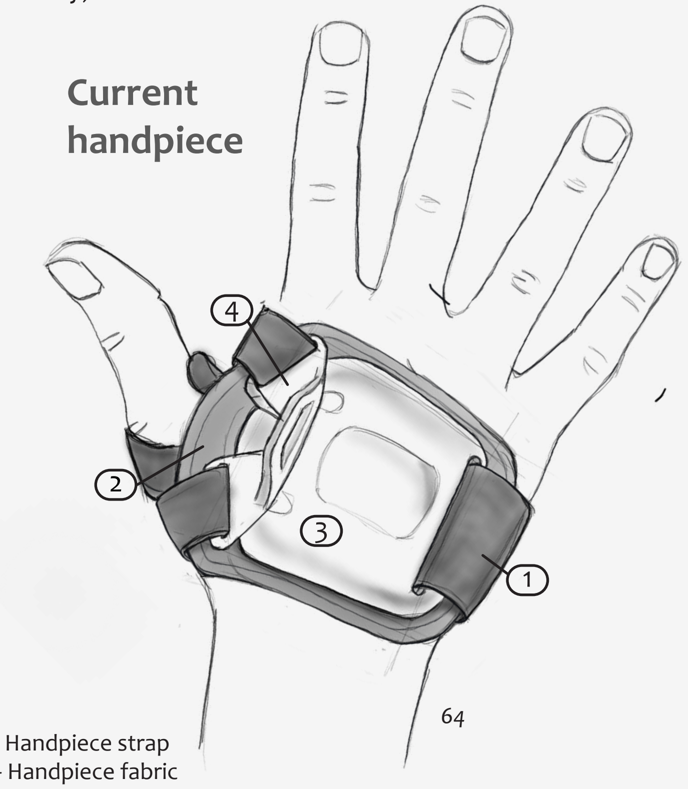
- Des 1.4.2.7 - The design has the same look and feel as the BEAM.

06

Final concept

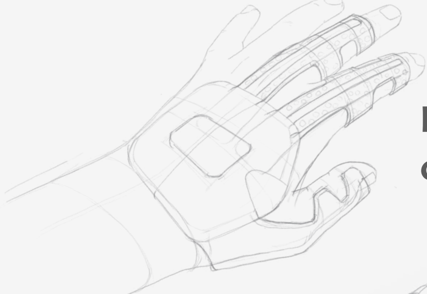
Chapter 6 concludes by presenting the final concept. The process behind this concept is outlined, focusing on sketches for the appearance and connection to the BEAM. For the connection with the BEAM two directions are researched: the replacement of the handpiece connection (see point 3) or **replacement of the fabric part (see point 2)**. The final concept **replaces the fabric parts.** Subchapter 6.1 presents the final prototype with a specific emphasis on aesthetic design, ergonomics, usability, and connection to the BEAM.

Current handpiece



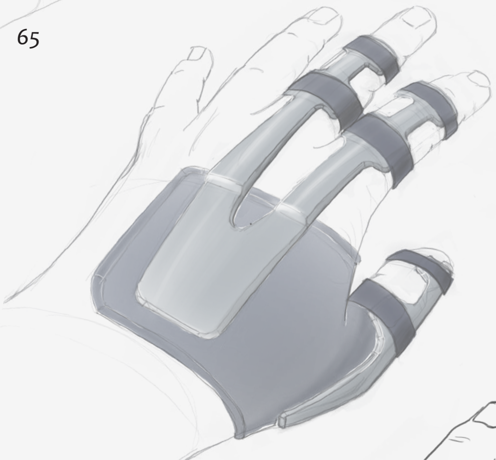
64

1 - Handpiece strap
2 - Handpiece fabric
3 - Handpiece connection
4 - Clip
5 - Handpiece with flexible finger splints
6 - Elastic bands
7 - Silicone in elastic fabric
8 - Handpiece fabric
9 - Push button to connect handpiece connection
10 - second wing from the index finger splint
11 - first wing from the index finger splint

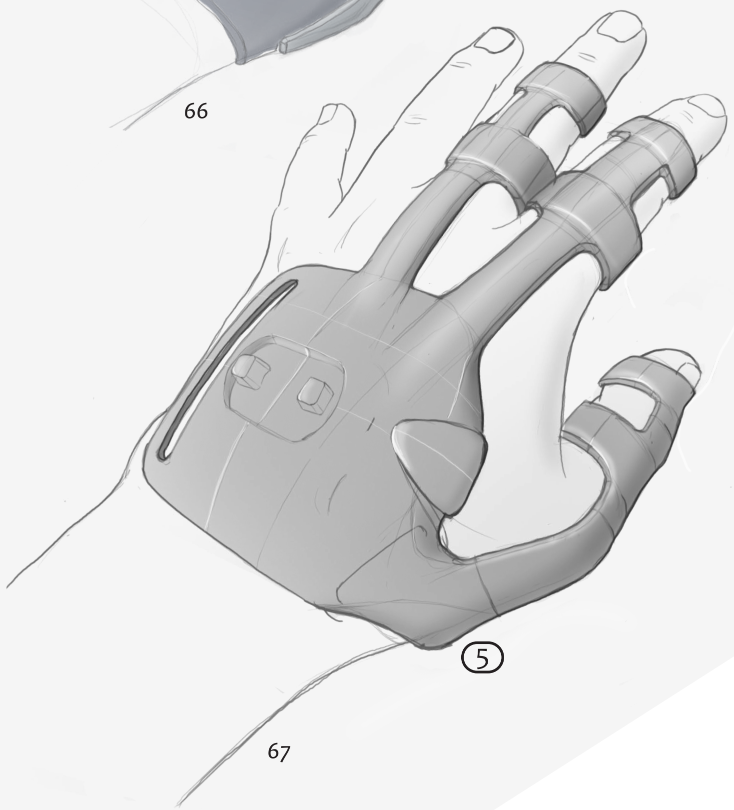


65

Replacement of handpiece connection (3)

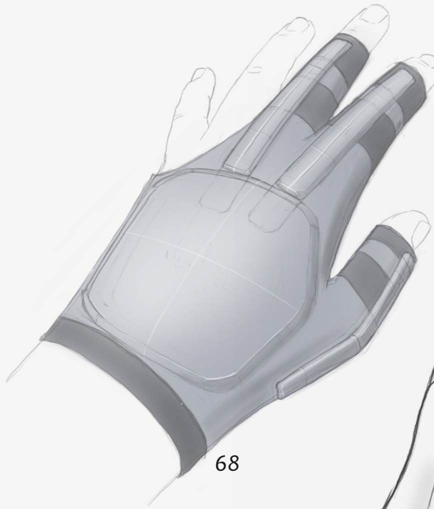


66

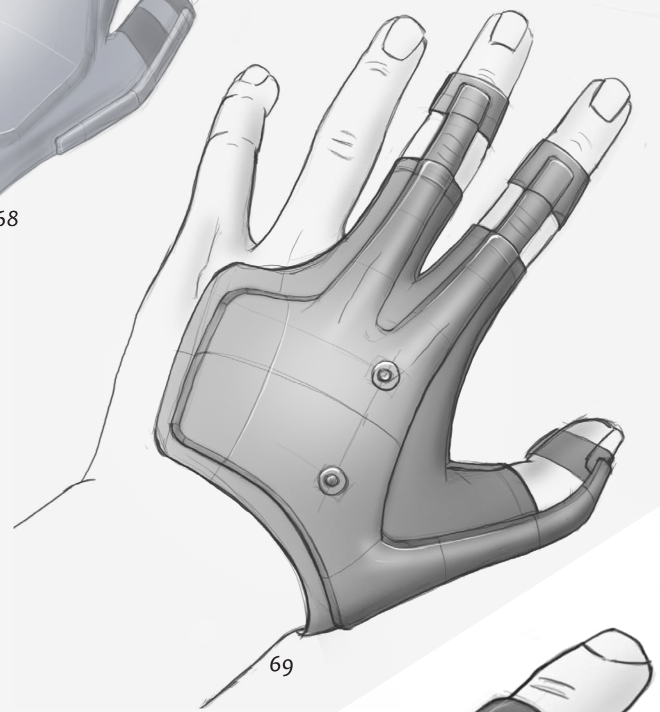


67

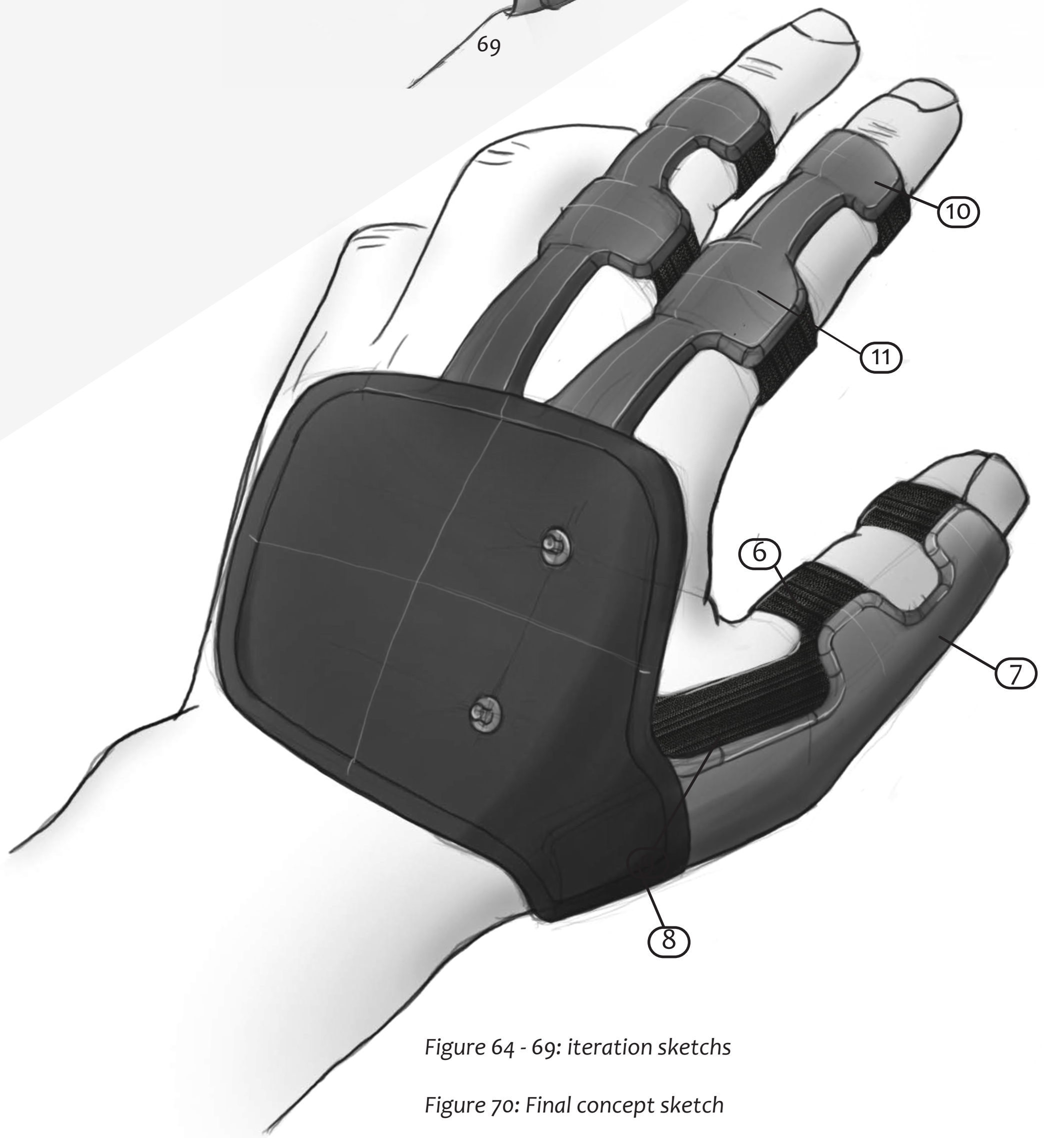
Replacement of handpiece fabric (2)



68



69



Final concept

The final concept replaces the handpiece fabric. In this case, STIL can introduce a new fabric part that the user can replace. The choice is made to use fabric to hold the splints in place. The color of the splints must be the same as the handpiece fabric. Elastic bands are used to connect the splint on the finger.

Figure 64 - 69: iteration sketchs

Figure 70: Final concept sketch

6.1 Final prototype

The finger-suppression wearable can be added to the BEAM by replacing the fabric under the handpiece with the finger-suppression fabric, as shown in image 1. For those who only want to use the finger-suppression wearable, a separate handpiece is available, as illustrated in image 2. The splints are secured in place with elastic bands, as shown in image 3, and are made of a combination of silicone and spring steel, which provides damping.

Figure 71: Final prototype

6.1.1 Usability

People with tremors need a wearable that is easy to put on and take off. The design must guide the user to place the orthosis correctly so that the dampers can effectively suppress tremors. STIL places high importance on the user's donning and doffing experience. In order to put on the orthosis, two clips are required to hold the orthosis in place. One clip is at the elbow piece, and one is at the handpiece. In the finger wearable, the handpiece lip secures the finger splints. See figure 72 for the donning and doffing process of the finger splint wearable. When the orthosis is extended with the fingers splint wearable, the extra donning and doffing is to put the fingers under the splints and the elastic bands around the finger. The handpiece clip can be attached in the same way.

Requirement:

- Req 1.2.3.1 - The wearable must be held in place by the handpiece clip.
- Req 1.2.3.2 - The user must easily don and for the wearable.

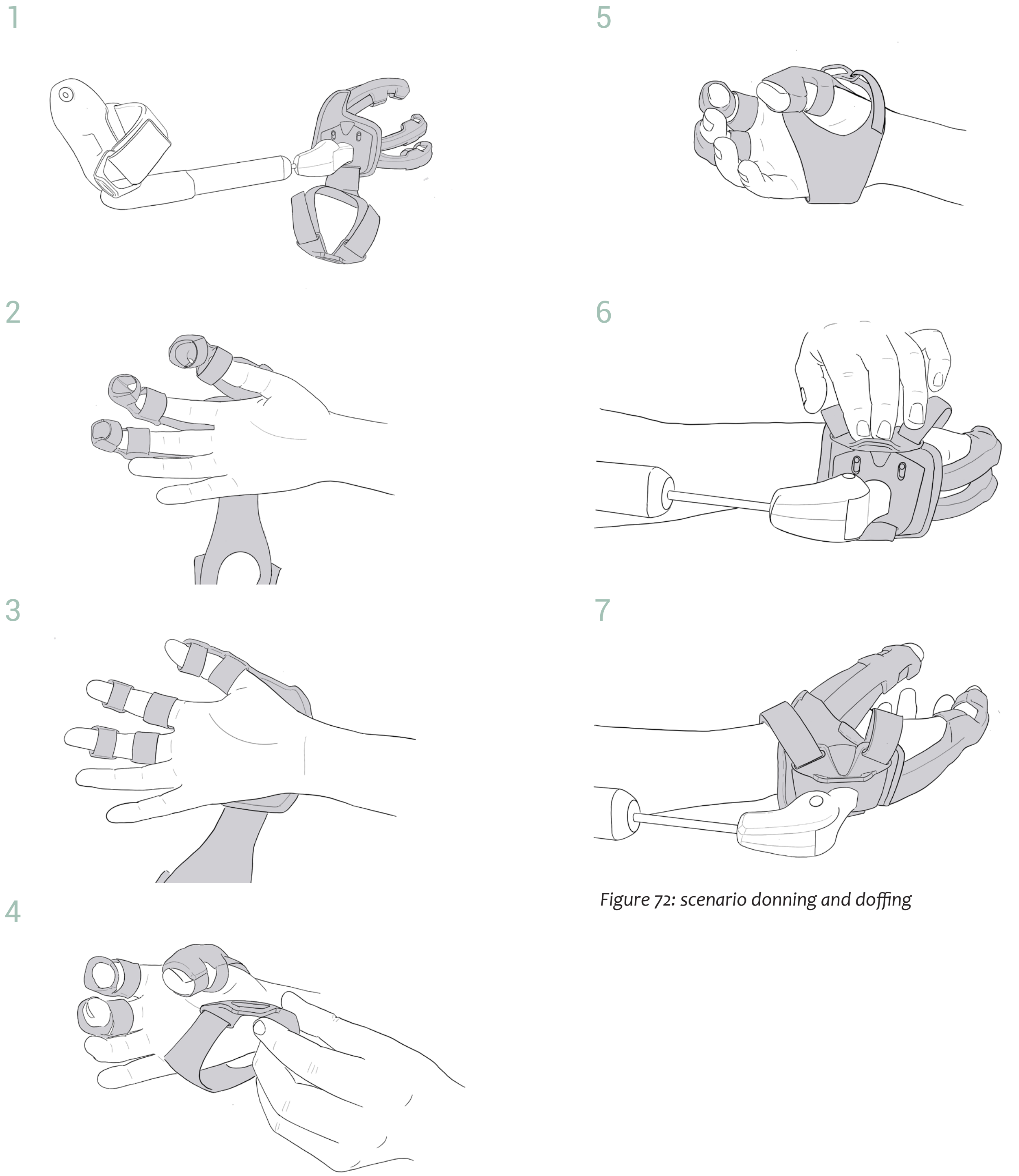


Figure 72: scenario donning and doffing

6.1.2 Connection to the BEAM

The finger tremor wearable can easily be added to the BEAM; the fabric only has to be changed. The fabric replacement is optional and up to the user's discretion. In the situation where the user only wants to use the finger tremor wearable, a separate handpiece designed explicitly for this purpose is provided and does not connect to the orthosis. Figure 74, shows the finger wearable with the handpiece of the BEAM, and figure 73 shows a handpiece without connection.

- Req 1.2.3.1 - The wearable uses the handpiece clip to secure the silicone splints.
- Req 1.2.3.3 - The wearable provides a solution to use the finger wearable on its one without the use of the orthosis.

Figure 73: Finger suppression wearable

Figure 74: Finger suppression with handpiece connection BEAM

Figure 75: Finger suppresion with the BEAM

6.1.3 Appearance

The appearance of the product is essential for people with a tremor. Ideally, they want a design that draws no attention or can be worn as a piece of jewelry (concluded in research design scope, chapter 3.5). People that experience tremors are sensitive to other people noticing the shaking resulting from the tremors, especially in social occasions. The appearance should therefore be as inconspicuous as possible. The following desires are essential for the design appearance:

- Req 1.4.2.6 - The wearable does not cover the fingertips.
- Des 1.4.2.1 - The wearable should consist of the least amount of materials and parts so as to ensure design unity.
- Des 1.4.2.2 - The wearable has an open look.
- Des 1.4.2.5 - The wearable looks as inconspicuous as possible

The BEAM will be offerend in dark colors, with black fabrics (figure 76). The splints are in black elastic fabric to merge with the design of the orthosis. The research design scope, participants indicated an overall preference for light colors. Light colors are white or skin color. The choice is made to merge the finger splints with the orthosis; therefore, the final prototype is black. With a light orthosis, the finger splint product can also be light.

The design of the wearable is depicted in figure 78. The shape between the MCP-DIP joint and the PIP-DIP joint features small wings on either side of the splint. The wings provide stability and secure the splint's position. Elastic bands are attached to the wings, allowing for an open design that keeps the splint on top of the fingers while allowing the dorsal side of the hand to remain unrestricted and the fingertip skin to remain uncovered.

Appendix 33 shows the making process of the fabric.

Figure 76: Fabric from prototype (STIL B.V., 2022)

Figure 77: Fabric from prototype

Figure 78: Fabric from prototype

6.1.4 Ergonomic

STIL will focus on the Dutch population for the first production and trading. For further development from the orthosis and future products, the market will extend to the rest of Europe. For an ergonomic design of the splints, the wings (see figure 70, number 10 and 11 for wings) must be located between the MCP - PIP and PIP - DIP. For the correct placement of the wings, more information about the dimensions between the joints is needed. No information is found on the dimensions between joints for the Dutch population. Therefore, the finger-suppression wearable design is based on Spanish research, which measured the dorsal side of the hand's dimensions for 69 females and 70 males. The hand dimensions between joints are crucial for the ergonomics of the splints. Figure 79 shows the average dimensions of the hand for man and women (Vergara et al., 2017). These dimensions formed the basis for the splints design. Figure 80 shows the dimensions of the splint for the index and middle finger, and figure 81 for the thumb. The silicone splints are soft and easy to bend. Therefore the difference between the index and middle finger splints was low. The dimensions of the middle finger are used for the index and middle fingers. Firstly, the splints were printed to determine the splint's size and angle. Appendix 23 shows the process of splint iterations. The relevant requirements for the splints are:

- Req 1.2.7.2 - The first wearable wings are located between the MCP and PIP joints for 95P of hand confirmation in the Netherlands.
- Req 1.2.7.3 - The second wearable wings are located between the PIP and DIP joints for 95P of hand confirmation in the Netherlands.
- Req 1.2.7.4 - The wearable does not pull the fingers back.

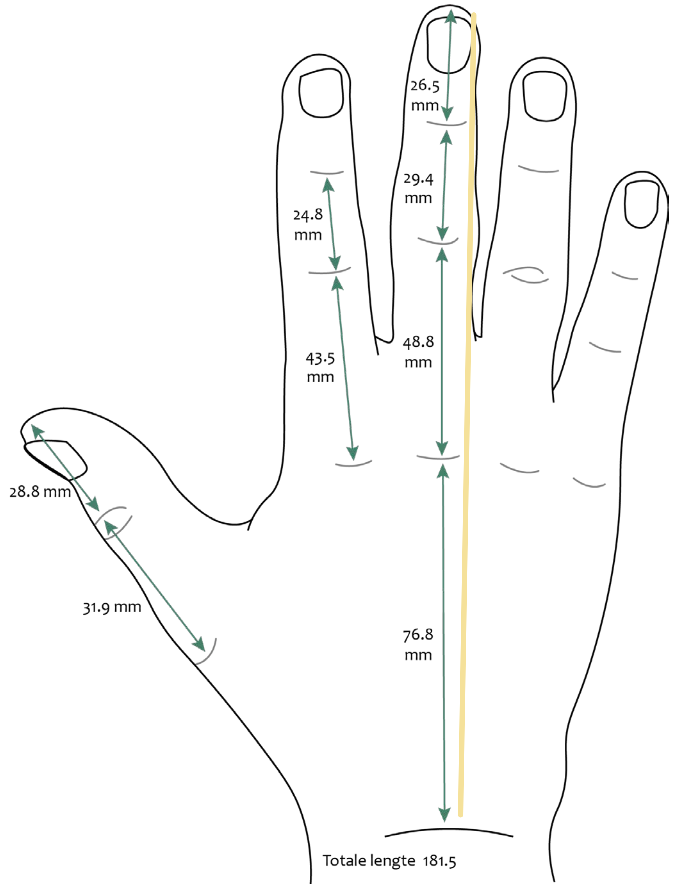


Figure 79: hand dimensions (Vergara et al.,2017)

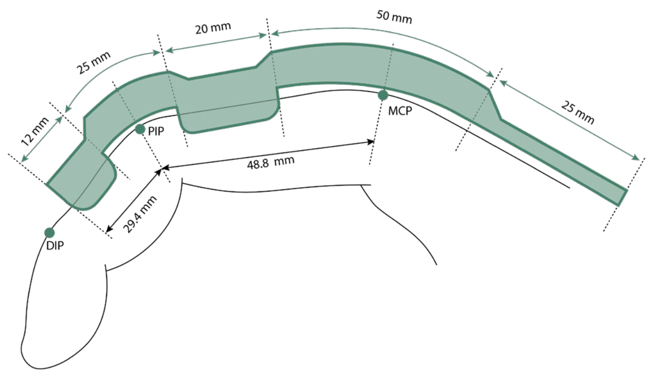


Figure 80: Splint ergonomics thumb

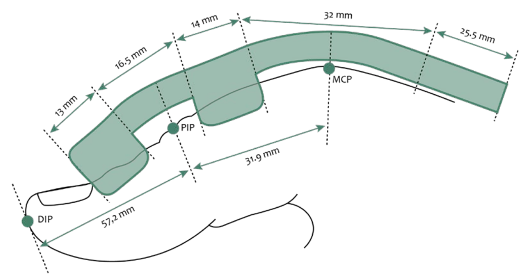
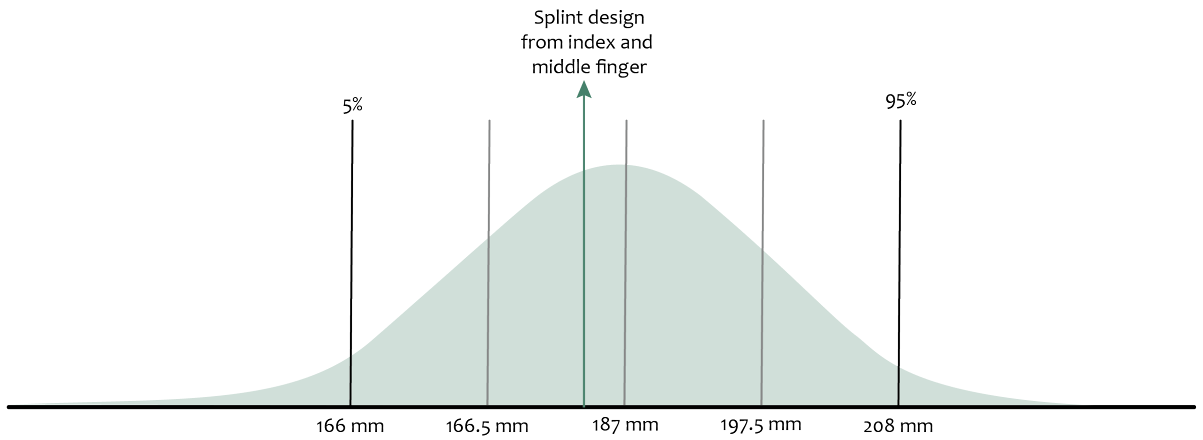


Figure 81: Splint ergonomics thumb

The lengths indicated are from a Spanish population; this is, of course, not the same as the Dutch. The hand lengths from the populations are compared to determine the relationship between the Dutch and Spanish populations. Figure 70 visualizes the hand length with the yellow line. DINED gives data about the hand length of the Dutch population. The data used is DINED-2004, based on adults aged 20 to 60. The data is from the Geron-project (1993-1998) and the Ceasar-project from TNO Human Factors Soesterberg. Table 23 gives the hand dimensions from the Dutch and Spanish population, from the female and male + female. Graph 2 gives the normal distribution of the hand length from the Dutch male + female. The green arrow determines the mean hand length of the Spanish population. The data shows that the Spanish mean is smaller than the Dutch mean. Important to consider that the hand length measurement for Spanish and Dutch populations could differ. The comparison doesn't say anything about the dimensions between the joints for the Dutch population. Further testing needs to show how the ergonomics of the splint are received for different finger sizes. The finger wearable fits correctly for one Dutch female with a hand length of 178.



Graph 2: normal distribution DINED-2004 adults 20-60, male and female

Population	Gender	Mean	5th	95th
Dutch adults ("Dutch Adults 2004 Dined2004," n.d.) age 20 - 60	Male and female	187 mm	166 mm	208 mm
Dutch adults ("Dutch Adults 2004 Dined2004," n.d.) age 20 - 60	Female	178 mm	165 mm	191 mm
Spanisch adults (Vergara et al., 2017) n = 139	Male and female	184.5 mm	159 mm	211 mm
Spanisch adults (Vergara et al., 2017) n = 69	Female	177.5 mm	157 mm	201 mm
Hand dimensions Dutch person	Female	178 mm	/	/

Table 23: hand dimensions DINED-2004 and Vergara et al., (2017)

The splints for the index and middle fingers are connected with a flat surface. This surface goes underneath the handpiece. The splints are silicone shore 40 and spring steel from 10 mm wide and 4 mm thick (figure 83). The silicone comforts the fingers, so bending does not hurt the joints. Figure 82 shows that the splints can bend easily. The spring steel needs to give suppression for the tremor. Appendix 32 documents the making process for the silicone splints.

Figure 82: Bending from prototype

Figure 83: Splints with springsteel 0,2 mm thick and 4 mm wide. Tested if less spring steel will also provide enough damping, this was not the case. see appendix 32, for the making proces.

6.2 Evaluation

A final patient visit was conducted for feedback and evaluation purposes. The prototype is designed for individuals with tremor in their right hand. However, this participant had a dominant finger tremor in her left hand, making it unsuitable for testing the working principle of the prototype. The evaluation focused on aspects such as appearance, ergonomics, ease of putting on and taking off, usability, and comfort. Further details and photographs of the evaluation can be found in Appendix 34

Appearance
The participant notes that the prototype looks good. She does not see herself wearing it immediately. But, she is interested in trying it for a longer time and experiencing what it does with her finger tremor. A condition has to be that the wearable is left-handed and has to fit well.

Ergonomics
The elastic bands fit well around the fingers. However, the MCP - PIP elastic bands are already high on the fingers. The PIP - DIP bands is located on the DIP joints in the case of the index and middle fingers. The thumb splint is located in the correct position; however, when the user stretches her finger, the second elastic band slips from the thumb. The splints are located well when the user bends the fingers in a fist.

''De spalk van de duim glijd van het topje af, vooral wanneer de vingers gestrekt zijn. ''

Donning and doffing
Before the participants put on the finger wearable with orthosis, a little instruction is given. The participant mentioned that the fingers slip easily in the orthosis. The little buttons, which connect the handpiece with the finger wearable slips out easily, which is not good. Figure 85 shows how the participant puts on the finger-wearable; here, the connection between the fabric and the handpiece is not connected anymore. The participant needed extra help to connect the handpiece with the fabric. The participant mentioned that the finger-wearable is really easy to put on.

Usability
Further explanation gave that the finger-wearable could also be used without the orthosis. For the participant, this would be interesting. She tries to fixate her shoulder and wrist for her crocheting work, so she does not shake uncontrollably. She can not fixate her fingers; the finger-wearable could be a solution.

Comfort
The participant mentioned that the splints felt comfortable; she was surprised that the splints also included spring steel. She is interested in trying the splints for her finger tremor.

''Dit ziet er goed uit en zit lekker ook.''

Confidential information

Figure 84: inside hand

Confidential information

Figure 85: inside hand

6.3 Recommendations

This subchapter lists recommendations for future product development. The recommendations are divided into topics. The topics refer to the requirements and give future focus points or opportunities. For the list of requirements and desires, see appendix 1. Requirements and desires that need further research are marked green.

Ergonomics splints
The research conducted in this project resulted in the development of a single size for the splints, which was based on studies of the Spanish population. The splints are designed for individuals with medium hand sizes, thus targeting the average user. Next to people with tremors, the ergonomics could be tested by people with no tremors. In further developments, an indication of different sizes is needed. Parts of the BEAM will be available in small, medium, and large sizes. For the finger wearable, this is also necessary. The evaluation of the last prototype showed that the participant's hands were too small for the wearable, which created a displacement from the splint (chapter 6.2). It is essential to gain more insights into the dimensions between the joints in the Dutch population.

- Req 1.2.7.1 The device does not give uncomfortable press points at the joints for 8 hours of use.
- Req 1.2.7.5 - The wearable is available in x sizes.

Ergonomics handpiece
The flat surface where the splints connect goes underneath the handpiece. This surface needs optimization, especially in the fit underneath the handpiece. The next step could be to research how thin the surface can be, how the splint design will integrate into the handpiece, and how comfortable the splints will be after long periods of use, especially in terms of the placement of the surface.

Donning and doffing
User tests have to show how the donning and doffing experience is from the finger wearable. Elastic bands hold the splints at the right spot. The fingers must go through these elastic bands when donning the wearable.

Working principle
The working principles combine the spring steel splints and the silicone. The splint stands in a natural finger position; when the user bends through the splints, the splints give a counterforce, suppressing the tremor. Further research should focus on the amount of suppression that is required. Also, an opportunity could be to provide different suppression types. People with mild finger tremors require a different amount in suppression which may show a different optimal suppression type.

- Des 1.1.2.13 - The splint design suppression is adjustuble to the amount is needed per user.

Durability working principle
A requirement is that the life span of the splint's working principle is two years. So the suppression needs to work for two years. With spring steel, it could be possible that the steel becomes weak after a certain amount of time. Further testing of the spring steel fatique strength could show whether it is durable enough for two years worth of suppression

- Req 1.1.2.12 - The working principle gives enough suppression for a lifetime of two years.

Handpiece
The finger wearable can be worn without the handpiece connection when the user does not need the orthosis. So another connection can be added to the finger wearable. For the version without the orthosis, it is important to focus on making the clip small and easily usable.

- Req 1.2.8.3 - The wearable provides a solution to use the finger wearable on its one without the use of the orthosis.

Splints with spring steel
The current splints exist out of silicone and spring steel. It would be interesting to research if a plastic with a high shore, so hard plastic, could replace the spring steel. Springs steel works with the working principle of counterforce. When plastic is used, little splints with a high stiffness could be included in a splint from soft plastic. A connex printer can print differently, so hard plastic could be placed in the soft plastic. This could create suppression and is more durable than the spring steel solution. See figure 86 for the solution with plastic.

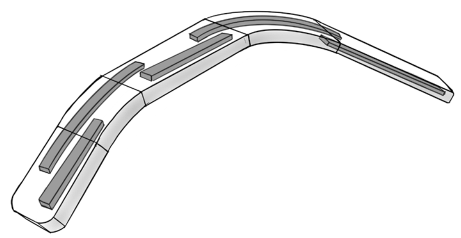


Figure 86: plastic splint

Amount of suppression
The silicone splint prototype is tested with three participants. These participants showed promising results for the use of silicone splints with spring steel. However, testing with more people with a finger tremors is important.

Finger tremor
An overall assesment shows that most people do not suffer from a finger tremor exclusively. In most cases the finger tremor presents itself in combination withmultiple tremors in the same arm, especially by persons with an ET tremor. An opportunity could be that in Parkinson's disease, the tremor mostly begins in the fingers. It could be an interesting target group for the finger wearable. For people with Parkinson, primarily thumb tremors occur. This project focused on people with an ET tremor.

Modular for differetent DOFs
Several researches on finger tremors show that no finger tremor is alike. For some people, the finger tremor is present in all the fingers, for some only in the thumb, and for others, in the MCP joints for the four fingers. A wearable with modular splints that can be added or removed would allow the user to customize the finger wearable.
- Des 1.1.1.9 - The device is modular to different DOFs.

Costs
For the costs of the finger wearable, no prohibitive costs are foreseen. Ideally, the splints could be injection molded. However, injection molding becomes difficult because the spring steel is in the silicone splints in this design. Further opportunities lay in the silicone splints injection molded and the spring steel on top of the silicone splints; in this way, the spring steel is not in direct contact with the finger (see figure 87). Another cost focus point is the production of the fabric around the splints; the difficult production method could raise costs.

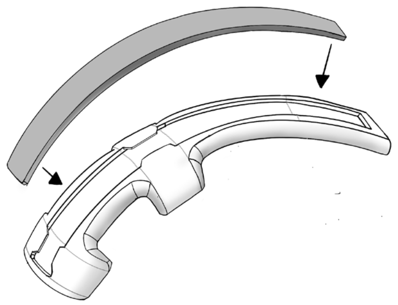


Figure 87: inside hand

Sustainability
There is no foreseen conflict in the sustainability of the wearable. The wearable does not make use of high-impact materials or production processes.
Materials cannot be seperated easily

Thumb suppression
The same silicone and spring steel are used for the thumb, index, and middle finger. When using the wearable, the suppression of the index and middle finger, compared to the thumb, feels different. The different form and length of the splint could cause this. Another cause could be the different placement and the muscle capacity of the thumb. It could be that the thumb needs more suppression.
- 1.5.1.1 The wearable splint of the thumb give ... N suppression.

Washable
In order to ensure sufficient hygenic capabilities, the steel splints are removable from the fabric in order to facilitate washing. Additional seperation of sillicone splints and fabric would be preferable for full washable features in future designs. Another solution could be that the fabric with the silicone splints can go in the washing machine together.
- Req 1.2.2.2 - The wearable fabric must be machine washable

Strectch and bending from fingers
When the fingers stretch or bend, the elastic band moves up and down the finger. The elastic bands can move a little bit, but the location of the splints needs to be secured. The last evaluation shows that the elastic bands are in the correct position when the user bends the fingers. When the fingers are stretched, the elastic band shifts upwards. The shifting effects of the splints could change the tremor suppression or the product's comfort. Further user tests must show if the shifting effects also occur by other people with a tremor.

6.4 Project evaluation

This project has been an journey of exploration and discovery. It started as a simple desire for extra research for a finger tremor wearable within STIL, but eventually became my graduation project. The initial goal was to investigate new solutions for finger tremors, as there was limited research and understanding of the condition.

The design process was challenging, as it required multiple iterations and discussions to establish a clear design scope and direction. However, conducting user tests with individuals who suffer from finger tremors was incredibly enlightening and helped to better understand their needs and desires. Seeing the positive impact that a finger wearable could have on their lives was truly inspiring.

Throughout the project, I learned the importance of quick prototyping and fast iteration. Whether it was using Fusion for 3D modeling or working with the sewing machine, I found the process to be enjoyable and constantly yielding new insights. For example, my initial assumption was that silicone splints could provide enough damping, but multiple iterations showed otherwise, leading to further prototyping.

Documenting the prototypes and keeping track of findings was crucial and was done using Miro. The two-week demo meeting with STIL allowed me to present my documentation and conclusions. The final prototype brought together ergonomics, appearance, and usability, and serves as a foundation for future developments within STIL

In the end, I believe the goal of exploring new solutions for people with a finger tremor is a success.

6.5 Acknowledgements

This project has not been the same with the guidance and coaching from the people involved. In this chapter, I would like to thank the people who have helped.

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The user tests have been of great value for my graduation project. Therefore, I want to thank all the participants for their honest opinion and time during the user tests. Their stories have resulted in the final prototype. Additionally, a thank you to Lucas for arranging and conducting the user tests and for the productive discussions that followed, this discussion have been of great value.

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