# Final Report
# Hand Tremor Stabilizer

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## Executive Summary

The Hand Tremor Stabilizer project represents a significant advancement in assistive device technology, aimed at improving the lives of individuals affected by hand tremors due to conditions such as essential tremor or Parkinson's disease. Throughout the design process, our team engaged in a comprehensive approach that included rapid prototyping, iterative testing, and direct feedback collection from potential users. This process was instrumental in refining the device to meet specific user needs effectively.

Key customer requirements that guided the design of the Hand Tremor Stabilizer included ease of use, portability, washability, accuracy of motion control, comfortable grip, breathability, a natural feel during use, and affordability. To meet these specifications, the device was designed as a wearable wrist brace/glove that incorporates a novel damper mechanism. This mechanism is specifically engineered to detect and suppress unintended tremor movements in the fingers and wrist, thereby enabling smoother and more controlled writing and other fine motor activities.

The functionality of the Hand Tremor Stabilizer was validated through a series of pilot tests, including spiral line tracing, line tracing, and sentence writing tests, coupled with qualitative feedback from initial users. These tests demonstrated a notable improvement in writing accuracy among participants, without hindering the natural writing process. Moreover, the device was found to be effective in dampening tremors, thereby confirming its potential to significantly enhance the quality of life for individuals with hand tremors.

## Introduction

The Hand Tremor Stabilizer project is to make a significant impact on the lives of millions of individuals grappling with the functional limitations imposed by hand tremors. With an estimated 7.5-8 million people in the United States affected by these rhythmic tremors, it has become increasingly evident that a solution is needed to help these individuals regain control over their daily lives. These tremors, which affect various aspects of life, including tasks as fundamental as writing, pouring, or even using utensils, have necessitated a transformative approach to their management.

This project endeavors to fill a crucial void in existing tremor management strategies. While various devices and treatments have sought to alleviate tremors in diverse ways, the focus on finger tremors, which is often overlooked, represents a pivotal aspect of the Hand Tremor Stabilizer's mission. The existing landscape of tremor management primarily centers on palm stabilization, leaving a significant gap when it comes to mitigating tremors occurring in the fingers and affecting fine motor control. By specifically targeting this unmet need, the Hand Tremor Stabilizer project aims to offer an innovative solution that significantly enhances stability, hand control, and grip for individuals afflicted by hand tremors when writing or utilizing small instruments.

As we delve deeper into the intricate mechanisms and designs behind the Hand Tremor Stabilizer, it becomes clear that this project is not just an advancement in tremor management but a step towards enhancing the overall quality of life for those it serves. By focusing on the intricate and complex nature of hand tremors and leveraging insights from existing research, this project aims to provide a newfound sense of independence and empowerment to individuals who have long been hindered by the disruptive impact of hand tremors on their daily routines.

With the Hand Tremor Stabilizer project, we stand at the threshold of innovation, ready to redefine the standards of tremor management and restore a sense of normalcy to the lives of countless individuals affected by this condition. This project serves as a beacon of hope for the enduring human spirit, demonstrating our unwavering commitment to addressing the challenges that tremor-afflicted individuals face daily.

**Background**

The clinical relevance of the Hand Tremor Stabilizer is underscored by the prevalence of essential tremor (ET) in the United States, affecting approximately 7 million individuals, with an additional 0.5-1 million experiencing various forms of rhythmic tremors, resulting in a substantial 2.4% of the U.S. population grappling with these conditions [1]. ET is acknowledged as one of the most common movement disorders, with incidence rates escalating in correlation with age, further emphasizing its impact on a broad demographic [1]. The clinical significance is through the profound challenges faced by those afflicted, as tremors profoundly hindered fundamental daily tasks such as writing, pouring, using utensils, and various routine activities [7].

Essential tremors exhibit frequencies ranging from 6 to 12 Hz, distinguishing them from Parkinson's disease-related tremors, which typically span between 3 and 6 Hz [7]. The underlying pathology of ET is associated with cerebellar malfunction, affecting the initiation and acceleration of joint movements [7]. Current strategies for tremor management encompass pharmacotherapy and surgical procedures, although each approach has its distinct limitations. Pharmacological interventions, primarily Propranolol, stand as the frontline therapy against tremors but exhibit varying effectiveness, with 30% of patients not responding optimally to the treatment [8]. Surgical methods, such as deep brain stimulation (DBS), entail inherent risks and are applicable to only a fraction of eligible patients [8].

Wearable tools like the GyroGlove and the Wearable Tremor Suppression Glove (WTSG) are part of the tremor treatment environment. These devices address the need for tremor suppression but primarily focus on the palm, omitting the mitigation of tremors in the fingers, a key target for the Hand Tremor Stabilizer [4]. GyroGlove employs a mechanical gyroscope to reduce tremor motion, mounted on a fabric strap worn on the hand [4]. Meanwhile, Project Emma, another innovative device, employs wrist-worn technology to introduce vibrations and counteract the erroneous signals sent to the brain [4]. However, these devices, although valuable, have shortcomings, with the continuous vibration emitted by Project Emma potentially causing discomfort for the wearer, and the GyroGlove slowing down voluntary hand movements [4]. Another device, known as (WOTAS), focuses on suppressing tremors in the forearm and wrist but does not address finger tremors effectively, and it may be considered bulky for some users [4].

The Hand Tremor Stabilizer aims to introduce a novel approach to tremor management by concentrating on finger tremor suppression, a pivotal and unmet need. As this project progresses, it is crucial to explore various mechanisms and designs, inspired by the diverse range of solutions documented in the literature. These existing devices employ strategies such as using soft actuators and pressure sensors to control tremor-induced movements. In particular, (WOTAS) introduced the concept of active and passive control modes, revealing the potential for significant tremor reduction [8]. Additionally, the emergence of non-invasive treatments like High-Intensity Focused Ultrasound (HIFU) showcases innovative approaches to tackling medically refractory ET [8].

Hand Tremor Stabilizer is composed to address the unmet need of finger tremor suppression, inspired by the clinical relevance and the limitations of current treatments. The diversity of mechanisms and devices explored in existing literature underscores the opportunity for innovation and the potential to enhance the quality of life for millions of individuals affected by hand tremors.

**Estimated Market Potential**

According to the National Library of Medicine (NLM), the number of people worldwide that were affected by essential tremor in 2020 was around 24.91 million people [12]. For our market, we are mostly looking into the people that live in the US, and also according to NLM, in 2012 there were 7 million people affected by hand tremors. That included people affected by both parkinsons and essential tremor (ET). Of those people, we are looking into the number of people that would also address themselves as creative. This would narrow down the market. In a survey from Pew Research in 2004, 57% of Amercans self-identify as either studying, practicing, or doing some sort of artistic activity in which 26% of those people are over the age of 50 [5]. The study that dealt with essential tremor designated the age of prevalence as 40, and so if we combine these two studies, then we can infer that about 1 million people in the US are artistic with hand tremors. Of those there are probably only around 10% of the people that would be excited to use our product, and that would be a total obtainable market as 100,000. This device would then be highly specialized for a small population of individuals.

**Preliminary Patent Search**

In our patent search, we've identified potential intellectual property concerns related to specific devices or the goals they aim to achieve, which could pose risks to our Hand Tremor Stabilizer project. Several claims from different patents align with aspects of our device's design:

One of the patents discovered pertains to an exoskeletal rehabilitation device for the index finger, a concept somewhat similar to our tremor suppression device design. To mitigate the risk, we need to ensure that our design distinctly focuses on the wearable tremor suppressor's intended purpose, differentiating it from the therapeutic goals of the finger rehabilitation device. In case our device incorporates an electronic control system, we should incorporate unique components like soft actuators to sidestep the patent's claims.

Another patent we encountered covers an exoskeletal rehabilitation device for the index finger, resembling the core purpose of our Hand Tremor Stabilizer. To address this concern, our design should prominently feature distinctive elements that set it apart from the patented device. Additionally, if our intended control method resembles the patent's claims, we should consider modifications to establish clear differences.

Furthermore, our search unveiled a patent involving an exoskeletal glove device with elements like a glove-shaped shell and finger joint control. While our device may include some of these elements, such as controlling finger movement, our device's primary function doesn't necessitate a glove. To avoid potential infringement, we must ensure our design doesn't align with the patent's structure. Also, the patent claims a fixing case for the actuator, an option of our design; we should incorporate unique mechanisms to distinguish our approach and reduce infringement risks.

We also encountered a patent relating to a wearable device featuring gyroscopic elements. While this patent is unlikely to affect our design due to fundamental differences in gyroscopic technology, we must ensure that our control means for managing tremor suppression are unique and well-differentiated from this patent's claims.

Our design should be reviewed meticulously to ensure that it doesn't resemble the patented claims related to gesture recognition systems and that our pressure sensors are used distinctly to avoid any interference.

By proactively addressing these potential infringement risks through design modifications and the incorporation of distinctive features, we aim to navigate the patent landscape while advancing our Hand Tremor Stabilizer project, contributing to improving the quality of life for individuals affected by hand tremors.

**Objectives**

The objective of the Hand Tremor Stabilizer is to develop a wearable device that effectively suppresses hand tremors through the wrist and fingers to enable people suffering from tremors to write or express creativity with similar movements (ex: drawing, painting, stylus). The device is intended to be worn for approximately 1 hour, which would be the time of creative flow. The device will be easy to use, portable, washable, and breathable for maximum comfort on the part of the user. Soft actuators and pressure sensors will be incorporated to provide natural and accurate motion control, using equations behind the coding of the pressure sensors to determine the reasonable range of spontaneous tremor forces as opposed to forces due to conscious exertion of force. This will not obstruct the initiation of intentional movement, but instead suppress unintentional movement due to tremors. The device will be cost-effective and enhance the quality of life for individuals with hand tremors.

**Indications for Use**

The Hand Tremor Stabilizer is intended for use in skeletally mature adults experiencing hand tremors, such as essential tremor or Parkinson's disease-related tremor, aiming to stabilize hand movements and enhance hand strength. We are designing a non-invasive device to suppress tremors with a focus on the fingers for users intending to draw, write, paint, and hold other small instruments.

**Customer Requirements**

The Hand Tremor Stabilizer project is grounded in a deep understanding of the needs of individuals afflicted with hand tremors, aiming to offer an innovative solution that significantly enhances their quality of life. The design and development process was meticulously guided by the following key customer requirements:

1. **Easy to Use**: The device must be intuitive and straightforward to operate, allowing users to effortlessly incorporate it into their daily routine without extensive training or technical assistance.
2. **Portable**: It should be lightweight and compact, enabling users to easily carry and use it both at home and in public settings, thus supporting a wide range of activities.
3. **Washable**: Considering the need for regular use, the device must be easy to clean and maintain, ensuring hygiene and durability over time.
4. **Accuracy of Motion**: The stabilizer must significantly improve the precision of hand movements, particularly in tasks that require fine motor skills, such as writing or drawing.
5. **Grip**: It should enhance the user’s ability to hold and manipulate objects, thereby increasing confidence and independence in daily tasks.
6. **Breathable, Natural Feeling**: Comfort is paramount; thus, the design incorporates breathable materials that maintain a natural feeling, avoiding any sense of constraint or discomfort.
7. **Affordable**: To ensure accessibility, the device must be economically feasible for the target user group, without compromising on quality or functionality.

**Engineering Metrics**

To quantitatively evaluate how well the Hand Tremor Stabilizer meets the identified customer requirements, the following engineering metrics were established, each rated on a scale of 1 to 10:

1. **Cost**: Measures the affordability of the device in relation to its target market, aiming for a balance between cost-effectiveness and quality.
2. **Weight**: Evaluates the device's portability and ease of use over extended periods, ensuring that it does not become a burden to the user.

3. **Material**: Assesses the quality, comfort, and durability of the materials used, ensuring they contribute to a breathable and natural feeling during use.
4. **Range of Motion**: Quantifies the device's ability to support natural hand movements while suppressing unwanted tremors, crucial for tasks requiring fine motor skills.
5. **Durability**: Measures the device's ability to withstand regular use and cleaning, maintaining its functionality and appearance over time.
6. **Size**: Considers the device's adaptability to various hand sizes, ensuring a comfortable and secure fit for a wide range of users.
7. **Material Breathability**: Evaluates the comfort and skin-friendliness of the materials used, particularly during prolonged use, to prevent discomfort and skin irritation.

**Project Management**

**Timeline (Fall Quarter)**

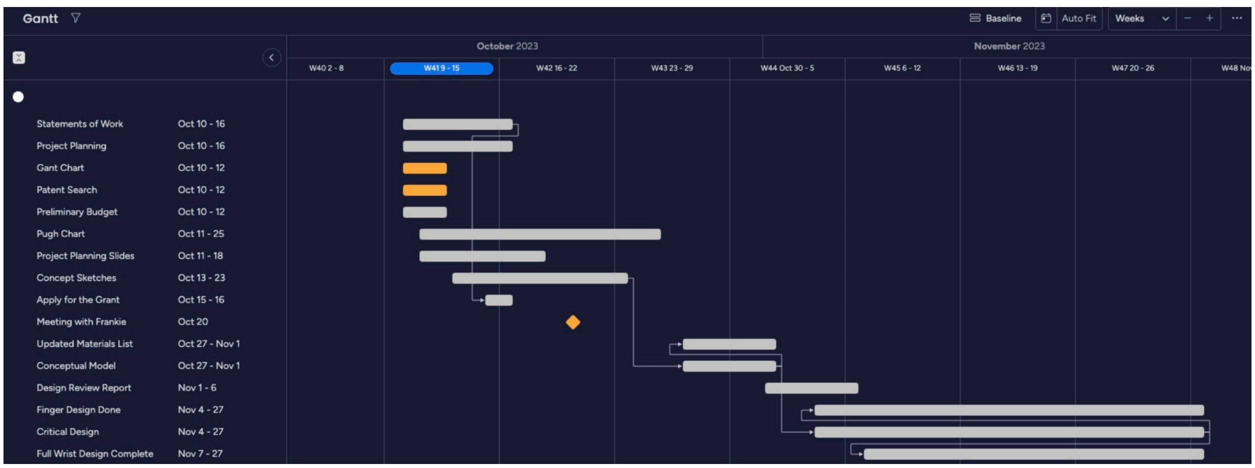


Figure 1: Gantt Chart made in monday.com illustrating the project timeline

Contents of the Gantt Chart include the following:

1. Pugh Chart and Concept Sketches
   - Pugh Chart takes three concepts (and accompanying concept sketches) and analyzes each concept relative to a series of stipulations outlined in house of quality (Appendix A)
2. Applying for Funding Grants
   - Proof of concept finalized and presented for funding
3. Meeting with Stakeholders
4. Material Procurement
   - Testing (tensile, elasticity, water permeability, etc) testing done on materials to ensure best alignment with customer requirements
5. Conceptual and Critical Design
   - Draft of design
6. Full Wrist Design Completion
   - Executed, final draft of design
7. Design Review Report

A detailed timeline outlines the duration of each task, starting from October 10, 2023, and extending into late November 2023. Key milestones include the completion of concept sketches, applying for grants, meeting with stakeholders, and finalizing the design as explained above.

**Timeline (Winter Quarter)**

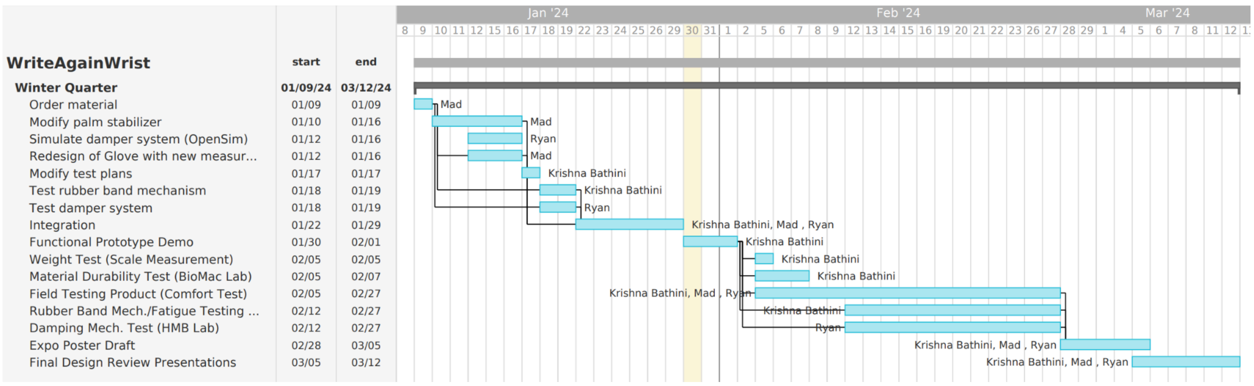



Figure 2: Gantt Chart made in teamgantt.com illustrating the project timeline

Contents of the Gantt Chart include the following:

1. Order Material (Mad)
   -Tasked with acquiring necessary materials for project development.
2. Modify Palm Stabilizer (Ryan)
   -Alterations to the palm stabilizer for improved functionality.
3. Simulate Damper System (OpenSim) (Mad)
   -Simulation work for the damper system using OpenSim software.
4. Redesign of Glove with New Measurements/Design (Krishna)
   -Leading the redesign process of the glove, incorporating new measurements and design elements.
5. Modify Test Plans (Krishna)
   -Responsible for revising test plans to align with project developments.
6. Test Rubber Band Mechanism (Ryan)
   -Conducting tests on the rubber band mechanism to assess performance.
7. Test Damper System (Krishna, Mad, Ryan)
   -Testing and evaluating the damper system.
8. Integration (Mad)
   -Focusing on integrating various components.
9. Functional Prototype Demo (Mad)
   -Presenting a functional prototype for demonstration purposes.
10. Expo Poster Draft (Krishna, Mad, Ryan)
    -Preparing a draft for the Expo poster.
11. Final Design Review Presentations (Krishna, Mad, Ryan)
    -Presenting the final design review.

A detailed timeline outlines the duration of each task, starting from January 09, 2023, and extending into late March 2024. Key milestones include the completion of integration, functional prototype demo, testing, and the final design review presentation.

**Budget**

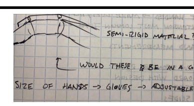
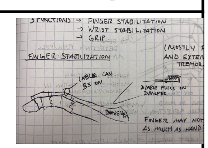
Table 5: Table of components, purpose, associated tasks, unit, quantity, and total cost for Hand Tremor Stabilizer.

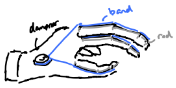
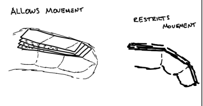
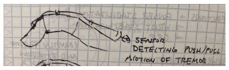
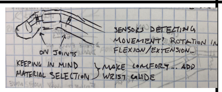
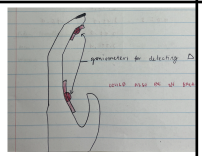
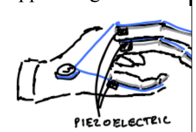
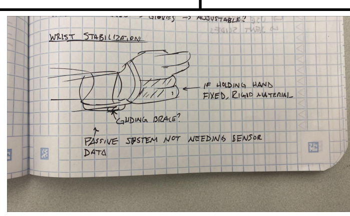
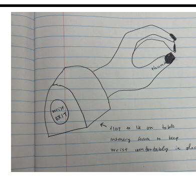
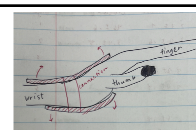
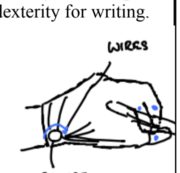
| Item Description | Purpose | Associated Task | Unit | Quantity | Planned Cost/Unit | Total Cost |
|---|---|---|---|---|---|---|
| Velcro | Fasten the brace | Material procurement | rolls | 2 | 10 | 20 |
| Rigid Tissue Nylon Fabric | For Brace | Material Procurement | yard | 2 | 15 | 30 |
| Damping Mechanism | Reduce Tremor | Component procurement | unit | 1 | 120 | 120 |
| Breathable Material | Comprising Structure | Component procurement | Ft sq | 1 | 7 | 7 |
| Bike Cable | To translate finger movements to damper | Component procurement | Ft | 1 | 1.20 | 1.20 |
| Bike Cable Sheath | To reduce friction between cable for smooth motion | Component procurement | Ft | 1 | 5 | 5 |
| Filament for 3D Printing | Plastic for 3D printing components | Material procurement | Roll | 2 | 40 | 80 |
| Matlab | Programming electrical components | Component procurement | N/A | N/A | 0 | 0 |
| | | | | | **TOTAL** | **263.20** |

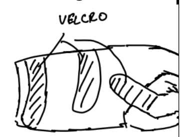
**Morphology**

There were three main functions that we were looking into with this design. The first was stabilizing the wrist. Second was the tremor detection and the finger tremor suppression in the fingers. The following is a table of the design morphology that was put into the design of the device.

Table 1: Morphology table of concepts

| **Morphology Table** | | | | | | |
|---|---|---|---|---|---|---|
| Product: Hand Tremor Stabilizer | | Organization Name : | | | | |
| Function | Concept 1 | Concept 2 | Concept 3 | Concept 4 | Concept 5 | Concept 6 |
| Stabilize Fingers | Elastic bands suppress tremors in the fingers by offering opposing resistance to the erratic movements. As the fingers shake, the bands stretch and contract, countering the tremors with an opposing force that stabilizes the fingers and mitigates the unintended movements, allowing for smoother and more controlled writing. Once a set position is set (writing position) then the bands will be resistant to sudden movements till the resistance is released. | Layer jamming can be employed to stabilize the fingers by integrating multiple layers of materials that exhibit increased friction as they compress. As the finger experiences tremors or unintended movement, these layered materials dynamically contract, creating resistance and effectively restricting finger motion, thus contributing to stabilization. This frictional feedback mechanism helps counteract involuntary | Pressure sensors that are calibrated to the natural range of tremor frequency and force output and hinder movements less than the max force output and enable movements all greater than that max force output. Would utilize soft actuators to support/hinder the movement. (combined with tremor sensing) | Employ a system (pressure sensors) that senses individual finger tremors and suppresses them when they are not in conjunction with another finger tremor. Writing utilizes fingers working together so all individual movement (aside from thumb) can be prohibited with soft actuators. (combined with tremor sensing) |   Using a semi-rigid material to suppress movement. Compliant systems use semi rigid movement to recreate mechanical systems using one continuous material. This may be an option, however lengthening of the finger on the top of the hand when flexing may inhibit the material |   Damping system connected to exoskeleton style brace. Passive system using dampers to reduce the effect of the tremor. There would be minimal sensors and minimal active reduction/ strength increase, but passive tremor suppression may be easier to create. |

| | | | | | | |
|---|---|---|---|---|---|---|
| |  | hand movements, enhancing control and precision when using writing instruments.<br> | | | | |
| Tremor Detection | <br>Using cable/cord attached to mechanical sensor to detect tension in cable to detect movement in finger. If the sensor is below a threshold, then the device will detect it as a tremor. Keeping tension in cable may be hard considering extension of the finger may not "push" back on sensor | <br>Similar idea to the cable/cord, but the idea is to use side mounted rotational sensors to detect movement. May detect extension better, but mounting on fingers in the middle i.e. middle and ring finger mount may inhibit movement and be | <br>Goniometer type device between the metacarpals & proximal phalanges, and at distal & intermediate phalanges to detect the extension-flexion ranges that are within tremor-range (suppress) and extension-flexion angles that are indicative of an intentional force (support) | Pressure sensors at the fingertips to detect the reasonable force output for tremor (suppress) and whether or not a movement is intentional(support) | Accelerometer based tremor detection:<br>By embedding sensitive accelerometers near the stabilized fingers, this concept detects tremors through rapid changes in acceleration. The recorded data is processed by an onboard microcontroller, which then adjusts the device's stabilization mechanism, such as tightening elastic bands or activating resistance mechanisms, to counteract and suppress the tremors.<br> | Elastic Band deformation sensing:<br>Utilizing deformation sensors like strain gauges or piezoelectric sensors within the elastic bands, this method passively detects tremors as the bands deform or stretch beyond a predefined threshold. When deformation is sensed, the device autonomously adjusts its stabilization level, either increasing or decreasing tension in the bands according to the extent of deformation, effectively suppressing tremors.<br> |
| Wrist Stabilization | <br>Using a rigid glove to support the wrist in one position along with the ring finger and pinkie in a single position. Using a gliding material for the contact with the table. | | <br>Block that goes around the wrist that is weighted to prevent pronation/supination | <br>Semi-rigid board that goes up the back and front of the hand to provide some stability that prevents flexion-extension | Micro adjustable wristband with ratchet mechanism:<br>This concept integrates a wristband with a micro-adjustable ratchet mechanism, allowing users to secure it around their wrist and fine-tune support levels incrementally, customizing the wrist's stability without complicating the lightweight design, ensuring uninterrupted dexterity for writing.<br> | Velcro strap wrist support:<br>Incorporating Velcro straps, this design offers a lightweight wrist support system, enabling users to effortlessly tailor their wrist's support by adjusting the straps, creating a secure and comfortable fit; the straightforward application and removal process prioritizes user-friendliness without adding extra |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | weight.   |

| | | | |
|---|---|---|---|
| Team member: Ryan Herrmann | Team member: Madeleine Beaupre | Prepared by: | |
| Team member: Krishna Bathini | Team member: | Checked by: | Approved by: |

The morphology included three designs with the combining of the ideas. The first was using cables and a piezoelectric detection system to actively suppress tremors. The second was using dampers on cables to passively suppress tremors, and the third was using layer jamming technology to suppress tremors. Layer jamming would be a passive suppression technology as well.

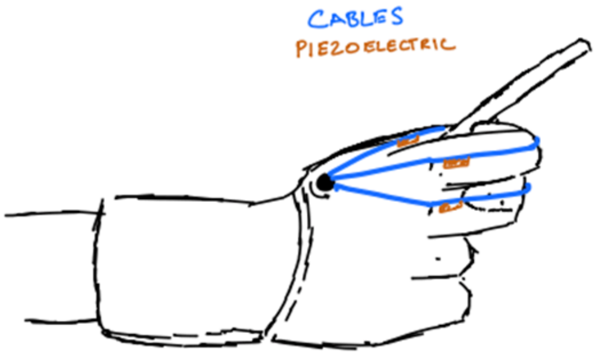



Figure 3: piezoelectric cables diagram

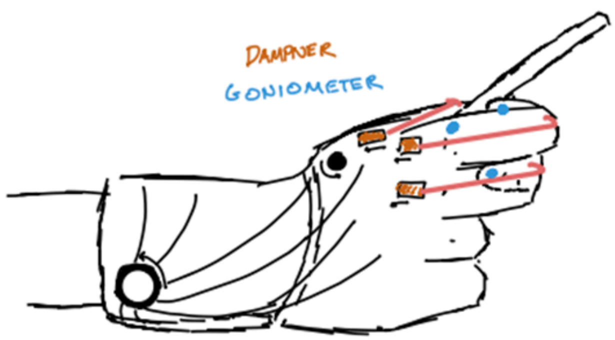



Figure 4: damping goniometer diagram

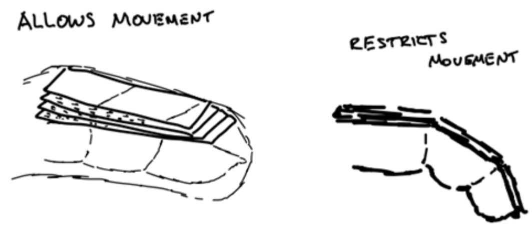



Figure 5: friction jamming diagram

**Concept Evaluation (Pugh Charts)**

*We did not pursue anti vibration mechanisms due to feasibility and scope, so we pursued layer jamming instead since it was similar in concept. A new Pugh Chart will be used in Quarter 2 to re-evaluate the layer jamming concept which failed as layer jamming in initial prototype.*

| | Weight | Cables | Dampner | Layer Jamming | Anti-Vibration Tool |
|---|---|---|---|---|---|
| Stabilize Fingers | 40 | 0 | 1 | 1 | -1 |
| Tremor Counteraction | 35 | 0 | 1 | -1 | 1 |
| No resistance to intentional motion | 25 | 0 | 1 | -1 | 0 |
| Totals | | 0 | 100 | -20 | -5 |

| | Weight | Dampner | Cables | Layer Jamming | Anti-Vibration Tool |
|---|---|---|---|---|---|
| Stabilize Fingers | 40 | 0 | -1 | 1 | 1 |
| Tremor Counteraction | 35 | 0 | -1 | 1 | 1 |
| No resistance to intentional motion | 25 | 0 | -1 | -1 | 0 |
| Totals | | 0 | -100 | 50 | 75 |

To copy for a new decision, File->"Make a Copy". To learn more, visit: http://leansoftwareengineering.com/pugh-decision-matrix/

| | Weight | Layer Jamming | Cables | Dampner | Anti-Vibration Tool |
|---|---|---|---|---|---|
| Stabilize Fingers | 40 | 0 | -1 | -1 | -1 |
| Tremor Counteraction | 35 | 0 | 1 | -1 | 1 |
| No resistance to intentional motion | 25 | 0 | 1 | 1 | 1 |
| Totals | | 0 | 20 | -50 | 20 |

| | Weight | Anti-Vibration Tool | Cables | Dampner | Layer Jamming |
|---|---|---|---|---|---|
| Stabilize Fingers | 40 | 0 | 1 | -1 | 1 |
| Tremor Counteraction | 35 | 0 | -1 | -1 | -1 |
| No resistance to intentional motion | 25 | 0 | -1 | 0 | -1 |
| Totals | | 0 | -20 | -75 | -20 |

Figure 6. Pugh matrix comparing four design parameters and four possible designs

Table 2: Table showing the sums of each design's weighted values

| SUMS | cables | dampener | anti-vibration | layer jamming |
|---|---|---|---|---|
| | -100 | -25 | 90 | 10 |

Figure 2 shows the averaged pugh matrix of all three team members. The Pugh matrix weighted values were summed and included in Table 2 which illustrates the final weighted totals of each possible design. Table 2 suggests that the anti-vibration mechanism is the strongest candidate by far with a weighted total of 90. Anti-vibration mechanisms excelled in tremor counteraction compared to all designs except layer jamming, which can be used in conjunction with anti-vibration mechanisms if needed. Anti-vibration mechanisms would absorb the displacement caused by the tremor and thus result in a lessened force output due to tremor, enabling smooth writing and drawing. Alternatives, such as cables or layer jamming would impair users' intentional motions and require more strength to overcome the constant counteraction in place. This would be detrimental and frustrating to users because loss of strength is a top symptom of tremor patients, and strength would be needed to overcome the constant counteraction or rigidity of layer jamming or cables.

Another aspect of anti-vibration mechanisms is that there are many different varieties that come in passive and active forms. To best suit our users' needs, an active anti-vibration mechanism could be calibrated to each user's frequency of tremors, allowing the vibration isolation mechanism to hinder tremor motions but allow standard motions associated with writing. This preserves patient autonomy and also would not require the patient to re-learn how to write with the device, which might have been a downside to layer jamming or cables which could impair movement and require more strength to operate. Anti-vibration mechanisms also can be paired with high-friction coatings, which would unify finger tremors by passively preventing the tremor via friction. If the need arises, anti-vibration mechanisms could be paired with a dampener, and both mechanisms could be stored in the wrist brace for comfort and ease of use.

**Conceptual Model**

*Layer jamming was produced and tested in strips that were intended to run along the back of the fingers (as opposed to surrounding the entire circumference of the finger as mentioned below), and it did not meet requirements for size or coefficient of friction sufficient to restrict tremor movement. Dampers were evaluated in winter quarter to replace this initial idea.*

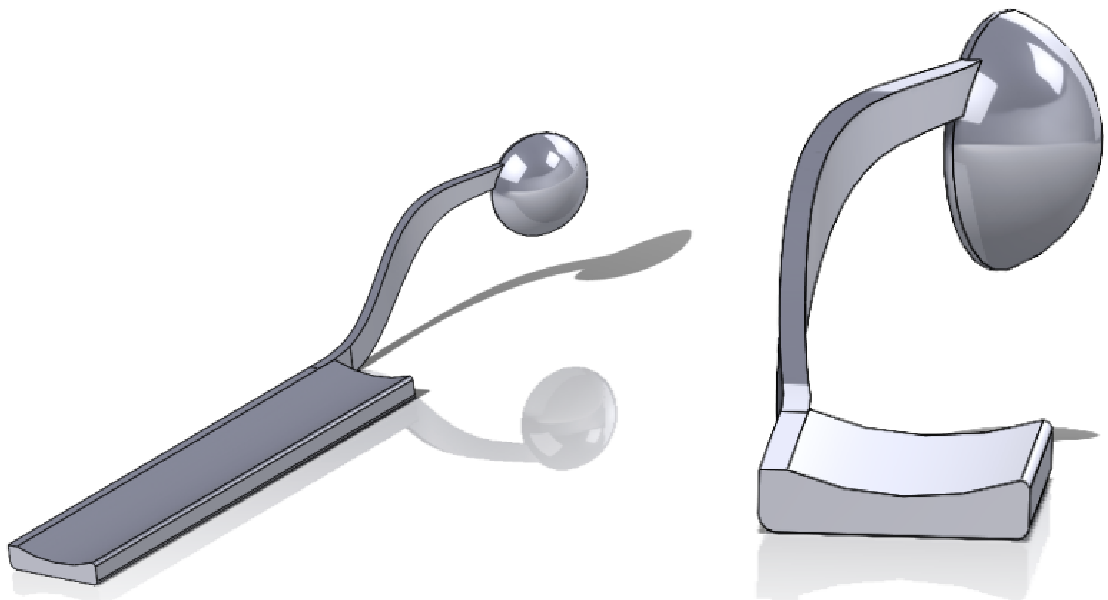


Figure 7: Solidworks models of rigid wrist piece

Figure 8: layer jamming diagram

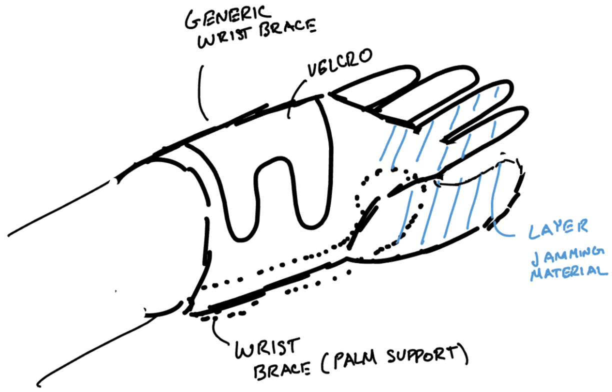



Figure 9: combined functional ideas

The Hand Tremor Stabilizer, designed for skeletally mature adults with hand tremors like essential tremor or Parkinson's disease-related tremor, aims to enhance hand stability and strength during daily activities. The model is created using SolidWorks and evolved from initial design concepts ranked using a Pugh chart. The device features a rigid wrist brace for ergonomic stability without hindering thumb movement, using layer jamming technology to stabilize finger movements when gripping a writing instrument. A half sphere at the palm enhances stabilization, and anti-vibration damping technology may be incorporated for further finger stability. A three-finger glove design is used to maintain natural feeling.

The above wrist piece diagram is one of the two functions of the device: stabilizing the wrist. This design was decided upon by reading scientific articles on tremors and the specific movements that are most common and their average frequencies and displacements. At the wrist, the most common tremor movement was flexion-extension, so this wrist piece shown above serves to prevent flexion and extension at the wrist when strapped to the hand. To ensure that the customers' ability to write will not be hindered by a rigid body, we practiced writing multiple sentences while under the observation of our teammates, who observed that there was no wrist movement needed to write the sentences. We also did this same experiment with a focus on each knuckle of the first two fingers and the thumb, which determined that layer jamming would be needed across the whole finger and would not impair intentional writing movements.

In our conceptual design, we incorporated layer jamming technology to stabilize the fingers when holding a writing instrument. Layer jamming is a cutting-edge tactile sensing and actuation technique that employs multiple layers with high-friction surfaces strategically positioned around the thumb, pointer, and middle fingers—the primary fingers in contact with the writing instrument. As the fingers bend, the layers respond by gradually closing the gaps between them, initiating a friction force that effectively halts finger movement illustrated in the third figure. This approach provides users with tactile feedback, enhancing stability and control when writing. By adjusting the parameters of layer jamming, such as friction levels and layer response speed, we can customize the user experience. Beyond writing, this technology promises to impact fields like wearable tech and haptic interfaces, providing new dimensions of control and tactile feedback for a wide range of applications. Our design will include layer jamming material surrounding the three fingers integrated with the wrist base design looking similar to a traditional wrist brace.

To collect data, we can conduct tests on displacement of motion of the layer jamming technology and strength tests for the brace material. Analyzing rigidity and flexibility at specific areas of the glove is also essential. The analysis revealed how components integrate and the practicality of certain technologies. It led to design modifications, such as allowing thumb movement for gripping the writing instrument and incorporating ergonomic features like the half sphere and ventilation for comfort.

This model's development will inform further design by enabling testing of its three functions: stabilizing fingers, countering tremors, and allowing intentional motion. This iterative process will involve making necessary modifications to improve finger and wrist stability through continued testing and analysis.

**FMEA**

Table 3: Functions and potential failures and repercussions

| Function Affected | Potential Failure Mode | Potential Effect(s) of Failure | OCC | DET | SEV | RPN | Cause of Failure | Recommended Actions | Responsible Person | Take Action |
|---|---|---|---|---|---|---|---|---|---|---|
| **Tremor Suppression in the wrist** | Wrist brace cracks or breaks | No Stabilization in the hand or function of entire device | 3 | 2 | 9 | 54 | Low Material Strength | Tensile testing? | Mad | Tensile tests performed and analyzed |
| **Tremor Suppression in the fingers** | Active damping system failure | Fingers lose stabilization | 2 | 2 | 8 | 32 | Damping system not effective | New damping technology (note this potential is if we take the route of active damping, the challenge of finding an active system that works is complicated, and this direction may not be continued to be developed on.) | Ryan | Measure Frequency Longevity Testing |
| **Stabilization of the hand** | Stabilization Dampers Fail | Fingers lose stabilization | 4 | 2 | 8 | 64 | Damping system not effective | New damping technology | Ryan | Measure Frequency |
| **Attachment of Device** | Brace on wrist falls off | Device comes undone | 2 | 1 | 9 | 18 | insecure attachments | better adhesive | Krishna | Fatigue and life testing |
| **Attachment of components** | Finger attachment to wrist come undone | Fingers become unattached | 2 | 1 | 9 | 18 | insecure attachments | better adhesive | Krishna | Tensile testing |
| **Suppression of intentional finger movement** | Brace for hand/fingers get stuck | Device suppresses intentional movements | 3 | 2 | 9 | 54 | hindered intentional movement | better design (mobility) smooth flexion | Mad | friction analysis of layers |

Most of the failures in our system would come from fastening the device on the person's hand as well as the motion of the damping. These failures since they would be passive, would be less about electrical failure and more with material failure.

**Detailed Design**

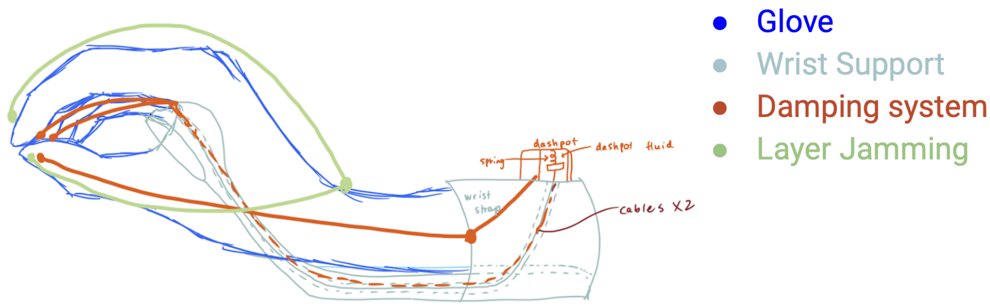



Figure 10: shows the overall design with four different functional components (Layer Jamming will be removed).

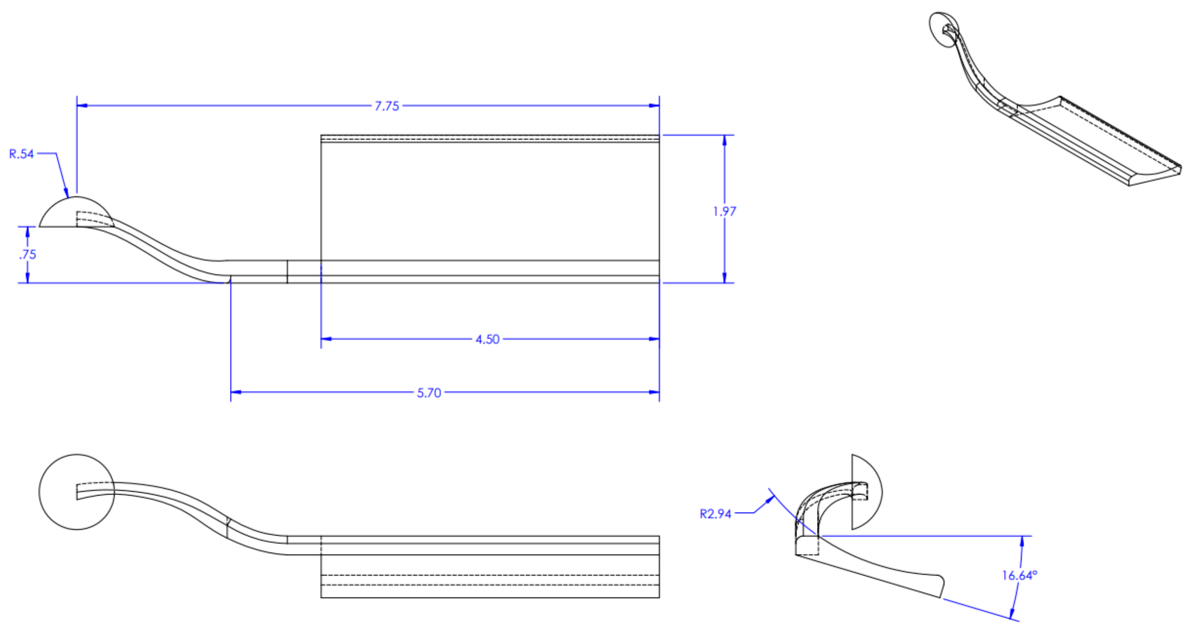



Figure 11: shows solid works drawing of rigid wrist piece.

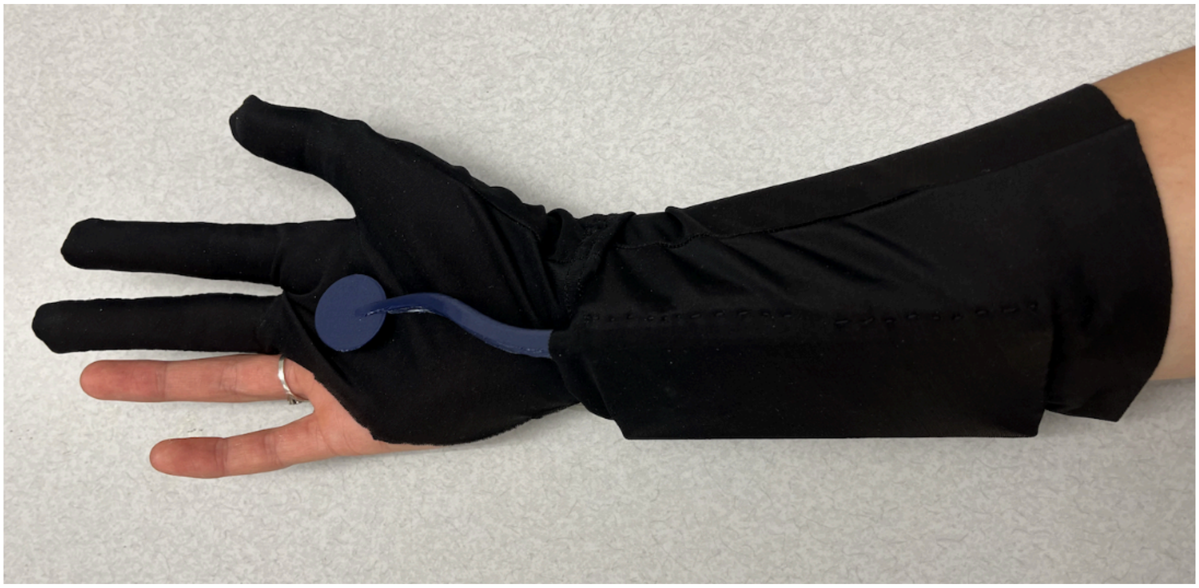


Figure 12: shows conceptual design prototype of glove with the above wrist piece inserted.

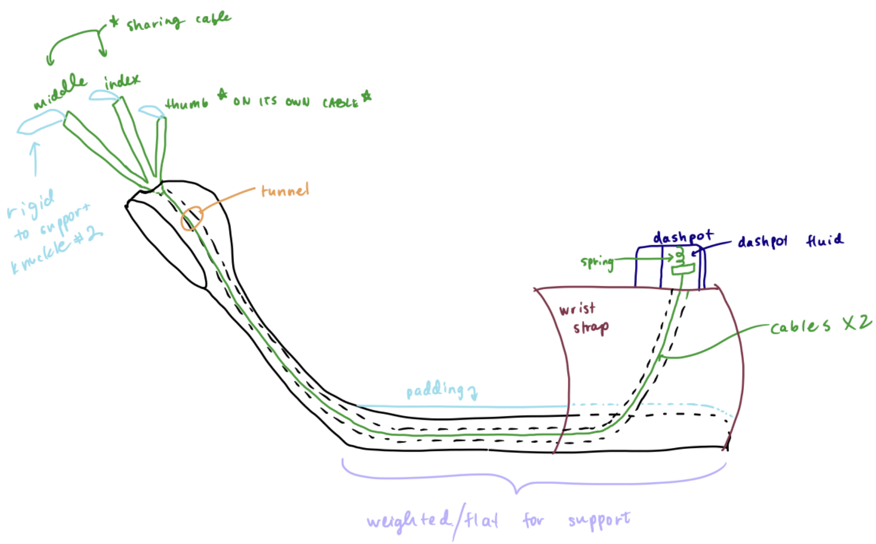



Figure 13: shows the functional components of the tremor stabilizer: the wrist strap (burgundy), rigid wrist piece (black), with emphasis on the damping system (green cables and blue dashpot)

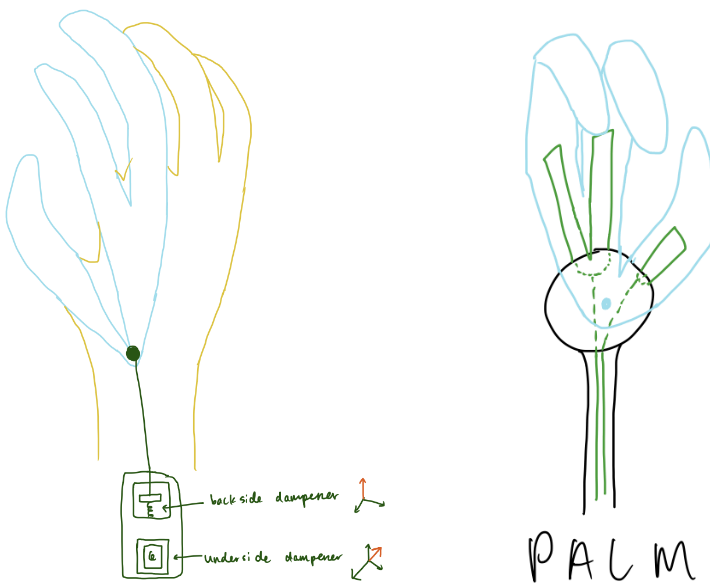



Figure 14: shows the cables (damping system) on the back of the hand (left) and palm (right)

Figure 10 shows the overall design with four categories of functional components: the glove, rigid wrist support, damping system, and friction jamming. The glove is intended to hold the rest of the functional components in place on the hand. In order to ensure maximum comfort, the glove is made of lycra, which is a breathable material used in athletic equipment. The glove will be made in three different sizes so as to support different anatomies of tremor patients. The part of the glove that covers the hand is connected to a wrist brace that houses the base of the rest of the functional components, with an insert for the rigid wrist piece. The glove is designed to slip on over an extended hand.

Figure 11 shows the rigid wrist support dimensioned in a CAD drawing. This is a small model and can be scaled for different sizing options. The flat bottom lays across the table under the user's wrist, preventing supination/pronation movement in the arm, and the angled extension piece and dome provide support for the center of the palm of the hand. The dome is raised above the flat wrist support to provide the center of the palm a line of force to exert upon, lessening flexion/extension tremors in the wrist. This design is shown 3D printed and inserted into the glove in Figure 12.

Figure 13 illustrates three of the functional components of the design with emphasis on the damping system. Through the center of the rigid wrist piece, a tube houses the cables that run from the fingertips to the damping system on the wrist. This allows the cables to stay tucked out of the way of the user and diminish risk of tangling or malfunctioning. The damping system consists of a dashpot in viscous fluid, which provides resistance to the cable when force is exerted upon it. The cable runs through a fabric tube connected to the inside of the fingers of the glove and through the rigid wrist piece up to the damper stationed on the back of the wrist as shown in Figure 13 and Figure 14 (right). This allows the damper in Figure 13 to control extension tremors. To control flexion tremors, Figure 14 (left) shows the backside damper connected to pieces of the glove on the thumb, index, and middle fingers. Within the glove in a fabric tube, cables run from the fingertips to the backside damper. This allows control of both flexion and extension in the fingers and reduces tremors in patients whilst allowing intentional smooth movements consistent with writing.

In conjunction with each other, these four functional design components aim to support each joint from the wrist to the fingertip in order to best support the tremor patient in writing. While suppressing tremors within the 3-12 Hz range, the tremor suppressing glove is designed to allow the patient to still execute intentional writing motions, giving them back their writing and drawing ability once again.

**Prototype Manufacturing Plans**

*Wrist stabilization brace*

The wrist stabilization component will be made in solidworks as a CAD design and will be made through rapid prototyping. Giving the ability to change and edit the specifications quickly. The initial prototype will be made for a specific hand and then edited after for various sizes that are yet to be determined.

*Surrounding Glove*

The glove will be sewn. It will include the hand as well as the wrist section. This will be done using a breathable fabric and a sewing machine. Like the wrist stabilizer, the glove will be initially designed around a specific hand and then edited for various sizes.

*Finger Stabilization Element - Damping Mechanism*

The finger stabilization through damping is created using the damper system located at the wrist. The bike cable is then connected to the cap of the damper and is routed through the 3D printed wrist brace and connected to the three fingers point finger joints. An addition of a sheath is to reduce skin irritation and sharp wire. A 3D printed box will be used to encase the damper system so that it is not exposed to the user. When the finger moves towards the palm, the bike cable will push against the damper, slowing the motion and requiring extra force to make fine movements to increase accuracy in movements of the fingers. The damper currently on the system is one way and we are looking to purchase a two way damper to control the movement of the fingers both in the flexion and extension direction. Currently the damper only suppresses movement in the flexion direction. In future plans a two way damper will be created and sized to fit the current design to allow for flexion and extension suppression.

Table 6: Device components, bill of materials, and resources needed for prototype manufacturing.

| **Component** | **Materials** | **Resources for Building** |
|---|---|---|
| Wrist stabilizer | PLA | 3D Printing through Innovation Sandbox |
| Sewn Glove | Elastic breathable fabric (lycra), thread | Sewing Machine |
| Dashpot | Damper, bike cable, sheath, 3D printed components | Super Glue / Sewing |

**Test Plan (Verification & Validation Testing)**

| Component | Test Name | Objective | Method | Criteria for Success | Equipment Required |
|---|---|---|---|---|---|
| **3D Printed Palm Stabilizer** | Cable Movement Test | Ensure smooth movement of cable through the stabilizer | Reprint the stabilizer with a larger hole for the sheath. Test the cable movement through this new design. | Cable moves smoothly without rubbing or friction. | 3D printer, redesigned stabilizer model, cable, sheath |
| | Damping Mechanism Test | Test cable's effectiveness in activating the damper | Evaluate if the cable properly pushes the damping mechanism when the fingers move. | Effective damping of finger motion, reducing movement speed by 50%. | Damper mechanism, cable, prototype glove |
| | Brace Angle Adjustment Test | Align the brace angle with the hand | Modify the angle of the brace in the stabilizer and test its alignment with the hand during writing tasks. | Brace aligns correctly with the hand, improving comfort and functionality. | 3D printer, modified brace model, prototype glove |
| **Damper (Dashpot)** | Oscillation Frequency Test | Ensure the damper slows down motion effectively | Test the frequency of oscillation with and without the damper to measure the reduction in movement speed. | Movement speed is reduced by 50% compared to normal tremor movements. | Damper mechanism, frequency measurement tools, prototype glove |

**Test Plan (User Testing)**

| Component | Test Name | Objective | Method | Sample Size | Data Analysis | Equipment Required | Pass/Fail Criteria |
|---|---|---|---|---|---|---|---|
| **3D Printed Palm Stabilizer** | Stability Test | Assess pressure stability | Have users perform a writing task and rate stability on a scale (Circle Tracing Test) | 5 users | User feedback analysis | Pen and paper, Spiral Template feedback forms | Stability rating ≥ 4/5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Comfort Test | Evaluate user comfort | Users wear the glove for 1 hour, then provide comfort feedback | 5 users | Comfort level analysis | Glove, timer, feedback forms | Comfort rating ≥ 3/5 |
| | Durability Test | Test material endurance | Repeated flexing of the stabilizer | 1 glove sample | Visual inspection for wear and tear | Glove, cycle testing (By hand) | No visible damage |
| **Damper System** | Motion Control Test | Measure tremor control effectiveness | Users perform a task requiring fine motor skills, then rate control effectiveness | 5 users | User feedback analysis | Fine motor skill task (Writing Sentences), feedback forms | Control rating ≥ 4/5 |
| | Response Time Test | Assess system's response to sudden movements | Users perform rapid movement tasks, observe system's response | 5 users | Observational analysis | Rapid movement task (e.g., Fast twitching of fingers), stopwatch | Movement gets slowed down by 30-40% |
| | Ease of Use Test | Evaluate the ease of operating the system | Users rate the ease of moving their fingers with the system | 5 users | User feedback analysis | Glove, feedback forms | Ease of use rating ≥ 3/5 |

*3D Printed Palm Stabilizer Tests*

The series begins with the Stability Test, where participants equipped with the glove undertake a writing task (spiral test). Their feedback on the stabilizer's ability to maintain hand stability during the task is collected and analyzed, aiming for an average stability rating of 4 or above to pass the test. Following this, the Comfort Test evaluates how the glove feels during extended use, with participants wearing it for an hour while engaging in various writing activities. Comfort levels are then rated, seeking an average rating of 3 or higher. The Durability Test pushes the palm stabilizer through flexing to simulate gripping and releasing, inspecting it afterwards for any damage. A lack of visible wear indicates a pass.

*Damper System Tests*
For the Damper System, the Motion Control Test assesses its effectiveness in controlling tremors through tasks that require fine motor skills. This test would include writing multiple sentences using the device.  Participants' ratings provide feedback on tremor control, with a goal of achieving an average rating of 4 or above. The Response Time Test measures how quickly the system reacts to rapid movements, aiming to reduce the response time by 30-40% compared to a finger tremor without the device.. The Ease of Use Test gathers participant ratings on the system's operability during various hand movements focusing on the damper system, with scores of 3 or higher indicating user-friendly operation.

**Testing Data and Analyses**

The pilot study was designed to assess the effectiveness of our device in improving writing accuracy for individuals with shaky hands. The testing protocol included three distinct tests: spiral line tracing, line tracing, and sentence writing. Additionally, qualitative feedback was collected from the participants. The preliminary results from this pilot test were promising. Participants noted an increase in writing accuracy, and there were no reports of the device hindering the writing process. The pilot study was conducted with a volunteer who has shaky hands, providing valuable insights into the device's potential. Prior to conducting this test, the necessary ethical approvals were secured, underlining our commitment to conducting research responsibly. Future studies are planned to expand on these initial findings, contingent upon receiving approval from the Institutional Review Board (IRB). This will enable us to further validate the device's effectiveness across a broader participant base.


Figure 14: Three Pilot Tests Performed

**Instructions for Use (Operation manual)**

**Step 1: Unpacking Your Stabilizer**
Gently remove the Hand Tremor Stabilizer and all accompanying components from its packaging. Ensure all parts are accounted for before proceeding.
**Step 2: Donning the Glove**
Begin by sliding your hand into the glove portion of the device, ensuring it comfortably fits over your hand. This first layer serves as the foundation for the stabilizing system.
**Step 3: Integrating the Palm Stabilizer**
Locate the 3D printed palm stabilizer and slide it into its designated compartment at the bottom of the wrist section of the glove. This integral piece works in tandem with the glove to enhance the stabilization effect.
**Step 4: Securing the Finger Supports**
With the palm stabilizer in place, proceed to adjust the Velcro straps around each finger. Apply two braces on the pointer finger and two on the middle finger for balanced support. The thumb requires a single brace. These adjustments are crucial for the precise functioning of the stabilization mechanism.
**Step 5: Fastening the Wrist Brace**

Wrap the wrist brace section around your wrist and secure it using the Velcro closure. This should resemble the process of fastening a regular wrist brace, providing an additional layer of support and stability.

**Step 6: Ensuring Device Functionality**

Double-check that the damper mechanism is correctly clipped into the housing and fully operational within the device.

**Step 7: Engaging in Activities**

With the Hand Tremor Stabilizer fully secured, you are now ready to engage in writing or any other fine motor tasks. Hold a writing instrument or other tools as you usually would. The device is designed to intuitively recognize and mitigate unwanted tremor movements through its advanced damping system, facilitating smoother and more controlled actions.

**Discussion**

Throughout the course of this project, our team gained substantial insight into Essential Tremor (ET) and Parkinson's disease, particularly noting the lack of effective solutions for managing finger tremors. Existing market solutions primarily focus on wrist tremors and are often bulky, limiting practicality and user mobility. Our project aimed to address this gap by designing a more user-friendly and efficient device. Through rapid prototyping and testing, we were able to evaluate our device's viability and alignment with customer requirements. The pilot test revealed promising outcomes, suggesting that our device could offer a significant improvement in managing finger tremors. However, we identified a potential enhancement by incorporating a two-way damper mechanism to suppress both flexion and extension tremors, which would necessitate a redesign and manufacturing of a specialized damper. This improvement, while time-intensive, represents a pivotal step towards optimizing our device's effectiveness and user satisfaction.

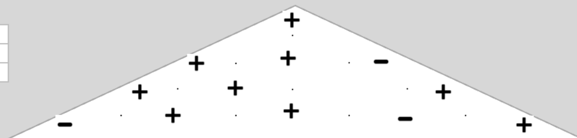
**Conclusion**

The development and preliminary testing of our innovative device have highlighted its potential to significantly improve the quality of life for individuals experiencing hand tremors. The positive feedback from the initial testing phase, coupled with the identified opportunities for further enhancements, underscores the viability and necessity of our solution in addressing a currently underserved need. As we move forward, our focus will be on refining the device's design to incorporate a two-way damper system, enhancing its functionality and user experience. Continued research and testing, guided by ethical considerations and regulatory approval, will be critical in advancing our understanding of the device's impact and optimizing its design for broader application. This project not only contributes to the technical field of assistive devices but also embodies our commitment to improving the lives of those affected by hand tremors through innovation and compassion.

## Appendix A

### Quality Function Deployment

| | |
|---|---|
| Project title: | Tremor Suppression Device |
| Project leader: | Mad, Ryan, Krishna |
| Date: | 10/10/23 |



| Correlation: | | |
|---|---|---|
| + | . | - |
| Positive | No correlation | Negative |

| Relationships: | | | |
|---|---|---|---|
| 9 | 3 | 1 | |
| Strong | Moderate | Weak | None |

| | Ranked out of | Functional Requirements (How's) | | | | | | | | Competitive evaluation (1: low, 5: high) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Desired direction of improvement (↑,0,↓) | ↓ | ↓ | ↑ | ↑ | ↑ | ↓ | ↑ | | | | |
| | Customer | Customer Requirements - (What's) | cost | weight | material: range of motion | battery life | durability | size | material: breathability | Weighted | Tremolo | Tremor | Electrode |
| 1 | 10 | Easy to use / wear / don+remove | | 3 | 9 | 1 | | 9 | 9 | 310 | 4 | 2 | 1 |
| 2 | 9 | Portable | | 9 | | 3 | | 9 | | 189 | 4 | 2 | 3 |
| 3 | 2 | Washable | | | | | 3 | 1 | | 8 | 5 | 1 | 1 |
| 4 | 12 | Range of Motion | | 1 | 9 | | | 3 | | 156 | 4 | 4 | 4 |
| 5 | 27 | Accuracy of Motion | 9 | 1 | 3 | | | | | 351 | 2 | 4 | 4 |
| 6 | 2 | Shelf Life / Battery Life | 9 | 3 | | 9 | | 3 | | 48 | 5 | 4 | 4 |
| 7 | 23 | Grip | | | 9 | | | | | 207 | 5 | 3 | 5 |
| 8 | 5 | Breathable | 3 | 3 | | | | | 9 | 75 | 2 | 2 | 3 |
| 9 | 5 | Natural Feeling | | 3 | 9 | | | 9 | 9 | 150 | 4 | 1 | 3 |
| 10 | 5 | Cheap | 9 | | | 3 | | | 3 | 75 | 3 | 5 | 4 |
| | 100 | Technical importance score | 321 | 171 | 486 | 70 | 6 | 215 | 150 | 1569 | **38** | 28 | 32 |
| | | Importance % | 20% | 11% | 31% | 4% | 0.38% | 14% | 10% | 90% | | | |
| | | Priorities rank | **2** | **4** | **1** | **6** | **7** | **3** | **5** | | | | |
| | | Current performance | | | | | | | | | | | |
| | | Target | | | | | | | | | | | |
| | | Benchmark | | | | | | | | | | | |
| | | Difficulty | 3 | 2 | 5 | 1 | 2 | 3 | 3 | 1: very easy, 5: very difficult | | | |
| | | Cost and time | 5 | 1 | 4 | 3 | 2 | 3 | 4 | 1: low, 5: high | | | |
| | | **Priority to improve** | **2** | **4** | **1** | **6** | **7** | **3** | **5** | | | | |

Figure 14: House of Quality matrix for quantitative analysis of correlation between customer requirements and engineering requirements

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